

Java™ Management Extensions (JMX™) Specification, version 1.4

Draft

Java™ Management Extensions (JMX™) Specification, version 1.4

Version: 1.4

Status: draft

Release: July 2006

Copyright 2006 Sun Microsystems, Inc.

4150 Network Circle, Santa Clara, California 95054, U.S.A

All rights reserved.

NOTICE; LIMITED LICENSE GRANTS

Sun Microsystems, Inc. (“Sun”) hereby grants you a fully-paid, non-exclusive, non-transferable, worldwide, limited license (without the right to sublicense), under the Sun’s applicable intellectual property rights to view, download, use and reproduce the Specification only for the purpose of internal evaluation, which shall be understood to include developing applications intended to run on an implementation of the Specification provided that such applications do not themselves implement any portion(s) of the Specification.

Sun also grants you a perpetual, non-exclusive, worldwide, fully paid-up, royalty free, limited license (without the right to sublicense) under any applicable copyrights or patent rights it may have in the Specification to create and/or distribute an Independent Implementation of the Specification that: (i) fully implements the Spec(s) including all its required interfaces and functionality; (ii) does not modify, subset, superset or otherwise extend the Licensor Name Space, or include any public or protected packages, classes, Java interfaces, fields or methods within the Licensor Name Space other than those required/authorized by the Specification or Specifications being implemented; and (iii) passes the TCK (including satisfying the requirements of the applicable TCK Users Guide) for such Specification. The foregoing license is expressly conditioned on your not acting outside its scope. No license is granted hereunder for any other purpose.

You need not include limitations (i)-(iii) from the previous paragraph or any other particular “pass through” requirements in any license You grant concerning the use of your Independent Implementation or products derived from it. However, except with respect to implementations of the Specification (and products derived from them) that satisfy limitations (i)-(iii) from the previous paragraph, You may neither: (a) grant or otherwise pass through to your licensees any licenses under Sun’s applicable intellectual property rights; nor (b) authorize your licensees to make any claims concerning their implementation’s compliance with the Spec in question.

For the purposes of this Agreement: “*Independent Implementation*” shall mean an implementation of the Specification that neither derives from any of Sun’s source code or binary code materials nor, except with an appropriate and separate license from Sun, includes any of Sun’s source code or binary code materials; and “*Licensor Name Space*” shall mean the public class or interface declarations whose names begin with “java”, “javax”, “com.sun” or their equivalents in any subsequent naming convention adopted by Sun through the Java Community Process, or any recognized successors or replacements thereof.

This Agreement will terminate immediately without notice from Sun if you fail to comply with any material provision of or act outside the scope of the licenses granted above.

TRADEMARKS

No right, title, or interest in or to any trademarks, service marks, or trade names of Sun or Sun’s licensors is granted hereunder. Sun, Sun Microsystems, the Sun logo, Java, JMX, and the Java Coffee Cup logo are trademarks or registered trademarks of Sun Microsystems, Inc. in the U.S. and other countries.

DISCLAIMER OF WARRANTIES

THE SPECIFICATION IS PROVIDED “AS IS”. SUN MAKES NO REPRESENTATIONS OR WARRANTIES, EITHER EXPRESS OR IMPLIED, INCLUDING BUT NOT LIMITED TO, WARRANTIES OF MERCHANTABILITY, FITNESS FOR A PARTICULAR PURPOSE, OR NON-INFRINGEMENT, THAT THE CONTENTS OF THE SPECIFICATION ARE SUITABLE FOR ANY PURPOSE OR THAT ANY PRACTICE OR IMPLEMENTATION OF SUCH CONTENTS WILL NOT INFRINGE ANY THIRD PARTY PATENTS, COPYRIGHTS, TRADE SECRETS OR OTHER RIGHTS. This document does not represent any commitment to release or implement any portion of the Specification in any product.

THE SPECIFICATION COULD INCLUDE TECHNICAL INACCURACIES OR TYPOGRAPHICAL ERRORS. CHANGES ARE PERIODICALLY ADDED TO THE INFORMATION THEREIN; THESE CHANGES WILL BE INCORPORATED INTO NEW VERSIONS OF THE SPECIFICATION, IF ANY. SUN MAY MAKE IMPROVEMENTS AND/OR CHANGES TO THE PRODUCT(S) AND/OR THE PROGRAM(S) DESCRIBED IN THE SPECIFICATION AT ANY TIME. Any use of such changes in the Specification will be governed by the then-current license for the applicable version of the Specification.

LIMITATION OF LIABILITY

TO THE EXTENT NOT PROHIBITED BY LAW, IN NO EVENT WILL SUN OR ITS LICENSORS BE LIABLE FOR ANY DAMAGES, INCLUDING WITHOUT LIMITATION, LOST REVENUE, PROFITS OR DATA, OR FOR SPECIAL, INDIRECT, CONSEQUENTIAL, INCIDENTAL OR PUNITIVE DAMAGES, HOWEVER CAUSED AND REGARDLESS OF THE THEORY OF LIABILITY, ARISING OUT OF OR RELATED TO ANY FURNISHING, PRACTICING, MODIFYING OR ANY USE OF THE SPECIFICATION, EVEN IF SUN AND/OR ITS LICENSORS HAVE BEEN ADVISED OF THE POSSIBILITY OF SUCH DAMAGES.

You will indemnify, hold harmless, and defend Sun and its licensors from any claims arising or resulting from: (i) your use of the Specification; (ii) the use or distribution of your Java application, applet and/or clean room implementation; and/or (iii) any claims that later versions or releases of any Specification furnished to you are incompatible with the Specification provided to you under this license.

RESTRICTED RIGHTS LEGEND

U.S. Government: If this Specification is being acquired by or on behalf of the U.S. Government or by a U.S. Government prime contractor or subcontractor (at any tier), then the Government's rights in the Specification and accompanying documentation shall be only as set forth in this license; this is in accordance with 48 C.F.R. 227.7201 through 227.7202-4 (for Department of Defense (DoD) acquisitions) and with 48 C.F.R. 2.101 and 12.212 (for non-DoD acquisitions).

REPORT

You may wish to report any ambiguities, inconsistencies or inaccuracies you may find in connection with your use of the Specification ("Feedback"). To the extent that you provide Sun with any Feedback, you hereby: (i) agree that such Feedback is provided on a non-proprietary and non-confidential basis, and (ii) grant Sun a perpetual, non-exclusive, worldwide, fully paid-up, irrevocable license, with the right to sublicense through multiple levels of sublicensees, to incorporate, disclose, and use without limitation the Feedback for any purpose related to the Specification and future versions, implementations, and test suites thereof.

(LFI#135575/Form ID#011801)

Contents

- 1. 21
- 2. **Introduction to the JMX Specification** 21
 - 1.1 Benefits of the JMX Architecture 21
 - 1.2 Scope of this Specification 23
 - 1.2.1 Reference Implementation 23
 - 1.2.2 Compatibility Test Suite 23
 - 1.2.3 JMX APIs as part of the Java Platform 24
 - 1.3 Architectural Overview 24
 - 1.3.1 Instrumentation Level 25
 - 1.3.2 Agent Level 26
 - 1.3.3 Distributed Services Level 27
 - 1.4 Component Overview 28
 - 1.4.1 Components of the Instrumentation Level 28
 - 1.4.1.1 Managed Beans (MBeans) 28
 - 1.4.1.2 Notification Model 29
 - 1.4.1.3 MBean Metadata Classes 30
 - 1.4.2 Components of the Agent Level 30
 - 1.4.2.1 MBean Server 30
 - 1.4.2.2 Agent Services 31
 - 1.5 JMX Remote API 32
 - 1.6 What Has Changed 32
 - 1.6.1 Changes to the JMX Specification (JSR 3) 33
 - 1.6.2 Changes to the JMX Remote Specification (JSR 160) 35

Part I. JMX Instrumentation Specification

- 3. **MBean Instrumentation** 39
 - 2.1 Definition 39

2.1.1	Public Management Interface	40
2.1.2	MBean Public Constructor	40
2.2	Standard MBeans	41
2.2.1	MBean Interface	42
2.2.1.1	The <code>MyClass</code> Example MBean	43
2.2.2	Lexical Design Patterns	44
2.2.2.1	Attributes	44
2.2.2.2	Operations	45
2.2.2.3	Case Sensitivity	46
2.3	Dynamic MBeans	46
2.3.1	<code>DynamicMBean</code> Interface	47
2.3.2	Behavior of Dynamic MBeans	49
2.3.2.1	Coherence	49
2.3.2.2	Dynamics	49
2.4	Inheritance Patterns	50
2.5	JMX Notification Model	54
2.5.0.1	Notification Type	54
2.5.1	Notification Class	55
2.5.2	<code>NotificationBroadcaster</code> and <code>NotificationEmitter</code> Interfaces	56
2.5.3	<code>NotificationListener</code> Interface	57
2.5.4	<code>NotificationFilter</code> Interface	58
2.6	Attribute Change Notifications	58
2.6.1	<code>AttributeChangeNotification</code> Class	59
2.6.2	<code>AttributeChangeNotificationFilter</code> Class	59
2.7	MBean Metadata Classes	60
2.7.1	<code>MBeanInfo</code> Class	61
2.7.2	<code>MBeanFeatureInfo</code> Class	62
2.7.3	<code>MBeanAttributeInfo</code> Class	63
2.7.4	<code>MBeanConstructorInfo</code> Class	63
2.7.5	<code>MBeanOperationInfo</code> Class	64

2.7.6	MBeanParameterInfo Class	64
2.7.7	MBeanNotificationInfo Class	65
4.	Open MBeans	67
3.1	Overview	67
3.2	Basic Data Types	68
3.2.1	Representing Complex Data	70
3.2.1.1	CompositeData Interface and Support Class	70
3.2.1.2	TabularData Interface and Support Class	71
3.2.2	Open Type Descriptions	71
3.3	Open MBean Metadata Classes	72
3.3.1	OpenMBeanInfo Interface and Support Class	73
3.3.2	OpenMBeanOperationInfo and OpenMBeanConstructorInfo Interfaces and Support Classes	74
3.3.3	OpenMBeanParameterInfo and OpenMBeanAttributeInfo Interfaces and Support Classes	75
3.4	Summary of Open MBean Requirements	76
5.	Model MBeans	77
4.1	Overview	77
4.1.1	Generic Notifications	79
4.1.2	Interaction with Managed Resources	80
4.1.3	Interaction with Management Applications	81
4.2	Model MBean Metadata Classes	81
4.2.1	Descriptor Interface	81
4.2.2	DescriptorAccess Interface	83
4.2.3	ModelMBeanInfo Interface	84
4.2.4	ModelMBeanInfo Implementation	85
4.2.5	ModelMBeanAttributeInfo Implementation	88
4.2.6	ModelMBeanConstructorInfo Implementation	89
4.2.7	ModelMBeanOperationInfo Implementation	89

4.2.8	ModelMBeanNotificationInfo Implementation	90
4.3	Model MBean Specification	90
4.3.1	ModelMBean Interface	91
4.3.2	ModelMBean Implementation	92
4.3.3	DynamicMBean Implementation	93
4.3.4	PersistentMBean Interface	95
4.3.5	ModelMBeanNotificationBroadcaster Interface	96
4.3.6	ModelMBeanNotificationBroadcaster Implementation	97
4.4	Descriptors	97
4.4.1	Attribute Behavior	98
4.4.2	Notification Logging Policy	98
4.4.3	Persistence Policy	99
4.4.4	Behavior of Cached Values	100
4.4.5	Protocol Map Support	100
4.4.6	Export Policy	101
4.4.7	Visibility Policy	101
4.4.8	Presentation Behavior	102
4.5	Predefined Descriptor Fields	102
4.5.1	MBean Descriptor Fields	102
4.5.2	Attribute Descriptor Fields	104
4.5.3	Operation Descriptor Fields	105
4.5.4	Notification Descriptor Fields	106

Part II. JMX Agent Specification

6. Agent Architecture 111

5.1	Overview	111
5.2	JMX Compliant Agent	113
5.3	Protocol Adaptors and Connectors	113

7. Foundation Classes 115

6.1	ObjectName Class	115
6.1.1	Domain Name	116
6.1.2	Key Property List	116
6.1.3	String Representation of Names	117
6.1.4	Pattern Matching	117
6.1.4.1	Pattern Matching Examples	118
6.2	ObjectInstance Class	119
6.3	Attribute and AttributeList Classes	119
6.4	JMX Exceptions	119
6.4.1	JMException Class and Subclasses	120
6.4.2	JMRuntimeException Class and Subclasses	121
6.4.3	Description of JMX Exceptions	122
6.4.3.1	JMException Class	123
6.4.3.2	ReflectionException Class	123
6.4.3.3	MBeanException Class	123
6.4.3.4	OperationsException Class	123
6.4.3.5	InstanceAlreadyExistsException Class	123
6.4.3.6	InstanceNotFoundException Class	124
6.4.3.7	InvalidAttributeValueException Class	124
6.4.3.8	AttributeNotFoundException Class	124
6.4.3.9	IntrospectionException Class	124
6.4.3.10	MalformedObjectNameException Class	124
6.4.3.11	NotCompliantMBeanException Class	124
6.4.3.12	ServiceNotFoundException Class	124
6.4.3.13	MBeanRegistrationException Class	124
6.4.3.14	JMRuntimeException Class	125
6.4.3.15	RuntimeOperationsException Class	125
6.4.3.16	RuntimeMBeanException Class	125
6.4.3.17	RuntimeErrorException Class	125

8. MBean Server 127

7.1	Role of the MBean Server	127
7.1.1	MBean Server Factory	127
7.1.2	MBean Server Permission Checking	128
7.1.3	Registration of MBeans	129
7.1.3.1	MBean Registration Control	129
7.1.4	Operations on MBeans	131
7.1.5	MBean Proxies	132
7.2	MBean Server Delegate MBean	132
7.3	Remote Operations on MBeans	133
7.4	MBean Server Notifications	134
7.5	Queries	135
7.5.1	Scope of a Query	135
7.5.2	Query Expressions	136
7.5.2.1	Methods of the Query Class	137
7.5.2.2	Query Expression Examples	139
7.5.3	Query Exceptions	139
7.5.3.1	BadAttributeValueExpException Class	140
7.5.3.2	BadStringOperationException Class	140
7.5.3.3	BadBinaryOpValueExpException Class	140
7.5.3.4	InvalidApplicationException Class	140
7.6	MBeanServerConnection Interface	140
7.7	Changing the MBean Server Implementation	141

9. Advanced Dynamic Loading 143

8.1	Overview of M-Lets	143
8.2	The MLET Tag	144
8.3	The M-Let Service	146
8.3.1	Loading MBeans From a URL	146
8.3.2	Class Loader Functionality	147
8.3.2.1	Native libraries	147
8.4	The Class Loader Repository	148

8.4.1	How to Add Loaders to the Class Loader Repository	148
8.4.2	Order of Loaders in the Class Loader Repository	149
8.4.3	M-Let Delegation to the Class Loader Repository	149
8.4.3.1	New Semantics in the JMX 1.2 Specification	150
8.5	Using the Correct Class Loader for Parameters	152
8.5.1	getClassLoaderFor	153
8.5.2	getClassLoader and getClassLoaderRepository	153
10.	Monitoring	155
9.1	Overview	155
9.1.1	Types of Monitors	155
9.2	MonitorNotification Class	156
9.2.1	Common Monitor Notification Types	157
9.3	CounterMonitor Class	158
9.3.1	Counter Monitor Notification Types	159
9.4	GaugeMonitor Class	160
9.4.1	Gauge Monitor Notification Types	161
9.5	StringMonitor Class	162
9.5.1	String Monitor Notification Types	163
9.6	Implementation of the Monitor MBeans	163
11.	Timer Service	165
10.1	Timer Notifications	165
10.1.1	TimerNotification Class	166
10.1.2	Adding Notifications to the Timer	166
10.1.3	Receiving Timer Notifications	167
10.1.4	Removing Notifications From the Timer	167
10.2	Starting and Stopping the Timer	168
12.	Relation Service	169
11.1	The Relation Model	169

11.1.1	Terminology	170
11.1.2	Example of a Relation	170
11.1.3	Maintaining Consistency	171
11.1.4	Implementation	172
11.1.4.1	External Relation Types	173
11.1.4.2	External Relations	174
11.2	Relation Service Classes	175
11.2.1	RelationService Class	177
11.2.2	RelationNotification Class	179
11.2.3	MBeanServerNotificationFilter Class	179
11.3	Interfaces and Support Classes	179
11.3.1	RelationType Interface	181
11.3.2	RelationTypeSupport Class	181
11.3.3	Relation Interface	182
11.3.3.1	Specified Methods	182
11.3.3.2	Maintaining Consistency	183
11.3.4	RelationSupport Class	184
11.4	Role Description Classes	184
11.4.1	RoleInfo Class	185
11.4.2	Role Class	186
11.4.3	RoleList Class	186
11.4.4	RoleUnresolved Class	187
11.4.5	RoleUnresolvedList Class	187
11.4.6	RoleResult Class	187
11.4.7	RoleStatus Class	188

13. Security 189

12.1	Permissions	189
12.1.1	MBeanServerPermission	190
12.1.2	MBeanPermission	191
12.1.2.1	MBeanPermission Target	191

12.1.2.2	MBeanPermission Actions	193
12.1.2.3	Unchecked MBean Server Methods	196
12.1.2.4	Permission Checking for Queries	196
12.1.2.5	Permission Checking for getDomains	197
12.1.2.6	Permission Checking for getAttributes and setAttributes	198
12.1.3	MBeanTrustPermission	198
12.2	Policy File Examples	199

Part III. JMX Remote API Specification

14.	Connectors	205
13.1	Sessions and Connections	206
13.2	Connection Establishment	206
13.3	MBean Server Operations Through a Connection	207
13.4	Adding Remote Listeners	208
13.4.1	Filters and Handbacks	208
13.4.2	Removing Listeners	209
13.4.3	Notification Buffer	210
13.4.4	Getting Notifications From the Notification Buffer	211
13.5	Concurrency	212
13.6	Normal Termination	212
13.7	Abnormal Termination	213
13.7.1	Detecting Abnormal Termination	213
13.8	Connector Server Addresses	214
13.9	Creating a Connector Client	214
13.9.1	JMXConnectorFactory	215
13.9.2	Connection Stubs	215
13.9.3	Finding a Server	216
13.10	Creating a Connector Server	216
13.10.1	Publishing a Server	218

- 13.11 Class Loading 218
 - 13.11.1 Class Loading on the Client End 219
 - 13.11.2 Class Loading on the Server End 219
- 13.12 Connector Server Security 221
 - 13.12.1 Subject Delegation 222
 - 13.12.2 Access Control Context 222
- 15. RMI Connector 225**
 - 14.1 RMI Transports 225
 - 14.2 Mechanics of the RMI Connector 225
 - 14.2.1 Wrapping the RMI Objects 228
 - 14.2.2 RMICConnection 228
 - 14.2.3 Notifications 229
 - 14.3 How to Connect to an RMI Connector Server 229
 - 14.4 Basic Security With the RMI Connector 230
 - 14.4.1 How Security Affects the RMI Connector Protocol 230
 - 14.4.2 Achieving Real Security 231
 - 14.5 Protocol Versioning 232
- 16. Generic Connector 233**
 - 15.1 Pluggable Transport Protocol 233
 - 15.2 Pluggable Object Wrapping 234
 - 15.3 Generic Connector Protocol 235
 - 15.3.1 Handshake and Profile Message Exchanges 236
 - 15.3.2 MBean Server Operation and Connection Message Exchanges 239
 - 15.3.3 Security Features in the JMXMP Connector 241
 - 15.3.3.1 TLS Profile 242
 - 15.3.3.2 SASL Profile 242
 - 15.3.4 Protocol Violations 242
 - 15.3.5 Protocol Versioning 243
 - 15.3.6 Properties Controlling Client and Server 244

15.3.6.1	Global Properties of the Generic Connector	244
15.3.6.2	TLS Properties	244
15.3.6.3	SASL Properties	245
17.	Defining a New Transport	247
18.	Bindings to Lookup Services	249
17.1	Terminology	249
17.2	General Principles	250
17.2.1	JMXServiceURL Versus JMXConnector Stubs	250
17.2.2	Lookup Attributes	251
17.3	Using the Service Location Protocol	254
17.3.1	SLP Implementation	254
17.3.2	SLP Service URL	254
17.3.3	SLP Lookup Attributes	254
17.3.4	Code Templates	254
17.3.4.1	Discovering the SLP Service	255
17.3.4.2	Registering a JMX Service URL With SLP	256
17.3.4.3	Looking up a JMX Service URL With SLP	257
17.4	Using the Jini Network Technology	258
17.4.1	Jini Networking Technology Implementation	258
17.4.2	Service Registration	258
17.4.3	Using JMX Remote API Connector Stubs	259
17.4.4	Jini Lookup Service Attributes	260
17.4.5	Code Templates	260
17.4.5.1	Discovering the Jini Lookup Service	261
17.4.5.2	Registering a JMX Remote API Connector Stub With the Jini Lookup Service	262
17.4.5.3	Looking up a JMX Connector Stub From the Jini Lookup Service	263
17.5	Using the Java Naming and Directory Interface (LDAP Backend)	264
17.5.1	LDAP Schema for Registration of JMX Connectors	265

17.5.2	Mapping to Java Objects	267
17.5.3	Structure of the JMX Remote API Registration Tree	267
17.5.4	Leasing	268
17.5.5	Code Templates	268
17.5.5.1	Discovering the LDAP Server	268
17.5.5.2	Registering a JMXServiceURL in the LDAP server	269
17.5.5.3	Looking up a JMX Service URL From the LDAP Server	271
17.6	Registration With Standards Bodies	272
19.	Summary of Environment Parameters	273
A.	Service Templates	277
A.1	Service Template for the service:jmx Abstract Service Type	277
A.2	Service Template for the service:jmx:jmxmp Concrete Service Type	279
A.3	Service Template for the service:jmx:rmi Concrete Service Type	280
A.4	Service Template for the service:jmx:iiop Concrete Service Type	282
B.	Non-standard environment parameters	285

Preface

This document provides an introduction to the *Java™ Management extensions (JMX™)* and then gives the JMX instrumentation, agent, and distributed services specifications that define these extensions. It is not intended to be a programming guide or a tutorial, but rather a comprehensive specification of the architecture, design patterns and programming interfaces for these components.

The complete JMX specification is composed of this document and the corresponding API documentation generated by the Javadoc™ tool, that completely defines all programming objects.

Who Should Use This Book

The primary focus of this specification is to define the extensions to the Java programming language for all actors in the software and network management field. Also, programmers who want to build devices, applications, or implementations that conform to JMX will find this specification useful as a reference guide.

Before You Read This Book

This specification assumes a working knowledge of the Java programming language and of the development environment for the Java programming language. It is essential to understand the Java Development Kit (JDK™) software and be familiar with system or network management. A working knowledge of the JavaBeans™ model is also helpful.

All object diagrams in this book use the Unified Modeling Language (UML) for specifying the objects in the Java programming language that comprise the JMX specification. This allows a visual representation of the relation between classes and their components. For a complete description of UML see:

<http://www.rational.com/uml/resources/documentation/>

How This Book Is Organized

Chapter 1 “ provides an overview of the scope and goals of the JMX specification. It explains the overall management architecture and presents the main components.

Part I “JMX Instrumentation Specification”

Chapter 2 “MBean Instrumentation presents standard and dynamic MBeans, their characteristics and design patterns, their naming scheme, the notification model and the MBean metadata classes.

Chapter 3 “Open MBeans” presents the open MBean components and their Java classes.

Chapter 4 “Model MBeans presents the model MBean concept and the Java classes on which it relies.

Part II “JMX Agent Specification”

Chapter 5 “Agent Architecture presents the architecture of the JMX agent and its components.

Chapter 6 “Foundation Classes defines the foundation classes used by the interfaces of the JMX agent components.

Chapter 7 “MBean Server defines the MBean server and the methods available to operate on managed objects, including queries that retrieve specific managed objects.

Chapter 8 “Advanced Dynamic Loading defines advanced class-loading features, including the m-let (management applet) service that loads classes and libraries dynamically from a URL over the network.

Chapter 9 “Monitoring defines the monitoring service that observes the value of an attribute in MBeans and signals when thresholds are reached.

Chapter 10 “Timer Service defines the timer service that provides scheduling capabilities.

Chapter 11 “Relation Service defines the relation service that creates relation types and maintains relations between MBeans based on these types.

Chapter 12 “Security defines the permissions that are used to control access to MBeans.

Part III “JMX Remote API Specification”.

Chapter 13 “Connectors defines the connectors added to the JMX specification by JMX Remote API.

Chapter 14 “RMI Connector defines the standard JMX Remote API connector.

Chapter 15 “Generic Connector defines an optional generic connector.

Chapter 16 “Defining a New Transport defines how other transport protocols can be implemented.

Chapter 17 “Bindings to Lookup Services defines how to register connectors with existing lookup services.

Chapter 18 “Summary of Environment Parameters lists the environment parameters used with JMX Remote API.

Appendix A “Service Templates

Appendix B “Non-standard environment parameters

Related Information

The model MBeans specification in Chapter 4 “Model MBeans, as well as the model MBean Reference Implementation and compatibility test cases, are based on an initial contribution from IBM.

The security specification in Chapter 12 “Security was developed in conjunction with Hewlett Packard and IBM.

The definitive specification for all Java objects and interfaces of the JMX specification is the API documentation generated by the Javadoc tool for these classes. It is available online as part of the Java Platform, Standard Edition (Java SE) documentation at the following URL:

<http://java.sun.com/j2se/1.6.0/docs/api/>

A number of Java Specification Requests (JSRs) developed through the Java Community ProcessSM make use of, or are related to the JMX specification:

- JSR 000018 - JAIN OAM API Specification
- JSR 000022 - JAIN SLEE API Specification
- JSR 000077 - J2EE™ Management Specification
- JSR 000151 - J2EE 1.4 Specification
- JSR 000160 - Java Management Extensions (JMX) Remoting
- JSR 000174 - Monitoring and Management Specification for the Java Virtual Machine
- JSR 000176 - J2SE 1.5 (Tiger) Release Content
- JSR 000255 - JMX Specification, version 2.0 (which will define the next version of this specification)
- JSR 000262 - Web Services Connector for JMX Agents

<http://java.sun.com/products/JavaManagement>

Typographic Conventions

The following table describes the typographic changes used in this book.

TABLE P-1 Typographic Conventions

Typeface or Symbol	Meaning	Example
AaBbCc123	The names of literals and the underlined text of URLs (Universal Resource Locators).	Set the value of the name descriptor. See the http://java.sun.com web site
AaBbCc123	The names of interfaces, classes, fields or methods in the Java programming language.	The <code>Timer</code> class implements the <code>TimerMBean</code> interface.
<i>AaBbCc123</i>	Book titles, new words or terms, or words to be emphasized.	Read Chapter 6 in the <i>User's Guide</i> . These are called <i>class options</i> . You <i>must</i> implement this interface.

Introduction to the JMX Specification

The Java Management extensions (also called the JMX specification) define an architecture, the design patterns, the APIs, and the services for application and network management and monitoring in the Java programming language. This chapter introduces all these elements, presenting the broad scope of these extensions. The JMX specification provides Java developers across all industries with the means to instrument Java code, create smart Java agents, implement distributed management middleware and managers, and smoothly integrate these solutions into existing management and monitoring systems. In addition, the JMX specification is referenced by a number of Java APIs for existing standard management and monitoring technologies.

It should be noted that, throughout the rest of the present document, the concept of *management* refers to both management and *monitoring* services.

The JMX architecture is divided into three levels:

- Instrumentation level
- Agent level
- Distributed services level

This chapter gives an introduction to each of these levels and describes their basic components.

1.1 Benefits of the JMX Architecture

Through an implementation of the JMX specification, the JMX architecture provides the following benefits:

- **Enables Java applications to be managed without heavy investment**

The JMX architecture relies on a core managed object server that acts as a *management agent* and can run on most Java-enabled devices. This allows Java applications to be manageable with little impact on their design. A Java application simply needs to embed a managed object server and make some of its functionality available as one or several managed beans (MBeans) registered in the object server; that is all it takes to benefit from the management infrastructure.

JMX provides a standard way to enable manageability for any Java based application, service or device. For example, Enterprise JavaBeans™ (EJB) applications can conform to the JMX architecture to become manageable.

- **Provides a scalable management architecture**

Every JMX agent service is an independent module that can be plugged into the management agent, depending on the requirements. This component-based approach means that JMX solutions can scale from small footprint devices to large telecommunications switches and beyond.

The JMX specification provides a set of core agent services. Additional services will be developed by conformant implementations, as well as by the integrators of the management solutions. All these services can be dynamically loaded, unloaded, or updated in the management infrastructure.

- **Integrates existing management solutions**

JMX smart agents are capable of being managed through HTML browsers or by various management protocols such as SNMP and WBEM. The JMX API are open interfaces that any management system vendor can leverage.

- **Leverages existing standard Java technologies**

Whenever needed, the JMX specification will reference existing Java specifications such as Java Naming and Directory Interface™ (JNDI), Java Database Connectivity API (JDBC™), Java Transaction Services (JTS), or others.

- **Can leverage future management concepts**

The APIs of the JMX specification can implement flexible and dynamic management solutions, through the Java programming language, that can leverage emerging technologies. For example, JMX solutions can use lookup and discovery services and protocols such as Jini™ network technology, Universal Plug'n'Play (Upnp), and the Service Location Protocol (SLP).

In a demonstration given by Sun Microsystems, Jini network technology provides spontaneous discovery of resources and services on the network, that are then managed by through a JMX application. The combination of these two capabilities is called the Sun Spontaneous Management™ Software.

- **Defines only the interfaces necessary for management**

The JMX API is not designed to be a general purpose distributed object system. Although it provides a number of services designed to fit into a distributed environment, these are focused on providing functionality for managing networks, systems, and applications.

1.2 Scope of this Specification

The JMX specification defines an architecture for management and a set of APIs that describe the components of this architecture. These APIs cover functionality, both on the manager and on the agent side, that compliant implementations will provide to the developer of management applications.

This JMX specification document addresses all three levels of the management architecture. These parts are:

- The instrumentation specification
- The agent specification
- The distributed services specification

1.2.1 Reference Implementation

The *reference implementation* (RI) is the first working application of the JMX specification, as mandated by the Java Community Process for defining extensions to the Java programming language. The RI for both the instrumentation and agent specifications has been developed by Sun Microsystems, Inc., in its role as the JMX specification lead.

As of version 1.3 of the JMX API, there is no separately-available RI for the specification. The RI is part of the RI for version 6 of the Java Platform, Standard Edition (Java SE) , codenamed “Mustang”.

1.2.2 Compatibility Test Suite

The *compatibility test suite* (CTS) for the JMX specification will check the conformance of JMX implementations. It is also mandated by the Java Community Process. The CTS verifies that applications claiming to conform to a specific part of JMX follow every point of the specification. The CTS for both the instrumentation and agent specifications has been developed by Sun Microsystems, Inc., in its role as the JMX specification lead.

Because the classes defined by the JMX specification are optional packages of the Java platform, the CTS is implemented as a Technology Compatibility Kit (TCK) that is run by the JavaTest™ software.

Each part of the JMX specification can identify mandatory and optional components. A JMX-compliant implementation must provide all mandatory services, and can provide any subset of the optional services, but those it does provide must conform to the specification.

When claiming JMX compliance, implementations list the optional services they support, and are tested by the CTS against their statement of conformance. This requires some modularity in the way the CTS can be run against various implementations that implement a number of subsets of the specification.

1.2.3 JMX APIs as part of the Java Platform

As of version 5.0 of the Java 2 Platform, Standard Edition (the J2SE™ platform), codenamed “Tiger”, the JMX API and JMX Remote API are part of the core platform. “Tiger” contains version 1.2 of the JMX API and version 1.0 of the JMX Remote API. The versions of those APIs covered by this document (version 1.4 of each API) are included in version 6 of the Java Platform, Standard Edition (also known as Java SE), codenamed “Mustang”, the successor to “Tiger”.

It is possible to replace the implementations of either or both of the JMX and JMX Remote APIs in “Tiger” with implementations of the APIs covered by this document. Such a replacement must pass the CTS for each API replaced.

The specification for MXBeans defines certain behavior when the annotation `@java.beans.ConstructorProperties` appears. Since this annotation does not exist in the “Tiger” platform, the behavior in question does not happen there.

1.3 Architectural Overview

This section describes each part of the JMX specification and its relation to the overall management architecture:

- Instrumentation level
- Agent level
- Distributed services level
- Additional management protocol APIs

FIGURE 1-1 shows how the key components of the JMX architecture relate to one another within the three levels of the architectural model. These components are introduced in the following subsections and further discussed in the “Component Overview” on page 28.

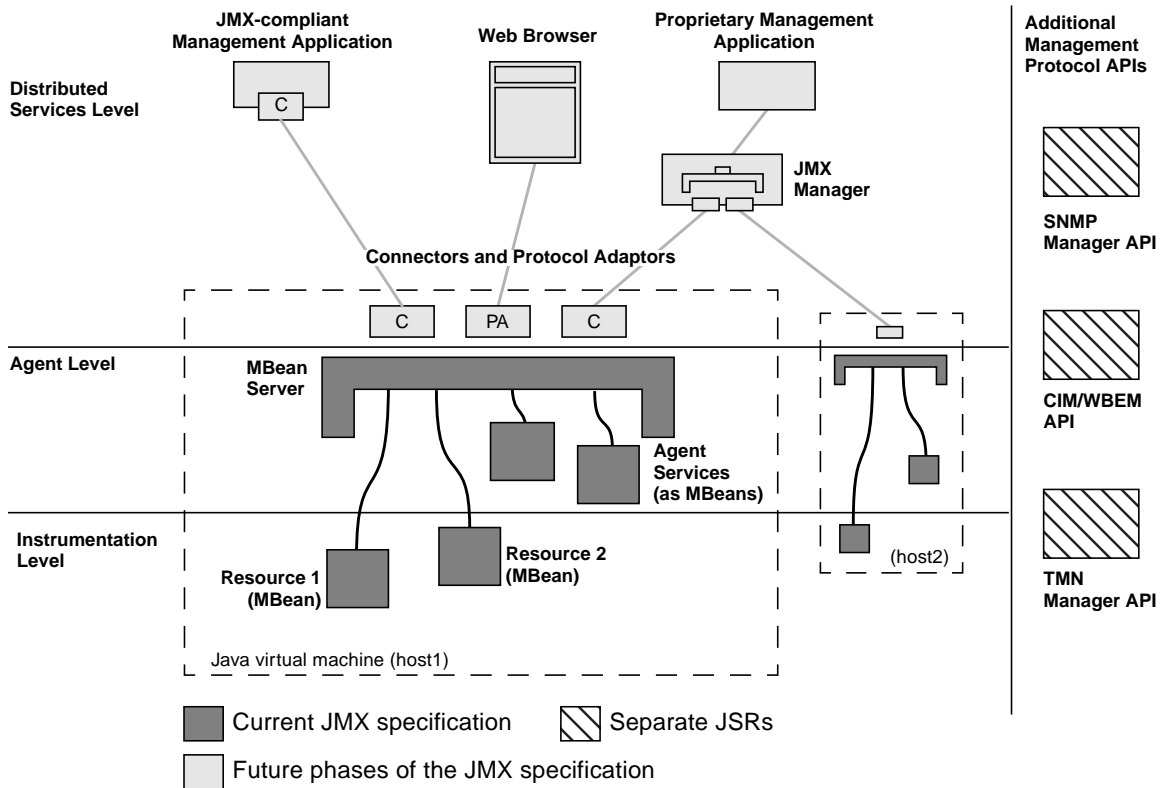


FIGURE 1-1 Relationship Between the Components of the JMX Architecture

1.3.1 Instrumentation Level

The instrumentation level provides a specification for implementing *JMX manageable resources*. A JMX manageable resource can be an application, an implementation of a service, a device, a user, and so forth. It is developed in Java, or at least offers a Java wrapper, and has been instrumented so that it can be managed by JMX-compliant applications.

The instrumentation of a given resource is provided by one or more Managed Beans, or MBeans, that are either standard or dynamic. Standard MBeans are Java objects that conform to certain design patterns derived from the JavaBeans™ component model. Dynamic MBeans conform to a specific interface that offers more flexibility at runtime. For further information, see “Managed Beans (MBeans)” on page 28.

The instrumentation of a resource allows it to be manageable through the agent level described in the next section. MBeans do not require knowledge of the JMX agent with that they operate.

MBeans are designed to be flexible, simple, and easy to implement. Developers of applications, services, or devices can make their products manageable in a standard way without having to understand or invest in complex management systems. Existing objects can easily be evolved to produce standard MBeans or wrapped as dynamic MBeans, thus making existing resources manageable with minimum effort.

In addition, the instrumentation level also specifies a notification mechanism. This allows MBeans to generate and propagate notification events to components of the other levels.

Because the instrumentation level consists of design patterns and Java interfaces, the reference implementation can only provide an example of the different MBeans and of their notification mechanism.

However, the compatibility test suite for the instrumentation level will check that MBeans being tested conform to the design patterns and implement the interfaces correctly.

JMX manageable resources are automatically manageable by agents compliant with the JMX specification. They can also be managed by any system that is not compliant with the JMX specification that supports the MBean design patterns and interfaces.

1.3.2 Agent Level

The agent level provides a specification for implementing agents. Management agents directly control the resources and make them available to remote management applications. Agents are usually located on the same machine as the resources they control, although this is not a requirement.

This level builds upon and makes use of the instrumentation level, to define a standardized agent to manage JMX manageable resources. The *JMX agent* consists of an MBean server and a set of services for handling MBeans. In addition, a JMX agent will need at least one communications adaptor or connector. The MBean server implementation and the agent services are mandatory in an implementation of the specification.

The JMX agent can be embedded in the machine that hosts the JMX manageable resources when a Java Virtual Machine (JVM) is available in that machine. Likewise, the JMX agent can be instantiated into a mediation/concentrator element when the managed resource only offers a proprietary (non-Java) environment. Otherwise, a JMX agent does not need to know which resources it will serve: any JMX manageable resource can use any JMX agent that offers the services it requires.

Managers access an agent's MBeans and use the provided services through a protocol adaptor or connector, as described in the next section. However, JMX agents do not require knowledge of the remote management applications that use them.

JMX agents are implemented by developers of management systems, who can build their products in a standard way without having to understand the semantics of the JMX manageable resources, or the functions of the management applications.

The agent compatibility test suite will check that agents being tested conform to the interfaces and functionality set forth in the agent specification. Agents that have been successfully tested against the agent CTS are qualified as JMX agents.

JMX agents run on the Java 2 Platform, Standard Edition (the J2SE™ platform) version 1.3 or above, and on certain profiles of the Java 2 Platform, Micro Edition (the J2ME™ platform). JMX agents that implement version 1.3 of the JMX specification must run on version 5.0 or above of the J2SE platform.

JMX agents will be automatically compatible with JMX distributed services, and can also be used by any non-JMX compliant systems or applications that support JMX agents.

1.3.3 Distributed Services Level

The distributed services level provides the interfaces for implementing JMX managers. This level defines management interfaces and components that can operate on agents or hierarchies of agents. These components can:

- Provide an interface for management applications to interact transparently with an agent and its JMX manageable resources through a connector
- Expose a management view of a JMX agent and its MBeans by mapping their semantic meaning into the constructs of a data-rich protocol (for example the hypertext mark-up language (HTML) or the simple network management protocol (SNMP))
- Distribute management information from high-level management platforms to numerous JMX agents
- Consolidate management information coming from numerous JMX agents into logical views that are relevant to the end user's business operations
- Provide security

Management components cooperate with one another across the network to provide distributed, scalable management functions. Customized Java-based management functions can be developed on top of these components to deploy a management application.

The combination of the manager level with the other agent and instrumentation levels provides a complete architecture for designing and developing complete management solutions. The Java Management Extensions technology brings unique facilities to such solutions, such as portability, on-demand deployment of management functionality, dynamic and mobility services, and security.

1.4 Component Overview

The key components of each architectural level are listed below and discussed in the subsequent sections.

- Instrumentation level
 - MBeans (standard, dynamic, open, and model MBeans)
 - Notification model
 - MBean metadata classes
- Agent level
 - MBean server
 - Agent services

1.4.1 Components of the Instrumentation Level

The key components of the instrumentation level are the Managed Bean (MBean) design patterns, the notification model, and the MBean metadata classes.

1.4.1.1 Managed Beans (MBeans)

An MBean is a Java object that implements a specific interface and conforms to certain design patterns. These requirements formalize the representation of the resource's *management interface* in the MBean. The management interface of a resource is the set of all necessary information and controls that a management application needs to operate on the resource.

The management interface of an MBean is represented as:

- Valued attributes that can be accessed
- Operations that can be invoked
- Notifications that can be emitted (see “Notification Model” on page 29)
- The constructors for the MBean's Java class

MBeans encapsulate attributes and operations through their public methods and follow the design patterns for exposing them to management applications. For example, a read-only attribute in a standard MBean will have just a *getter* method, whereas a *getter* and a *setter* methods implement read-write access.

Any objects that are implemented as an MBean and registered with the agent can be managed from outside the agent's Java virtual machine. Such objects include:

- The resources your application manages
- Value-added services provided to help manage resources
- Components of the JMX infrastructure that can be managed

Other JMX components, such as agent services, are specified as fully instrumented MBeans, which allows them to benefit from the JMX infrastructure and offer a management interface.

The JMX architecture does not impose any restrictions on where compiled MBean classes are stored. They can be stored at any location specified in the classpath of the agent's JVM, or at a remote site if class loading is used (see Chapter 8 "Advanced Dynamic Loading" on page 143).

The JMX specification defines four types of MBean: standard, dynamic, open and model MBeans. Each of these corresponds to a different instrumentation need:

- **Standard MBeans** are the simplest to design and implement, their management interface is described by their method names. **MXBeans** are a kind of Standard MBean that uses concepts from Open MBeans to allow universal manageability while simplifying coding.
- **Dynamic MBeans** must implement a specific interface, but they expose their management interface at runtime for greatest flexibility.
- **Open MBeans** are dynamic MBeans that rely on basic data types for universal manageability and that are self describing for user-friendliness.
- **Model MBeans** are also dynamic MBeans that are fully configurable and self described at runtime; they provide a generic MBean class with default behavior for dynamic instrumentation of resources.

1.4.1.2 Notification Model

The JMX specification defines a generic notification model based on the Java event model. Notifications can be emitted by MBean instances, as well as by the MBean server. This specification describes the notification objects and the broadcaster and listener interfaces that notification senders and receivers must implement.

This specification includes services that allow distribution of this notification model, thus allowing a management application to listen to MBean events and MBean server events remotely.

1.4.1.3 MBean Metadata Classes

The instrumentation specification defines the classes that are used to describe the management interface of an MBean. These classes are used to build a standard information structure for publishing the management interface of an MBean. One of the functions of the MBean server at the agent level is to provide the metadata of its MBeans.

The metadata classes contain the structures to describe all the components of an MBean's management interface: its attributes, operations, notifications and constructors. For each of these, the metadata includes a name, a description and its particular characteristics. For example, one characteristic of an attribute is whether it is readable, writable or both; a characteristic of an operation is the signature of its parameter and return types.

The different types of MBean extend the metadata classes to provide additional information. Through this inheritance, the standard information will always be available and management applications that know how to access the subclasses can obtain the extra information.

1.4.2 Components of the Agent Level

The key components in the agent level are the MBean server, a registry for objects in the instrumentation level, and the agent services that enable a JMX agent to incorporate management intelligence for more autonomy and performance.

1.4.2.1 MBean Server

The managed bean server, or *MBean server* for short, is a registry for objects that are exposed to management operations in an agent. Any object registered with the MBean server becomes visible to management applications. However, the MBean server only exposes an MBean's management interface, never its direct object reference.

Any resource that you want to manage from outside the agent's Java virtual machine (JVM) must be registered as an MBean in the server. The MBean server also provides a standardized interface for accessing MBeans within the same JVM, giving local objects all the benefits of manipulating manageable resources. MBeans can be instantiated and registered by:

- Another MBean
- The agent itself
- A remote management application (through the distributed services)

When you register an MBean, you must assign it a unique *object name*. A management application uses the object name to identify the object on which it is to perform a management operation. The operations available on MBeans include:

- Discovering the management interface of MBeans
- Reading and writing their attribute values
- Performing operations defined by the MBeans
- Getting notifications emitted by MBeans
- Querying MBeans based on their object name or their attribute values

The MBean server relies on *protocol adaptors* and *connectors* to make the agent accessible from management applications outside the agent's JVM. Each adaptor provides a view through a specific protocol of all MBeans registered in the MBean server. For example, an HTML adaptor could display an MBean on a Web browser. **The view provided by protocol adaptors is necessarily different for each protocol and none are addressed in this phase of the JMX specification.**

Connectors provide a manager-side interface that handles the communication between manager and agent. Each connector will provide the same remote interface though a different protocol. When a remote management application uses this interface, it can connect to an agent transparently through the network, regardless of the protocol.

Adaptors and connectors make all MBean server operations available to a remote management application. For an agent to be managed, it must include at least one protocol adaptor or connector. However, an agent can include any number of these, allowing it to be managed by multiple managers, through different protocols.

1.4.2.2 Agent Services

Agent services are objects that can perform management operations on the MBeans registered in the MBean server. By including management intelligence into the agent, JMX helps you build more powerful management solutions. Agent services are often MBeans as well, allowing them and their functionality to be controlled through the MBean server. The JMX specification defines the following agent services:

- **Dynamic class loading** through the management applet (m-let) service retrieves and instantiates new classes and native libraries from an arbitrary network location.
- **Monitors** observe the numerical or string value of an attribute of several MBeans and can notify other objects of several types of changes in the target.
- **Timers** provide a scheduling mechanism based on a one-time alarm-clock notification or on a repeated, periodic notification.
- **The relation service** defines associations between MBeans and enforces the cardinality of the relation based on predefined relation types.

All the agent services are mandatory in a JMX-compliant implementation.

1.5 JMX Remote API

The JMX Remote API was defined by JSR 160. For convenience of presentation, this document combines the specification of Maintenance Review 1 of JSR 160 with the specification of Maintenance Review 3 of JSR 3. Formally, Parts I and II of this document are defined by JSR 3, while Part III and the appendices are defined by JSR 160. For simplicity, the same version number 1.3 is used for the two specifications. The ongoing JSR 255 is defining version 2.0 of the JMX Specification, which will integrate the JMX Remote API into the JMX API. As such, it will merge the specifications originally defined by JSRs 3 and 160.

The principal goals of the JMX Remote API are *interoperability*, *transparency*, *security*, and *flexibility*.

The API is *interoperable* because it completely defines the standard protocols that are used between client and server, so that two different implementations of the standard can communicate.

The API is *transparent* because it exposes an API to the remote client that is as close as possible to the API defined by the JMX specification for access to instrumentation within the agent.

The API is *secure* because it builds on the Java technology standards for security, namely the Java Secure Socket Extension (JSSE), the Simple Authentication and Security Layer (SASL), and the Java Authentication and Authorization Service (JAAS). These standards enable connections between clients and servers to be private and authenticated and allow servers to control what operations different clients can perform.

The API is *flexible* because, in addition to the required protocol, it provides ways for new transport protocols to be added and new implementations of the existing protocols to be substituted.

1.6 What Has Changed

This document merges and updates two previous specifications, namely *JMX Instrumentation and Agent Specification, v1.2, December 2002*, and *JMX Remote API Specification, v1.0, October 2003*. This section lists the major changes to these two specifications.

All changes to either specification are marked in the text with change bars.

1.6.1

Changes to the JMX Specification (JSR 3)

- The JMX API has been generified. For example, `MBeanServer.queryNames` previously returned a `Set`, while now it returns a `Set<ObjectName>`.
- The MBeans feature, introduced in J2SE 5.0 for the `java.lang.management` package, has been generalized so that users can create their own MBeans.
- Descriptors, previously only supported for Model MBeans, are now supported for all types of MBean.
 - Information about legal types that was previously only available with Open MBeans can now be expressed through Descriptors with any type of MBean.
 - A parent of `DescriptorAccess` called `DescriptorRead` has been added and is implemented by the various `MBean*Info` classes.
 - A second, immutable implementation of the `Descriptor` interface called `ImmutableDescriptor` has been added.
 - A number of new conventional `Descriptor` items (“fields”) are documented in the API specification for the `Descriptor` interface.
 - Predefined `Descriptor` field names have corresponding string constants in the new class called `JMX`.
 - A new annotation `DescriptorKey` can be used to add information to the Descriptors for a Standard MBean (or MXBean) via annotations in its Java interface.
 - The method `Descriptor.getFieldValues(String...)` and the constructor `DescriptorSupport(String...)` previously took a `String[]` parameter.
 - The `Descriptor` interface defines an `equals` method and specifies how array values are compared.
 - The order the returned array is sorted with is clarified for `Descriptor.getFieldValues(null)`.
 - Exception wrapping for `Descriptor.setField` and `Descriptor.setFields` is specified.
- A new class `javax.management.JMX` has been added to house constants and static methods.
- Notification handling has been updated, as follows:
 - New constructors have been added to `NotificationBroadcasterSupport` that specify the `MBeanNotificationInfo[]` that will be returned by `getNotificationInfo()`.
 - The threading model for `NotificationBroadcasterSupport` has been specified explicitly and a constructor with an `Executor` parameter added to allow changing it.
 - The behavior when a filter or listener in `NotificationBroadcasterSupport` throws an exception is specified.

- A new class, `javax.management.StandardEmitterMBean`, is a subclass of `javax.management.StandardMBean` that is a `NotificationEmitter`.
- `ObjectName` has been modified, as follows:
 - Wildcards `*` and `?` can appear in the value of a key property for matching. New methods `isPropertyValuePattern()` and `isPropertyValuePattern(String property)` tell whether a given `ObjectName` has such a wildcard.
 - New `ObjectName` constants are added for the name of the MBean Server Delegate and for a wildcard that matches all `ObjectNames`.
 - `ObjectName` implements `Comparable<ObjectName>`.
- The text forbidding getters and setters as if they were operations was confusing in the previous version of this specification.
- Standard MBeans support covariant return types in MBean interfaces.
- `MBeanServer.isInstanceOf` semantics for Dynamic MBeans have been clarified.
- Various small changes have been applied to the Model MBean specification, as follows:
 - The `value` and `displayName` fields in Model MBean Descriptors are optional but the previous version of this specification did not show them in italics.
 - `RequiredModelMBean.setAttribute` should throw an exception if there is no `setMethod` and no `currencyTimeLimit`, because the `setAttribute` call would have no effect in this case.
 - The `role` field in `ModelMBeanOperationInfo` Descriptors is optional.
 - The value of the `targetType` Descriptor field is case insensitive but was omitted from the explicit list of case-insensitive fields.
 - The `targetType` Descriptor field is not included in the serial form of a `DescriptorSupport` instance.
 - `ModelMBeanInfoSupport.clone` is explicitly shallow (does not clone the contained `ModelMBeanAttributeInfoSupport` etc).
 - New `OnUnregister` value for the `persistPolicy` field of a Descriptor.
 - `DescriptorSupport(String[], Object[])` forbids null parameters - this was previously ambiguous.
- Open MBeans have been updated as follows:
 - Open MBeans can reference arrays of primitive type. An `ArrayType` object can be constructed that represents such an array.
 - In the constructor `ArrayType(int dimension, OpenType<?> elementType)`, the `elementType` parameter can now be an `ArrayType` instance.
 - `CompositeDataSupport.equals` compares arrays element-by-element.

- `TabularDataSupport.entrySet()` specifies the key in the returned `Set` is wrapped into a `List`.
- The *impact* of an `MBeanOperationInfo` can be `UNKNOWN`.
- The Monitor Service supports complex types when the monitored attribute looks like "a.b.c".
- Monitor tasks are specified to run within the access control context of the caller of `Monitor.start()`.
- Inconsistencies in the specification for past dates in the Timer Service have been resolved.
- The `MLetContent` class has been made public.
- The `RelationNotification` constructor now allows the source to be either a `RelationService` instance or an `ObjectName`.
- `RelationService.addRelationType` rejects a null relation name.
- The `RelationSupport` specification has been clarified regarding `RoleNotFoundException` thrown from `setRole` and `IllegalArgumentException` thrown from `setRoles`.
- A new query, `Query.isInstanceOf`, has been added.
- Proxies constructed with `MBeanServerInvocationHandler` no longer forward the methods `hashCode()`, `toString()`, and `equals(Object)` to the proxied `MBean`, unless they are explicitly declared in the proxy interface.
- The API documentation now clearly specified the `serialVersionUID` of all serializable classes and calls for queries to be serialized using standard non-public classes.

1.6.2 Changes to the JMX Remote Specification (JSR 160)

- `JMXConnector` interface extends `java.io.Closeable`.
- JMX connection provider exception handling clarified.
- Serialized form of `RMICConnector` class included spurious `clientNotifID` field.
- Added `JMXAddressable` interface to get the address to which a connector client is connected.

I JMX Instrumentation Specification

MBean Instrumentation

The instrumentation level of the JMX specification defines how to instrument resources in the Java programming language so that they can be managed. Resources developed according to the rules defined in this chapter are said to be JMX manageable resources.

The Java objects that implement resources and their instrumentation are called managed beans, or MBeans. MBeans must follow the design patterns and interfaces defined in this part of the specification. This ensures that all MBeans provide the instrumentation of managed resources in a standardized way.

MBeans are manageable by any JMX agent, but they can also be managed by non-compliant agents that support the MBean concept.

This part of the specification is primarily targeted at developers of applications or devices that want to provide management capabilities to their resources.

Developers of applications and devices are free to choose the granularity of objects that are instrumented as MBeans. An MBean might represent the smallest object in an application, or it could represent the entire application. Application components designed with their management interface in mind can typically be written as MBeans. MBeans can also be used as wrappers for legacy code without a management interface or as proxies for code with a legacy management interface.

2.1 Definition

An MBean is a concrete Java class that includes the following instrumentation:

- The implementation of its own corresponding MBean interface
or an implementation of the `DynamicMBean` interface
- Optionally, an implementation of the `NotificationBroadcaster` interface

A class that implements its own MBean interface is referred to as a *standard* MBean. This is the simplest type of instrumentation available when developing new JMX manageable resources. An MBean that implements the `DynamicMBean` interface specified in this chapter is known as a *dynamic* MBean, because certain elements of its instrumentation can be controlled at runtime.

Which interface the MBean implements determines how it will be developed, not how it will be managed. JMX agents provide the abstraction for handling both types of instrumentation transparently. In fact, when both types of MBean are being managed in a JMX agent, management applications handle them in a similar manner.

The Java class of a standard MBean exposes the resource to be managed directly through its attributes and operations. Attributes are internal entities that are exposed through getter and setter methods. Operations are the other methods of the class that are available to managers. All these methods are defined statically in the MBean interface and are visible to an agent through introspection. This is the most straightforward way of making a new resource manageable.

When developing a Java class from the `DynamicMBean` interface, attributes and operations are exposed indirectly through method calls. Instead of introspection, JMX agents must call one method to find the name and nature of attributes and operations. Then when accessing an attribute or operation, the agent calls a generic getter, setter or invocation method whose argument is the name of the attribute or operation. Dynamic MBeans enable you to rapidly instrument existing resources and other legacy code objects you want to manage.

2.1.1 Public Management Interface

It is not a requirement for an MBean of any type to be a public Java class. However, to be manageable, an MBean must have a public management interface. This public management interface is the MBean's own interface in the case of a standard MBean, or the `DynamicMBean` interface, in the case of a dynamic MBean.

2.1.2 MBean Public Constructor

The Java class of an MBean, whether standard or dynamic, can optionally be of a public class and have one or more public constructors. An MBean must be of a public concrete class with a public constructor if it is to be instantiated by a JMX agent on demand from a management application.

An MBean can have any number of constructors, to allow an agent to perform an instantiation. An MBean can also optionally have any number of public constructors, all of which are available to a management application through a JMX agent that can instantiate this MBean class.

Public constructors of an MBean can have any number of arguments of any type. It is the developer's and administrator's responsibility to guarantee that the classes for all argument types are available to the agent and manager when instantiating an MBean.

An MBean can omit all constructors and rely on the *default constructor* which the Java compiler provides automatically in such a case. The default constructor takes no arguments and is public if the class is public. The Java compiler does not provide a default public constructor if any other constructor is defined.

CODE EXAMPLE 2-1 shows a simple MBean example with two constructors, one of which is the public constructor.

CODE EXAMPLE 2-1 Constructors of the Simple MBean Example

```
public class Simple {  
  
    private int state = 0;  
  
    // Default constructor only accessible from subclasses  
    //  
    protected Simple() {  
    }  
  
    // Public constructor: this class is an MBean candidate  
    //  
    public Simple (int s) {  
        state = s;  
    }  
    ...  
}
```

2.2 Standard MBeans

To be manageable through a JMX agent, a standard MBean explicitly defines its management interface. The management interface defines the handles on the resource that are exposed for management. An MBean's interface is made up of the methods it makes available for reading and writing its attributes and for invoking its operations.

Standard MBeans rely on a set of naming rules, called *design patterns*, that must be observed when defining the interface of their Java object. These naming rules define the concepts of attributes and operations inspired by the JavaBeans™ component model. However, the actual design patterns for the JMX architecture take into consideration the inheritance scheme of the MBean, as well as lexical design patterns to identify the management interface. As a result, the design patterns for MBeans are specific to the JMX specification.

The management interface of a standard MBean is composed of:

- Its constructors: only the public constructors of the MBean class are exposed
- Its attributes: the properties that are exposed through getter and setter methods
- Its operations: the remaining methods exposed in the MBean interface
- Its notifications: the notification objects and types that the MBean broadcasts

As described in “MBean Public Constructor” on page 40, constructors are an inherent component of an MBean. The attributes and operations are methods of an MBean, but they are identified by the MBean interface, as described below. The notifications of an MBean are defined through a different interface: see “JMX Notification Model” on page 54.

The process of inspecting the MBean interface and applying these design patterns is called *introspection*. The JMX agent uses introspection to look at the methods and superclasses of a class, determine if it represents an MBean that follows the design patterns, and recognize the names of both attributes and operations.

2.2.1 MBean Interface

The Java class of a standard MBean must implement a Java interface that is named after the class. This interface mentions the complete signatures of the attribute and operation methods that are exposed. A management application can access these attributes and operations. A management application cannot access methods of the MBean’s Java class that are not listed in this interface.

The name of an MBean’s Java interface is formed by adding the `MBean` suffix to the MBean’s fully-qualified Java class name. For example, the Java class `MyClass` would implement the `MyClassMBean` interface; the Java class `com.example.MyClass` would implement the `com.example.MyClassMBean` interface. The interface of a standard MBean is referred to as its *MBean interface*.

By definition, the Java class of an MBean must implement all the methods in its MBean interface. How it implements these methods determines its response to management operations. An MBean can also define any other methods, public or otherwise, that do not appear in its MBean interface.

The MBean interface can list methods defined in the MBean, as well as methods that the MBean inherits from its superclasses. This enables MBeans to extend and instrument classes whose Java source code is inaccessible.

A standard MBean can also inherit its management interface if one of its superclasses implements a Java interface named after itself (the superclass). For example, if `MySuperClass` is an MBean and `MyClass` extends `MySuperClass` then `MyClass` is also an MBean. The same is true if `MySuperClass` is a dynamic MBean; `MyClass` would also be dynamic. If `MyClass` does not implement a `MyClassMBean` interface, then it will have the same management interface as `MySuperClass`. Otherwise, `MyClass` can redefine its management interface by implementing its own `MyClassMBean` interface.

In this case, `MyClassMBean` defines the management interface, and any management interface of `MySuperClass` is ignored. However, interfaces can also extend parent interfaces, and all methods in the inheritance tree are also considered. Therefore, `MyClassMBean` can extend `MySuperClassMBean`, allowing `MyClass` to extend the management interface of its parent. For more information about how an MBean inherits its management interface, see “Inheritance Patterns” on page 50.

Having to define and implement an MBean interface is the main constraint put on a standard MBean for it to be a JMX manageable resource.

As of the JMX 1.2 specification, the `javax.management.StandardMBean` class can be used to define standard MBeans with an interface whose name is not necessarily related to the class name of the MBean.

2.2.1.1 The `MyClass` Example MBean

CODE EXAMPLE 2-2 gives a basic illustration of the explicit definition of the management interface for an MBean named `MyClass`. Among the public methods it defines, `getHidden` and `setHidden` will not be part of the management interface because they do not appear in the `MyClassMBean` interface.

CODE EXAMPLE 2-2 `MyClassMBean` interface and `MyClass` Example

```
public interface MyClassMBean {
    public int getState();
    public void setState(int s);
    public void reset();
}
```

```

public class MyClass implements MyClassMBean {
    private int state = 0;
    private String hidden = null;

    public int getState() {
        return(state);
    }
    public void setState(int s) {
        state = s;
    }
    public String getHidden() {
        return(hidden);
    }
    public void setHidden(String h) {
        hidden = h;
    }
    public void reset() {
        state = 0;
        hidden = null;
    }
}

```

2.2.2 Lexical Design Patterns

The lexical patterns for attribute and operation names rely on the method names in an MBean interface. They enable a JMX agent to identify the names of attributes and operations exposed for management in a standard MBean. They also allow the agent to make the distinction between read-only, write-only and read-write attributes.

2.2.2.1 Attributes

Attributes are the fields or properties of the MBean that are in its management interface. Attributes are discrete, named characteristics of the MBean that define its appearance or its behavior, or are characteristics of the managed resource that the MBean instruments. For example, an attribute named `ipackets` in an MBean representing an Ethernet driver could be defined to represent the number of incoming packets.

Attribute names must begin with a character for which `Character.isJavaIdentifierStart` is true. The remaining characters in the name must also be true for `Character.isJavaIdentifierPart`.

Attributes are always accessed via method calls on the object that owns them. For readable attributes, there is a *getter* method to read the attribute value. For writable attributes, there is a *setter* method to allow the attribute value to be updated.

The following design pattern is used to identify attributes:

```
public AttributeType getAttributeName();  
public void setAttributeName(AttributeType value);
```

If a class definition contains a matching pair of *getAttributeName* and *setAttributeName* methods that take and return the same type, these methods define a read-write attribute called *AttributeName*. If a class definition contains only one of these methods, the method defines either a read-only or write-only attribute.

The *AttributeName* cannot be overloaded, that is, there cannot be two setters or a getter and setter pair for the same name that operate on different types. An object with overloaded attribute names is not a compliant MBean. The *AttributeType* can be of any Java type, including array types, provided that this type is valid in the MBean's runtime context or environment.

When the type of an attribute is an array type, the getter and setter methods operate on the whole array. The design patterns do not include any getter or setter method for accessing individual array elements. If access to individual elements of arrays is needed, it must be implemented through MBean operations.

In addition, for boolean type attributes, it is possible to define a getter method using the following design pattern:

```
public boolean isAttributeName();
```

To reduce redundancy, only one of the two getter methods for boolean types is allowed. An attribute can have either an *isAttributeName* method or a *getAttributeName* method, but not both in the same MBean.

2.2.2.2 Operations

Operations are the actions that a JMX manageable resource makes available to management applications. These actions can be any computation that the resource exposes, and they can also return a value.

In a standard MBean, an operation is a Java method specified in its interface and implemented in the class itself. Any method in the MBean interface that does not fit an attribute design pattern is considered to define an operation.

A typical usage is shown in CODE EXAMPLE 2-2 on page 43 where the MBean exposes the `reset` method to reinitialize its exposed attributes and private fields. Simple operations can also be written to access individual elements of an indexed array attribute.

2.2.2.3 Case Sensitivity

All attribute and operation names derived from these design patterns are case-sensitive. For example, this means that the methods `getState` and `setState` define two attributes, one called `state` that is read-only, and one called `State` that is write-only.

While case sensitivity applies directly to component names of standard MBeans, it is also applicable to all component names of all types of MBeans, standard or dynamic. In general, all names of classes, attributes, operations, methods, and internal elements defined in the JMX specification are case sensitive, whether they appear as data or as functional code when they are manipulated by management operations.

2.3 Dynamic MBeans

Standard MBeans are ideally suited for straightforward management structures, where the structure of managed data is well defined in advance and unlikely to change often. In such cases, standard MBeans provide the quickest and easiest way to instrument manageable resources. When the data structures are likely to evolve often over time, the instrumentation must provide more flexibility, such as being determined dynamically at runtime. Dynamic MBeans bring this adaptability to the JMX specification and provide an alternative instrumentation with more elaborate management capabilities.

Dynamic MBeans are resources that are instrumented through a predefined interface that exposes the attributes and operations only at runtime. Instead of exposing them directly through method names, dynamic MBeans implement a method that returns all attributes and operation signatures. For example, this information could be determined by reading an XML file at runtime.

Because the names of the attributes and operations are determined dynamically, these MBeans provide great flexibility when instrumenting existing resources. An MBean that implements the `DynamicMBean` interface provides a mapping for existing resources that do not follow standard MBean design patterns. Instead of introspection, JMX agents call the method of the MBean that returns the name of the attributes and operations it exposes.

When managed through a JMX agent, dynamic MBeans offer all the same capabilities that are available through standard MBeans. Management applications that rely on JMX agents can manipulate all MBeans in exactly the same manner regardless of their type.

2.3.1 DynamicMBean Interface

For a resource object to be recognized as a dynamic MBean by the JMX agent, its Java class or one of its superclasses must implement the `DynamicMBean` public interface.

The `DynamicMBean` interface is defined by the UML diagram in FIGURE 2-1 below. Each of the methods it defines is described in the following subsections.

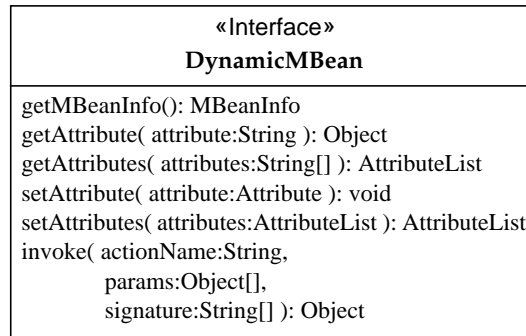


FIGURE 2-1 Definition of the `DynamicMBean` Interface

getMBeanInfo Method

This method returns an `MBeanInfo` object that contains the definition of the MBean’s management interface. Conceptually, dynamic MBeans have both attributes and operations, only they are not exposed through method names. Instead, dynamic MBeans expose attribute names and types and operation signatures through the return value of this method at runtime.

This method returns an `MBeanInfo` object that contains a list of attribute names and their types, a list of operations and their parameters, and other management information. This type and its constituent classes are further described in “MBean Metadata Classes” on page 60.

getAttribute and getAttributes Methods

These methods take an attribute name and a list of attribute names, respectively, and return the value of the corresponding attribute(s). These are like a standard getter method, except the caller supplies the name of the attribute requested. It is up to the implementation of the dynamic MBean to map the exposed attribute names correctly to their values through these methods.

The classes that are used to represent attribute names and values and lists of names and values are described in “Attribute and AttributeList Classes” on page 119. These data types are also used by the `setAttribute` methods below.

setAttribute and setAttributes Methods

These methods take attribute name-value pairs and, like standard setter methods, they write these values to the corresponding attribute. When setting several attributes at a time, the list of attributes for which the write operation succeeded is returned. When setting only one attribute, there is no return value and any error is signaled by raising an exception. Again, it is up to the implementation of the dynamic MBean to map the new values correctly to the internal representation of their intended attribute target.

invoke Method

The `invoke` method lets management applications call any of the operations exposed by the dynamic MBean. Here the caller must provide the name of the intended operation, the objects to be passed as parameters, and the types for these parameters. By including the operation signature, the dynamic MBean implementation can verify that the mapping is consistent between the requested operation and that which is exposed. It can also choose between methods that have the same name but different signatures (overloaded methods), though this is not recommended.

If the requested operation is successfully mapped to its internal implementation, this method returns the result of the operation. The calling application will expect to receive the return type exposed for this operation in the `MBeanInfo` method.

2.3.2 Behavior of Dynamic MBeans

When registered in a JMX agent, a dynamic MBean is treated in exactly the same way as a standard MBean. Typically, a management application will first obtain the management interface through the `getMBeanInfo` method, to have the names of the attributes and operations. The application will then make calls to getters, setters and the `invoke` method of the dynamic MBean.

In fact, the interface for dynamic MBeans is very similar to that of the MBean server in the JMX agent (see “Role of the MBean Server” on page 127). A dynamic MBean provides the management abstraction that the MBean server provides for standard MBeans. This is why management applications can manipulate both kinds of MBean without distinction: the same management operations are applied to both.

In the case of the standard MBean, the MBean server uses introspection to find the management interface and then call the operations requested by the manager. In the case of the dynamic MBean, these tasks are taken over by the dynamic MBean’s implementation. In effect, the MBean server delegates the self description functionality to the `getMBeanInfo` method of a dynamic MBean.

2.3.2.1 Coherence

With this delegation comes the responsibility of ensuring coherence between the dynamic MBean’s description and its implementation. The MBean server does not test or validate the self description of a dynamic MBean in any way. Its developer must guarantee that the advertised management interface is accurately mapped to the internal implementation. For more information about describing an MBean, see “MBean Metadata Classes” on page 60.

From the manager’s perspective, how the dynamic MBean implements the mapping between the declared management interface and the returned attribute values and operation results is not important; it only expects the advertised management interface to be available. This gives much flexibility to the dynamic MBean to build more complex data structures, expose information that it can gather off-line, or provide a wrapper for resources not written in the Java programming language.

2.3.2.2 Dynamics

Because the management interface of a dynamic MBean is returned at runtime by the `getMBeanInfo` method, the management interface itself can be dynamic. That is, subsequent calls to this method might not describe the same management interface. It should be noted that the `getMBeanInfo` method is allowed to vary.

Therefore, truly dynamic MBeans, in which you can change the MBean interface, are possible, though they can only be managed by proprietary management applications designed specifically to handle them.

Truly dynamic MBeans of this sort can only be used in limited circumstances, because in general there is no way for a management application to notice that the interface has changed. Developers implementing such systems should consider how they work when more than one management application is connected to the system. Race conditions also need to be considered: for instance, if the MBean sends a notification to say that its interface has changed, at the same time a management application might be performing an operation on the MBean based on its old interface.

The *descriptor field* (see page 60) `immutableInfo` can be used to declare explicitly whether the management interface of an MBean will change over its lifetime.

2.4 Inheritance Patterns

The *introspection* of an MBean is the process that JMX agents use to determine its management interface. This algorithm is applied at runtime by a JMX compliant agent, but it is described here because it determines how the inheritance scheme of an MBean influences its management interface.

When introspecting a standard MBean, the management interface is defined by the design patterns used in its MBean interface. Because interfaces can also extend parent interfaces, all public methods in the inheritance tree of the interface are also considered. When introspecting a dynamic MBean, the management interface is given through the `DynamicMBean` interface. In either case, the algorithm determines the names of the attributes and operations that are exposed for the given resource.

The introspection algorithm used is the following:

1. If `MyClass` is an instance of the `DynamicMBean` interface, then the return value of its `getMBeanInfo` method will list the attributes and operations of the resource. In other words, `MyClass` is a dynamic MBean.
2. If the `MyClass` MBean is an instance of a `MyClassMBean` interface, then only the methods listed in, or inherited by, the interface are considered among all the methods of, or inherited by, the MBean. The design patterns are then used to identify the attributes and operations from the method names in the `MyClassMBean` interface and its ancestors. In other words, `MyClass` is a standard MBean.

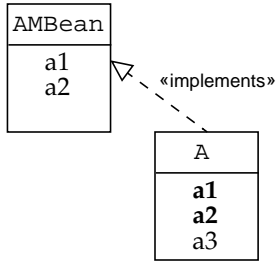
3. If `MyClass` is an instance of the `DynamicMBean` interface, then `MyClassMBean` is ignored. If `MyClassMBean` is not a public interface, it is not a JMX manageable resource. If the `MBean` is an instance of neither `MyClassMBean` nor `DynamicMBean`, the inheritance tree of `MyClass` is examined, looking for the nearest superclass that implements its own `MBean` interface.
 - a. If there is an ancestor called `SuperClass` that is an instance of `SuperClassMBean`, the design patterns are used to derive the attributes and operations from `SuperClassMBean`. In this case, the `MBean` `MyClass` then has the same management interface as the `MBean` `SuperClass`. If `SuperClassMBean` is not a public interface, it is not a JMX manageable resource.
 - b. When there is no superclass with its own `MBean` interface, `MyClass` is not a `Standard MBean`.
4. If none of the above conditions applies and `MyClass` implements an `MXBean` interface, then `MyClass` is an `MXBean` and its attributes and operations are determined by the `MXBean` interface as detailed in the API documentation for `javax.management.MXBean`.

As a general rule, the management interface is defined either by the `DynamicMBean` interface, if the `MBean` is an instance of `DynamicMBean`, or by the `MBean` class or the nearest ancestor that implements its own `MBean` interface. If neither the class nor any of its superclasses follows the rules for a standard or dynamic `MBean`, it is not a JMX manageable resource and the JMX agent will raise an `MBean` error (see “JMX Exceptions” on page 119). Similarly, an `MBean` interface implemented by a standard `MBean` must be public.

These rules do not exclude the rare case of a class that inherits from a standard `MBean` but is itself a dynamic `MBean` because it implements the `DynamicMBean` interface. On the other hand, a class that inherits from a dynamic `MBean` is always a dynamic `MBean`, even if it follows the rules for a standard `MBean`.

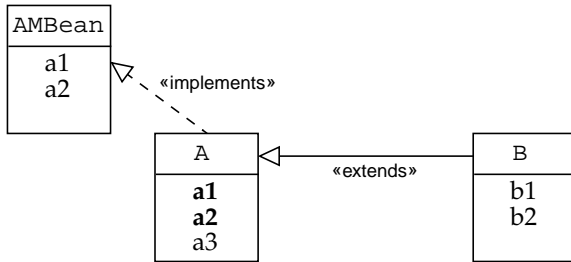
Standard MBean Inheritance

For standard `MBeans`, the management interface can be built up through inheritance of both the class and its interface. This is shown in the following examples, where the class fields `a1`, `a2`, and so on, stand for attributes or operations recognized by the design patterns for standard `MBeans`. Various combinations of these example cases are also possible.



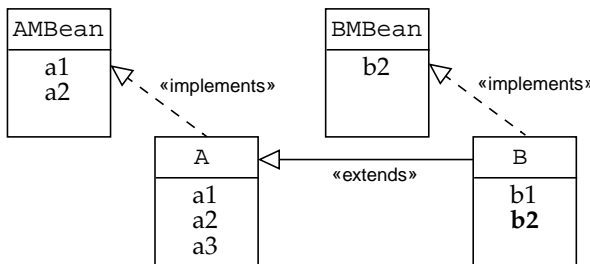
In the simplest case, class A implements class `AMBean`, which therefore defines the management interface for A: {a1, a2}.

FIGURE 2-2 Standard MBean Inheritance (Case 1)



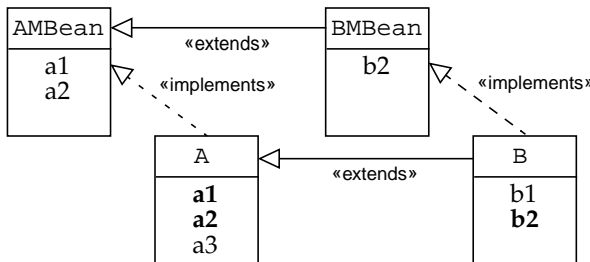
If class B extends A without defining its own MBean interface, then B is also an MBean. B has the same management interface as A: {a1, a2}

FIGURE 2-3 Standard MBean Inheritance (Case 2)



If class B does implement the `BMBean` interface, then this defines the only management interface considered: {b2}.

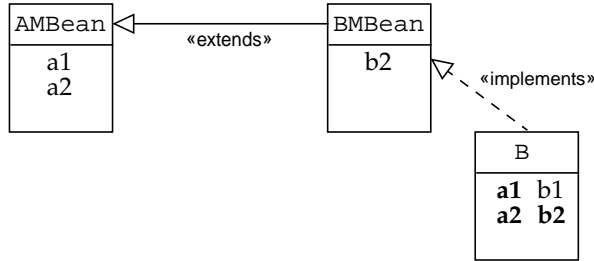
FIGURE 2-4 Standard MBean Inheritance (Case 3)



The `BMBean` interface and all interfaces it extends make up the management interface for the elements which B defines or inherits: {a1, a2, b2}.

Whether or not A implements `AMBean` makes no difference with regards to B.

FIGURE 2-5 Standard MBean Inheritance (Case 4)



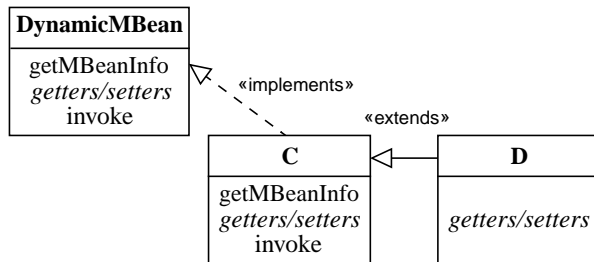
The class B must implement all methods defined in or inherited by the BMBean interface. If it does not inherit them, it must implement them explicitly: {a1, a2, b2}.

FIGURE 2-6 Standard MBean Inheritance (Case 5)

Dynamic MBean Inheritance

Like standard MBeans, dynamic MBeans can also inherit their instrumentation from a superclass. However, the management interface cannot be composed from the inheritance tree of the dynamic MBean class. Instead, the management interface is defined in its entirety by the `getMBeanInfo` method or the nearest superclass implementation of this method.

In the same way, subclasses can also redefine getters, setters and the `invoke` method, thus providing a different behavior for the same management interface. It is the MBean developer's responsibility that the subclass' implementation of the attributes or operations matches the management interface that is inherited or exposed.



If class D extends C without redefining the `getMBeanInfo` method, then D is a dynamic MBean with the same management interface. However, D overrides the getter and setter methods of C, thus providing a different implementation of the same attributes.

FIGURE 2-7 Dynamic MBean Inheritance

2.5 JMX Notification Model

The management interface of an MBean allows its agent to perform control and configuration operations on the managed resources. However, such interfaces provide only part of the functionality necessary to manage complex, distributed systems. Most often, management applications need to react to a state change or to a specific condition when it occurs in an underlying resource.

This section defines a model that allows MBeans to broadcast such management events, called *notifications*. Management applications and other objects register as *listeners* with the *broadcaster* MBean. The MBean notification model of JMX enables a listener to register only once and still receive all the different events that might occur in the broadcaster.

The JMX notification model relies on the following components:

- A generic event type, `Notification`, that can signal any type of management event. The `Notification` event can be used directly, or can be subclassed, depending on the information that needs to be conveyed with the event.
- The `NotificationListener` interface, which needs to be implemented by objects requesting to receive notifications sent by MBeans.
- The `NotificationFilter` interface, which needs to be implemented by objects that act as a *notification filter*. This interface lets notification listeners provide a filter to be applied to notifications emitted by an MBean.
- The `NotificationBroadcaster` interface, which needs to be implemented by each MBean that emits notifications. This interface allows listeners to register their interest in the notifications emitted by an MBean.
- The `NotificationEmitter` interface, that extends `NotificationBroadcaster` to allow more control when removing listeners.

By using a generic event type, this notification model allows any one listener to receive all types of events from a broadcaster. The filter is provided by the listener to specify only those events that are needed. Using a filter, a listener only needs to register once to receive all selected events of an MBean.

Any type of MBean, standard or dynamic, can be either a notification broadcaster, a notification listener, or both at the same time. Notification filters are usually implemented as callback methods of the listener itself, but this is not a requirement.

2.5.0.1 Notification Type

The *type* of a notification, not to be confused with its Java class, is the characterization of a generic notification object. The type is assigned by the broadcaster object and conveys the semantic meaning of a particular notification.

The type is given as a `String` field of the `Notification` object. This string is interpreted as any number of dot-separated components, allowing an arbitrary, user-defined structure in the naming of notification types.

All notification types prefixed by “JMX.” are reserved for the notifications emitted by the components of the JMX infrastructure defined in this specification, such as `JMX.mbean.registered`. Otherwise, notification broadcasters are free to define all the types they use when naming the notifications they emit. Usually, MBeans will use type strings that reflect the nature of their notifications within the larger management structure in which they are involved.

For example, a vendor who provides JMX manageable resources as part of a management product might prefix all its notification types with `VendorName`. FIGURE 2-8 below shows a tree representation of the structure induced by the dot notation in notification type names.

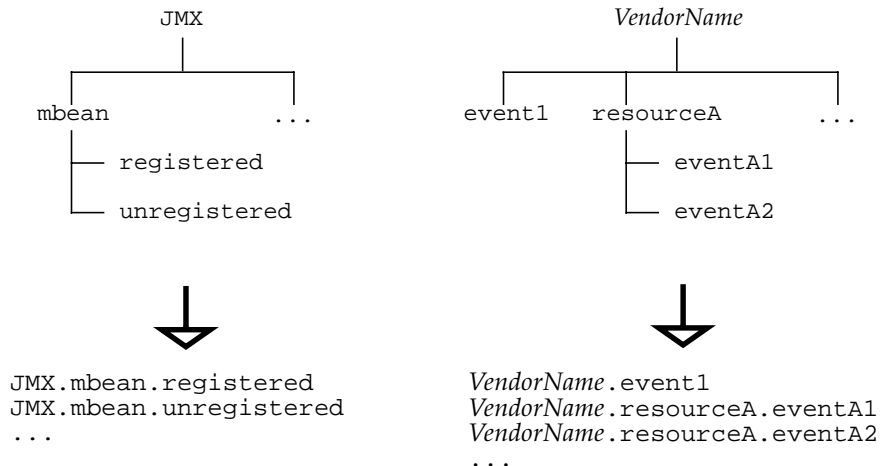


FIGURE 2-8 Structure of Notification Type Strings

2.5.1 Notification Class

The `Notification` class extends the `java.util.EventObject` base class and defines the minimal information contained in a notification. It contains the following fields:

- The *notification type*, a string expressed in a dot notation similar to Java properties, for example: `vendorName.resourceA.eventA1`
- A *sequence number*, a serial number identifying a particular instance of notification in the context of the notification broadcaster

- A *time stamp*, indicating when the notification was generated
- A *message* contained in a string, which could be the explanation of the notification for displaying to a user
- *User data* is used for whatever other data the notification broadcaster will communicate to its listeners

Notification broadcasters use the notification type to indicate the nature of the event to their listeners. Additional information that needs to be transmitted to listeners is placed in the message or in the user data fields.

In most cases, this information is sufficient to allow broadcasters and listeners to exchange instances of the `Notification` class. However, subclasses of the `Notification` class can be defined when additional semantics are required within the notification object.

2.5.2 NotificationBroadcaster and NotificationEmitter Interfaces

This interface specifies three methods that MBeans acting as notification broadcasters must implement:

- `getNotificationInfo` - Gives a potential listener the description of all notifications this broadcaster can emit. This method returns an array of `MBeanNotificationInfo` objects, each of which describes a notification. For more information about this class, see “`MBeanNotificationInfo` Class” on page 65.
- `addNotificationListener` - Registers a listener’s interest in notifications sent by this MBean. This method takes a reference to a `NotificationListener` object, a reference to a `NotificationFilter` object, and a `handback` object.

The `handback` object is provided by the listener upon registration and is opaque to the broadcaster MBean. The implementation of the broadcaster interface must store this object and return its reference to the listener with each notification. This `handback` object can allow the listener to retrieve context information for use while processing the notification.

The same listener object can be registered more than once, each time with a different `handback` object. This means that the `handleNotification` method of this listener will be invoked several times, with different `handback` objects.

The MBean has to maintain a table of listener, filter and `handback` triplets. When the MBean emits a notification, it invokes the `handleNotification` method of all the registered `NotificationListener` objects, with their respective `handback` object.

If the listener has specified a `NotificationFilter` when registering as a `NotificationListener` object, the MBean will invoke the filter's `isNotificationEnabled` method first. Only if the filter returns an affirmative (`true`) response will the broadcaster then call the notification handler.

- `removeNotificationListener` - Unregisters the listener from a notification broadcaster. If a listener has been registered several times with this broadcaster, all entries corresponding to the listener will be removed.

Any type of MBean can implement the `NotificationBroadcaster` interface. This might lead to a special case of a standard MBean that has an empty management interface: its role as a manageable resource is to be a broadcaster of notifications. It must be a concrete class, and it must implement an MBean interface, which in this case defines no methods. The only methods in its class are those implementing the `NotificationBroadcaster` interface. This MBean can be registered in a JMX agent, and its management interface only contains the list of notifications that it may send.

Instead of `NotificationBroadcaster`, an MBean can implement its subinterface `NotificationEmitter`, introduced in version 1.2 of the JMX specification. It is recommended that new code use `NotificationEmitter` rather than `NotificationBroadcaster`. `NotificationEmitter` adds a second `removeNotificationListener` method that specifies the filter and handback values for the listener to be removed. If the listener is registered more than once with different filter and handback values, only a matching one is removed.

Instead of implementing `NotificationBroadcaster` or `NotificationEmitter`, an MBean can inherit from the standard JMX class `NotificationBroadcasterSupport`. This class manages a list of listeners, modified by the `addNotificationListener` and `removeNotificationListener` methods. Its `sendNotification` method sends a notification to all listeners in the list whose filters accept it.

2.5.3 NotificationListener Interface

This interface must be implemented by all objects interested in receiving notifications sent by any broadcaster. It defines a unique callback method, `handleNotification`, which is invoked by a broadcaster MBean when it emits a notification.

Besides the `Notification` object, the listener's handback object is passed as an argument to the `handleNotification` method. This is a reference to the same object that the listener provided upon registration. It is stored by the broadcaster and returned unchanged with each notification.

Because all notifications are characterized by their type string, notification listeners only implement one handler method for receiving all notifications from all potential broadcasters. This method then relies on the type string, other fields of the notification object and on the `handback` object to determine the broadcaster and the meaning of the notification.

2.5.4 NotificationFilter Interface

This interface is implemented by objects acting as a notification filter. It defines a unique method, `isNotificationEnabled`, which will be invoked by the broadcaster before it emits a notification. This method takes the `Notification` object that the broadcaster intends to emit and, based on its contents, returns `true` or `false`, indicating whether or not the listener will receive this notification.

The filter object is provided by the listener when it registers for notifications with the broadcaster, so each listener can provide its own filter. The broadcaster must apply each listener's filter, if defined, before calling the `handleNotification` method of the corresponding listener.

Listeners rely on the filter to screen all possible notifications and only handle the ones in which they are interested. An object can be both a listener and a filter by implementing both the `NotificationListener` and the `NotificationFilter` interfaces. In this case, the object reference will be given for both the listener and the filter object when registering it with a broadcaster.

2.6 Attribute Change Notifications

This section introduces a specific family of notifications, the *attribute change notifications*, that allows management services and applications to be notified whenever the value of a given MBean attribute is modified.

In the JMX architecture, the MBean has the full responsibility of sending notifications when an attribute change occurs. The mechanism for detecting changes in attributes and triggering the notification of the event is not part of the JMX specification. The attribute change notification behavior is therefore dependent upon the implementation of each MBean's class.

MBeans are not required to signal attribute changes, but if they need to do so within the JMX architecture, they rely on the following components:

- A specific event class, `AttributeChangeNotification`, which can signal any attribute change event.
- A specific filter support, `AttributeChangeNotificationFilter`, which allows attribute change notification listeners to filter the notifications depending on the attributes of interest.

Otherwise, attribute change notification broadcasters and listeners are defined by the same interfaces as in the standard notification model. Any MBean sending attribute change notifications must implement the `NotificationBroadcaster` interface, as described in the “JMX Notification Model” on page 54. Similarly, the `NotificationListener` interface must be implemented by all objects interested in receiving attribute change notifications sent by an MBean.

2.6.1 AttributeChangeNotification Class

The `AttributeChangeNotification` class extends the `Notification` class and defines the following additional fields:

- The name of the attribute that has changed
- The type of the attribute that has changed
- The old value of the attribute
- The new value of the attribute

When implementing the attribute change notification model, broadcaster MBeans must use this class when sending notifications of attribute changes. They can also send other `Notification` objects for other events. The additional fields of this class provide the listener with information about the attribute that has changed. The notification type of all attribute change notifications must be `jmx.attribute.change`. This type is defined by the static string `ATTRIBUTE_CHANGE` declared in this class.

2.6.2 AttributeChangeNotificationFilter Class

The `AttributeChangeNotificationFilter` class implements the `NotificationFilter` interface and defines the following additional methods:

- `enableAttribute` - Enables notifications for the given attribute name.
- `disableAttribute` - Filters out notifications for the given attribute name.
- `disableAllAttributes` - Effectively disables all attribute change notifications.
- `getEnabledTypes` - Returns a list of all attribute names that are currently enabled for receiving notifications

Notification listeners observing certain attributes for changes can instantiate this class, configure the set of “enabled” attributes and use this object as the filter when registering as a listener with a known attribute change broadcaster. The attribute change filter allows the listener to receive attribute change notifications only for those attributes that are desired.

2.7 MBean Metadata Classes

This section defines the classes that describe an MBean. These classes are used both for the introspection of standard MBeans and for the self description of all dynamic MBeans. These classes describe the management interface of an MBean in terms of its attributes, operations, constructors and notifications.

The JMX agent exposes all its MBeans, regardless of their type, through the MBean metadata classes. All clients, whether management applications or other local MBeans viewing the management interface of an MBean, need to be able to interpret these objects and their constructs. Certain MBeans might provide additional data by extending these classes (see “Open Type Descriptions” on page 71 and “Model MBean Metadata Classes” on page 81).

In addition to providing an internal representation of any MBean, these classes can be used to construct a visual representation of any MBean. One approach to management is to present all manageable resources to an operator through a graphical user interface. To this end, the complete description of all MBeans includes a descriptive text for each of their components. How this information is displayed is completely dependent upon the application that manages the MBean and is outside the scope of this specification.

The following classes define an MBean’s management interface; they are referred to collectively as the *MBean metadata classes* throughout this document:

- `MBeanInfo` - lists the attributes, operations, constructors and notifications
- `MBeanFeatureInfo` - superclass for the following classes
- `MBeanAttributeInfo` - describes an attribute
- `MBeanConstructorInfo` - describes the signature of a constructor
- `MBeanOperationInfo` - describes the signature of an operation
- `MBeanParameterInfo` - describes a parameter of an operation or constructor
- `MBeanNotificationInfo` - describes a notification

All of these classes include a *descriptor*, which is a collection of (key,value) pairs where the key is a string. Several keys are predefined by the JMX specification. For example, the `units` key can be added in the descriptor for an attribute to express what units the value of the attribute is in. Descriptors are further defined in Section 4.4 “Descriptors” on page 97, and in the API documentation for `javax.management.Descriptor`. For a Standard MBean, the contents of the descriptor can be supplied by annotations in the Standard MBean interface, as described in the API documentation for `javax.management.DescriptorKey`.

The following UML diagram shows the relationship between these classes as well as the components of each. Each class is fully described in the subsequent sections.

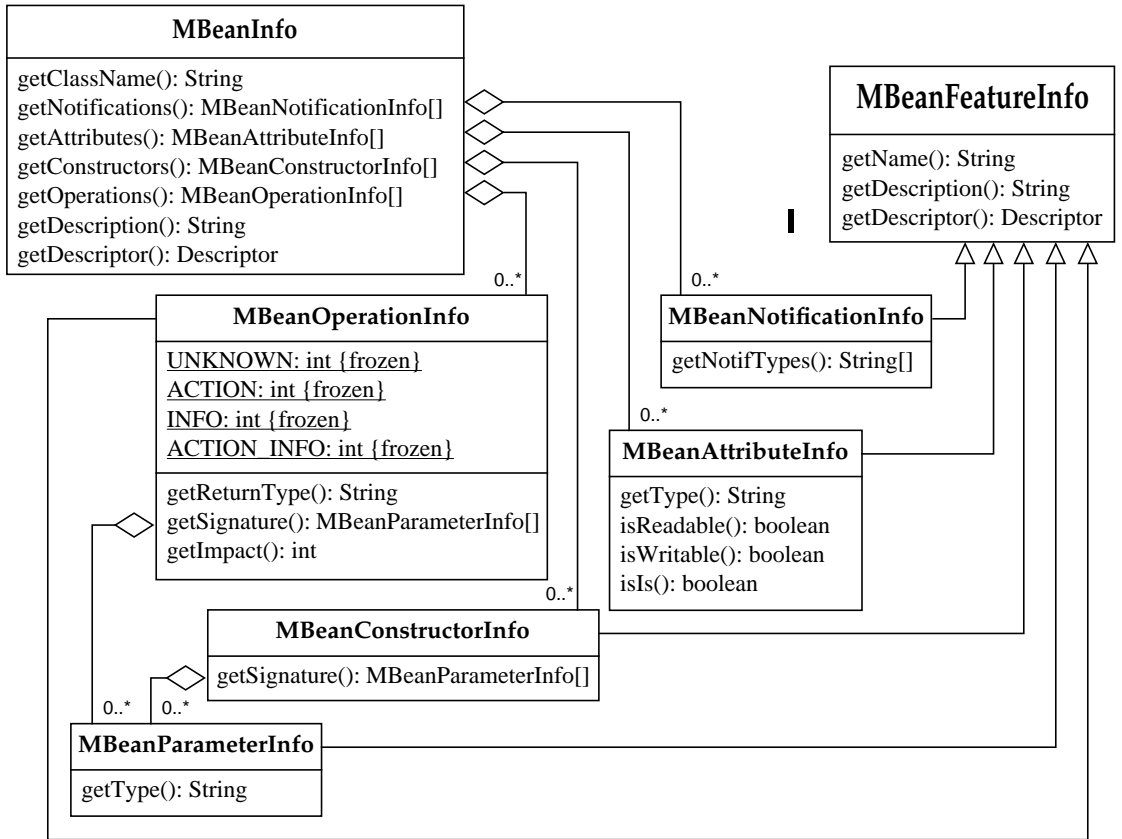


FIGURE 2-9 The MBean Metadata Classes

2.7.1 MBeanInfo Class

This class is used to fully describe an MBean: its attributes, operations, its constructors, and the notification types it can send. For each of these categories, this class stores an array of metadata objects for the individual components. If an MBean has no component in a certain category, for example no notifications, the corresponding method returns an empty array.

Each metadata object is a class that contains information that is specific to the type of component. For example, attributes are characterized by their type and read-write access, and operations by their signature and return type. All components have a case-sensitive name and a description string.

Besides the array of metadata objects for each component category, the `MBeanInfo` class has three descriptive methods. The `getClassName` method returns a string containing the Java class name of this MBean. The `getDescription` method is used to return a string describing the MBean that is suitable for displaying to a user in a GUI. It describes the MBean's overall purpose or functionality. The `getDescriptor` method returns the descriptor for this MBean as a whole.

In the case of a standard MBean, the information contained in the `MBeanInfo` class is provided by the introspection mechanism of the JMX agent. Introspection can determine the components of the MBean, but it cannot provide a qualitative description. The introspection of standard MBeans provides a simple generic description string for the `MBeanInfo` object and all its components. Therefore, all standard MBeans will have the same description. The `StandardMBean` class provides a way to add custom descriptions while keeping the convenience of the standard MBean design patterns.

For dynamic MBeans, it is the developer's responsibility to ensure that the description strings for the `MBeanInfo` object and all its components provide correct and useful information about the MBean.

2.7.2 MBeanFeatureInfo Class

This class is not directly returned by an `MBeanInfo` object, but it is the parent of all the other component metadata classes. All the subsequent objects subclass `MBeanFeatureInfo` and inherit its three methods, `getName`, `getDescription`, and `getDescriptor`.

The `getName` method returns a string with the name of the component. This name is case-sensitive and identifies the given component within the MBean. For example, if an MBean interface exposes the `getState` method, it will be described by an `MBeanAttributeInfo` object whose inherited `getName` method will return "state".

The `getDescription` method returns a string that provides a human readable explanation of a component. In the case of dynamic MBeans, this string must be provided by the developer. For example, this string must be suitable for displaying to an operator through the user interface of a management application.

The `getDescriptor` method returns a descriptor containing arbitrary extra information about the component.

2.7.3 MBeanAttributeInfo Class

The `MBeanAttributeInfo` class describes an attribute in the MBean's management interface. An attribute is characterized by its type and by how it is accessed.

The type of an attribute is the Java class that is used to represent it when calling its getter or setter methods. The `getType` method returns a string containing the fully qualified name of this class. The format of this string is identical to that of the string returned by the `getName` method of the `java.lang.Class` class.

For a complete description of this format, please see the API documentation generated by the Javadoc tool for the `java.lang.Class` class in the Java 2 platform standard edition (J2SE) online documentation. As an example, an array of `java.util.Map` type is represented as the string "[Ljava.util.Map;", and a two-dimensional array of bytes is represented as the string "[[B". Non-array objects are simply given as their full package name, such as "java.util.Map".

MBean access is either readable, writable or both. Read access implies that a manager can get the value of this attribute, and write access that it can set its value:

- The `isReadable` method will return `true` if this attribute has a getter method in its MBean interface or if the `getAttribute` method of the `DynamicMBean` interface will succeed with this attribute's name as the parameter; otherwise it will return `false`.
- The `isWritable` method will return `true` if this attribute has a setter method in its MBean interface or if the `setAttribute` method of the `DynamicMBean` interface will succeed with this attribute's name as a parameter; otherwise it will return `false`.
- The `isIs` method will return `true` if this attribute has a boolean type and a getter method with the *is* prefix (versus the *get* prefix); otherwise it will return `false`. Note that this information is only relevant for a standard MBean.

See "Lexical Design Patterns" on page 44 for the definition of getter and setter methods in standard MBeans.

Note – By this definition, the access information does not take into account any read or write access to an attribute's internal representation that an MBean developer might provide through one of the operations.

2.7.4 MBeanConstructorInfo Class

MBean constructors are described solely by their signature: the order and types of their parameters. This class describes a constructor and contains one method, `getSignature`, that returns an array of `MBeanParameterInfo` objects. This array has no elements if the given constructor has no parameters. Elements of the

parameter array are listed in the same order as constructor parameters, and each element gives the type of its corresponding parameter (see “MBeanParameterInfo Class” on page 64).

2.7.5 MBeanOperationInfo Class

The `MBeanOperationInfo` class describes an individual operation of an MBean. An operation is defined by its signature, return type, and its impact.

The `getImpact` method returns an integer that can be mapped using the static fields of this class. Its purpose is to communicate the impact this operation will have on the managed entity represented by the MBean. A method described as `INFO` will not modify the MBean, it is a read-only method that only returns data. An `ACTION` method has some effect on the MBean, usually a write operation or some other state modification. The `ACTION_INFO` method has both read and write roles.

The `UNKNOWN` value is reserved for the description of all operations of a standard MBean, as introspected by the MBean server.

Impact information is very useful for making decisions on which operations to expose to users at different times. It can also be used by some security schemes. It is the dynamic MBean developer’s responsibility to assign the impact of each method in its metadata object correctly and consistently. Indeed, the difference between “information” and “action” is dependent on the design and usage of each MBean.

The `getReturnType` method returns a string containing the fully qualified class name of the Java object returned by the operation being described. The format of this string is identical to that of the string returned by the `getName` method of the `java.lang.Class` class, as described by the API documentation generated by the Javadoc tool in the J2SE online documentation.

The `getSignature` method returns an array of `MBeanParameterInfo` objects where each element describes a parameter of the operation. The array elements are listed in the same order as the operation’s parameters, and each element gives the type of its corresponding parameter (see below).

2.7.6 MBeanParameterInfo Class

The `MBeanParameterInfo` class is used to describe a parameter of an operation or of a constructor. This class gives the class type of the parameter and also extends the `MBeanFeatureInfo` class to provide a name and description.

As in the “MBeanAttributeInfo Class” on page 63, the `getType` method returns a string containing the fully qualified name of this class. The format of this string is identical to that of the string returned by the `getName` method of the `java.lang.Class` class, as described by the API documentation generated by the Javadoc tool in the J2SE online documentation.

2.7.7 MBeanNotificationInfo Class

The `MBeanNotificationInfo` class is used to describe the notifications that are sent by an MBean. This class extends the `MBeanFeatureInfo` class to provide a name and a description. The name must give the fully qualified class name of the notification objects that are actually broadcast.

The `getNotifTypes` method returns an array of strings containing the notification types that the MBean can emit. The notification type is a string containing any number of elements in dot notation, not the name of the Java class that implements this notification. As described in “JMX Notification Model” on page 54, a single notification class can be used to send several notification types. All these types are returned in the string array returned by this method.

Open MBeans

This chapter defines a way of instrumenting resources to which MBeans must conform if they are to be “open” to the widest range of management applications. These MBeans are called open MBeans.

In version 1.0 of the JMX specification, open MBeans were incompletely specified and could not be implemented. In version 1.1, open MBeans were completely specified but were optional in implementations. As of version 1.2, open MBeans are a mandatory part of any JMX implementation.

3.1 Overview

The goal of open MBeans is to provide a mechanism that will allow management applications and their human administrators to understand and use new managed objects when they are discovered at runtime. These MBeans are called “open” because they rely on small, predefined set of universal Java types and they advertise their functionality.

Management applications and open MBeans are thus able to share and use management data and operations at runtime without requiring the recompilation, reassembly or expensive dynamic linking of management applications. In the same way, human operators can intelligently use the newly discovered managed object without having to consult additional documentation. Thus, open MBeans contribute to the flexibility and scalability of management systems.

Open MBeans are particularly useful where the management application does not necessarily have access to the Java classes of the agent. By using only standard, self describing types, agents and management applications can interoperate without having to share application-specific classes.

In addition, because the set of open MBean data-types is fixed, and does not include self referential types or subclassing, open MBeans are accessible even when the connection between the management application and the agent does not support Java serialization. An important case of this is when the management application is in a language other than Java.

To provide its own description to management applications, an open MBean must be a dynamic MBean (see “Dynamic MBeans” on page 46). Beyond the `DynamicMBean` interface, there is no corresponding “open” interface that must be implemented. Instead, an MBean earns its “openness” by providing a descriptively rich metadata and by using only certain predefined data types in its management interface.

An open MBean has attributes, operations, constructors and possibly notifications like any other MBeans. It is a dynamic MBean with the same behavior and all the same functionality. It also has the responsibility of providing its own description. However, all the object types that the MBean manipulates, its attribute types, its operation parameters and return types, and its constructor parameters, must belong to the set defined in “Basic Data Types” on page 68 below. It is the developer’s responsibility to implement the open MBean fully using these data types exclusively.

An MBean indicates whether it is open or not through the `MBeanInfo` object it returns. Open MBeans return an `OpenMBeanInfo` object, a subclass of `MBeanInfo`. Other component metadata classes are also subclassed and it is the developer’s responsibility to describe the open MBean fully using the proper classes. If an MBean is marked as open in this manner, it is a guarantee that a management application compliant with the JMX specification can immediately make use of all attributes and operations without requiring additional classes.

Because open MBeans are also dynamic MBeans and provide their own description, the MBean server does not check the accuracy of the `OpenMBeanInfo` object (see “Behavior of Dynamic MBeans” on page 49). The developer of an open MBean must guarantee that the management interface relies on the basic data types and provides a rich, human-readable description. As a rule, the description provided by the various parts of an open MBean must be suitable for displaying to a user through a Graphical User Interface (GUI).

3.2 Basic Data Types

In order for management applications to make use immediately of MBeans without recompilation, reassembly, or dynamic linking, *all* MBean attributes, method return values, and method arguments must be limited to a universal set of data types. This set is called the *basic data types* for open MBeans.

In addition, any array of the basic data types, or an array of a primitive type (for example `byte[]`) can be used in open MBeans. A special class, `javax.management.openmbean.ArrayType` is used to represent the definition of single or multi-dimensional arrays in open MBeans.

The following list specifies all data types that are allowed as scalars or as any-dimensional arrays in open MBeans:

Table 1:

- | | |
|---|---|
| • <code>java.lang.Boolean</code> | • <code>java.lang.Float</code> |
| • <code>java.lang.Byte</code> | • <code>java.lang.Integer</code> |
| • <code>java.lang.Character</code> | • <code>java.lang.Long</code> |
| • <code>java.lang.Double</code> | • <code>java.lang.Short</code> |
| • <code>boolean[]</code> | • <code>float[]</code> |
| • <code>byte[]</code> | • <code>int[]</code> |
| • <code>char[]</code> | • <code>long[]</code> |
| • <code>double[]</code> | • <code>short[]</code> |
| • <code>java.lang.String</code> | • <code>java.lang.Void</code> (operation return only) |
| • <code>java.math.BigDecimal</code> | • <code>java.math.BigInteger</code> |
| • <code>java.util.Date</code> | • <code>javax.management.ObjectName</code> |
| • <code>javax.management.openmbean.CompositeData</code> (interface) | |
| • <code>javax.management.openmbean.TabularData</code> (interface) | |

All the wrapper classes for the primitive types are defined and implemented in all Java virtual machines, as are the `BigDecimal`, `BigInteger`, and `Date` classes. The `ObjectName` class is provided by the implementation of the JMX specification. The `CompositeData` and `TabularData` interfaces are used to define aggregates of the basic data types and provide a mechanism for expressing complex data objects in a consistent manner.

Because `CompositeData` and `TabularData` objects are also basic data types, these structures can contain other composite or tabular structures and have arbitrary complexity. A `TabularData` object represents a homogeneous table of `CompositeData` objects, a very common structure in the management domain. The basic data types can therefore be used alone or in combination to satisfy most data representation requirements.

3.2.1 Representing Complex Data

This section presents the two non-primitive types from this specification that are included in the set of basic data types: `CompositeData` and `TabularData`. These two types are specified as interfaces and are supported by an implementation.

These classes represent complex data types within open MBeans. Both kinds of objects are used to create aggregate structures that are built up from the primitive data types and these objects themselves. This means that any JMX agent or any JMX-compliant management application can manipulate any open MBean and use the arbitrarily complex structures it contains.

The two interfaces and implementations provide some semantic structure to build aggregates from the basic data types. An implementation of the `CompositeData` interface is equivalent to a hash table: values are retrieved by giving the name of the desired data item. An instance of a `TabularData` object contains an array of `CompositeData` instances that can be retrieved individually by giving a unique key. A `CompositeData` object is immutable once instantiated; you cannot add an item to it and you cannot change the value of an existing item. Tables are modifiable, and rows can be added or removed from existing instances.

3.2.1.1 `CompositeData` Interface and Support Class

The `CompositeDataSupport` class defines an immutable map with an arbitrary number of entries, called data items, that can be of any type. To comply with the design patterns for open MBeans, all data items must have a type among the set of basic data types. Because this set also includes `CompositeData` objects, complex hierarchies can be represented by creating composite types that contain other composite types.

When instantiating the `CompositeDataSupport` class, the user must provide the description of the composite data object in a `CompositeType` object (see “Open Type Descriptions” on page 71). Then, all the items provided through the constructor must match this description of the composite type. Because the composite object is immutable, all items must be provided at instantiation time, and therefore the constructor can verify that the items match the description. The `getOpenType` method will return this description so that other objects that interact with a `CompositeData` object can know its structure.

A `CompositeData` object associates string keys with the values of each data item. The methods of the class then search for and return data items based on their string key. The enumeration of all data items is also possible.

3.2.1.2 TabularData Interface and Support Class

The `TabularDataSupport` class defines a table structure with an arbitrary number of rows that can be indexed by any number of columns. Each row is a `CompositeData` object, but all rows must have the same composite data description (`CompositeType`). The columns of the table are headed by the names of the data items that make up the uniform `CompositeData` rows. The constructor and the methods for adding rows verify that all rows are described by the same `CompositeData` instance.

The index consists of a subset of the data items in the common composite data structure, with the requirement that this subset must be a key that uniquely identifies each row of the table. When the table is instantiated, or when a row is added, the methods of this class must ensure that the index can uniquely identify all rows.

Both the description of composite object that makes up each row and the list of items that form the index are given by the table description returned by the `getOpenType` method. This method defined in the `TabularData` interface returns the `TabularType` object that describes the table (see “Open Type Descriptions” on page 71).

The access methods of the `TabularData` class take an array of objects representing a key value that indexes one row and returns the `CompositeData` instance that makes up the designated row. A row of the table can also be removed by providing its key value. All rows of the table can also be retrieved in an enumeration.

3.2.2 Open Type Descriptions

To manipulate the basic data types, management applications must be able to identify them. Primitive types are given by their wrapper class names and arrays can be represented in a standard way (see the API documentation generated by the Javadoc tool for the `getName` method of the `java.lang.Class` class). However, the complex data types need more structure than a flat string to represent their contents. Therefore, open MBeans rely on description classes for all the basic data types, including special structures for describing complex data.

These description classes are collectively known as the open types because they describe the open MBean basic data types. The abstract `OpenType` class is the superclass for the specialized open type classes for each category of basic data type. It defines common methods for providing a name for the type, giving it a description, and specifying the actual class that is being described. For simple types, this information can be redundant, that is the name is the same as the class name. For composite types, this information allows the user to name each of the items in a

complex data structure. The user should also give items a meaningful description for other users who have to manipulate a composite data instance described by this type.

The `SimpleType`, `ArrayType`, `CompositeType`, and `TabularType` classes extend the `OpenType` class to accommodate the different sorts of basic data types.

The primitive types and the `ObjectName` class are described by instances of the `SimpleType` class when they are not used in arrays. This class does not define any more methods than its `OpenType` superclass, it only defines constant fields for each of the primitive types (and for the `ObjectName` class). These fields are themselves instances of the `SimpleType` class where the name, description and class name are predefined. These constants avoid having to instantiate and provide the information for the simple types every time their description is needed.

The `ArrayType` class provides a description of arrays of the basic data types. It inherits its description of the type from the `OpenType` class and adds the information about the number of its dimensions. The `ArrayType` class can also be used to describe arrays of primitive type such as `int[]`.

Finally, the open type classes for composite and tabular types provide the structure for describing these aggregate types that are specific to open MBeans. These structures are recursive, that is, they are built up from other open type instances. For complex structures, the name and description inherited from `OpenType` provide overall information about the structure.

A `CompositeType` instance gives the name, description and open type object for each item in the data structure. When associated with a `CompositeData` object (see “`CompositeData` Interface and Support Class” on page 70), the composite type describes the open type for each item of the composite data. This allows any manager that needs to handle the composite data instance to understand how to handle each of its constituent items.

Similarly, the `TabularType` gives the description needed to manipulate a `TabularData` object (see “`TabularData` Interface and Support Class” on page 71). This includes the open type instance that describes the composite structure of each row, and the list of item names in this structure that index the table.

3.3 Open MBean Metadata Classes

To distinguish open MBeans from other MBeans, JMX provides a set of metadata classes that are used specifically to describe open MBeans. These classes inherit from the `MBeanInfo` class and its components. The `MBeanInfo` classes are fully described in “`MBean` Metadata Classes” on page 60. The present section discusses only those components that are particular to open MBeans.

As of version 1.3 of this specification, an alternative to using these classes is to add certain fields to the descriptor in a `MBeanAttributeInfo`, `MBeanOperationInfo`, or `MBeanParameterInfo`. The `openType` field specifies the Open Type for an attribute, parameter, or operation return value. The `defaultValue`, `minValue`, `maxValue`, and `legalValues` fields specify default and allowed values for attributes, parameters, and operatino return values.

The following interfaces in the `javax.management.openmbean` package define the management interface of an open MBean:

- `OpenMBeanInfo` - lists the attributes, operations, constructors and notifications
- `OpenMBeanOperationInfo` - describes the method of an operation
- `OpenMBeanConstructorInfo` - describes a constructor
- `OpenMBeanParameterInfo` - describes a method parameter
- `OpenMBeanAttributeInfo` - describes an attribute

For each of the above interfaces, a support class provides an implementation and directly extends the MBean metadata class, the name of which is given by removing the `Open` prefix. Each of these classes describes a category of components in an open MBean. However, open MBeans do not have a specific metadata object for notifications: they use the `MBeanNotificationInfo` class described on page 65.

Through methods inherited from their superclasses, the open MBean metadata objects describe the management interface of an open MBean. Beyond this description, they provide new methods for returning the extra information required of open MBeans and to return the description of the new aggregate data types. This description is given by the appropriate subclass of the `OpenType` class.

Because open MBeans are a universal way of exchanging management functionality, their description must be rich enough for an operator to understand and use their functionality. All the open MBean metadata classes inherit the `getDescription` method that must return a non-empty string. Each component of an open MBean must use this method to provide a description of itself, for example, the side-effects of an operation or the significance of an attribute. All descriptions must be suitable for displaying to a user in a GUI.

The extra information that the open MBean model allows the developer to provide is a list of legal values and one default value for all attributes and all operation parameters. This information allows any user to manipulate a new or unfamiliar open MBean intelligently.

3.3.1 OpenMBeanInfo Interface and Support Class

The `OpenMBeanInfoSupport` class provides the main information structure for describing an open MBean. It implements the `OpenMBeanInfo` interface and extends the `MBeanInfo` class. Thus, it inherits the methods for specifying the class

name and overall MBean description. It also inherits the method for returning an array of notification metadata objects, as notifications are described in the same way as for dynamic MBeans.

However, this class overrides all other methods that describe each category of MBean component: attributes, operations and constructors. Their new implementation still describes all components of a given category, but they now rely on the open MBean metadata classes. Because each of the open MBean metadata objects subclasses the original metadata object, each method returns an array of the subclass type to describe an open MBean. The open MBean metadata classes for each category of component are described in the following sections.

3.3.2 OpenMBeanOperationInfo and OpenMBeanConstructorInfo Interfaces and Support Classes

The `OpenMBeanOperationInfoSupport` and `OpenMBeanConstructorInfoSupport` classes implement their corresponding interface and extend the `MBeanOperationInfo` and `MBeanConstructorInfo` classes, respectively (see their definition on page 63). The former describes an operation of an open MBean, and the latter describes one of its constructors.

Both of these classes override the `getSignature` method of their respective superclass, again only to describe their parameters with open MBean metadata objects. The `getSignature` method nominally returns an array of `MBeanParameterInfo` objects, but both implementations actually return an array of `OpenMBeanParameterInfo` instances whose class is described in the next section.

The `OpenMBeanOperationInfo` interface specifies the `getReturnOpenType` method. The open MBean metadata use this method to provide the description of the open type class that is actually returned by the method. For example, if the return type is actually a complex data object, this method returns either a `CompositeType` or `TabularType` instance that describes the data structure of the return type. When the return type is one of the Java primitive types, this information is redundant with the result of the `getReturnType` method. However, by returning the appropriate `SimpleType` instance, this method allows managers to treat all the open types homogeneously.

Only the `OpenMBeanOperationInfo` interface specifies the `getImpact` method, and in the case of open MBean, it cannot return `UNKNOWN`. This means that all operations must be identified as `ACTION`, `INFO`, or `ACTION_INFO` when instantiating their metadata objects. It is the open MBean developer's responsibility to assign the impact of each operation correctly. The `getImpact` method provides information to the user about an operation's side effects, as a complement to its self description.

3.3.3 OpenMBeanParameterInfo and OpenMBeanAttributeInfo Interfaces and Support Classes

The `OpenMBeanParameterInfoSupport` and `OpenMBeanAttributeInfoSupport` classes implement their corresponding interface extend the `MBeanParameterInfo` and `MBeanAttributeInfo` classes, respectively (see their definition on page 64 and page 63). The former describes one parameter of an operation or constructor, and the latter describes an attribute of an open MBean.

Because these classes are specific to open MBeans, all parameter and attribute types returned by the inherited `getType` method are necessarily one of the basic data types. To describe the complex data types, both interfaces also specify the `getOpenType` method, that returns the `OpenType` subclass that describes the parameter or attribute. This allows a management application to handle all open types, including complex data structures that must be described by `ArrayType`, `CompositeType` or `TabularType` instances.

The open MBean attribute metadata inherits `isReadable`, `isWritable`, and `isIs` for defining attribute access. None of these methods are overridden and therefore have the same functionality as in the superclass.

Both classes also define the `getDefaultValue` and `getLegalValues` methods to provide additional information about the parameter or attribute. These methods have exactly the same functionality in each class.

The `getDefaultValue` method is used to indicate an optional default value for a given parameter or attribute. At runtime, it returns an `Object` that must be assignment compatible with the type named by the `getType` method of the same parameter or attribute description object. The default value can be used to initialize an attribute or to provide a parameter value when the operation's caller has no particular preference for some parameter. It can be `null`.

The `getLegalValues` method is used to return an optional list of permissible values for a given parameter or attribute. It returns an `Object` array, the elements of which must be assignment compatible with the type named by the `getType` method of the same parameter or attribute description object. The legal values can be used to provide the user with a list of choices when editing writable attributes or filling in operation parameters. For readable attributes, this method provides a list of legal values that can be expected. If a set of legal values is supplied, then the methods that implement the `DynamicMBean` interface must verify that any value written to the attribute or used for this parameter is a member of this set. If `getLegalValues` returns `null`, then all assignment compatible values are legal.

3.4 Summary of Open MBean Requirements

To summarize, an open MBean must possess the following properties:

- It must fully implement the `DynamicMBean` interface.
- All attributes, method arguments, and non-void return values must be objects in the set of basic data types for open MBeans, described by an instance of the appropriate `OpenType` subclass.
- The implementation of the `getMBeanInfo` method must return an instance of a class that implements the `OpenMBeanInfo` interface. This object must fully describe the MBean components using the open MBean metadata objects.
- All the following methods must return valid, meaningful data (non-empty strings) suitable for display to users:
 - `OpenMBeanInfo.getDescription`
 - `OpenMBeanOperationInfo.getDescription`
 - `OpenMBeanConstructorInfo.getDescription`
 - `OpenMBeanParameterInfo.getDescription`
 - `OpenMBeanAttributeInfo.getDescription`
 - `MBeanNotificationInfo.getDescription`
- Instances of `OpenMBeanOperationInfo.getImpact` must return one of the constant values `ACTION`, `INFO`, or `ACTION_INFO`. The value `UNKNOWN` cannot be used.

Note – As with other dynamic MBeans, the MBean server does not verify the proper usage of the open MBean metadata classes. It is up to the MBean developer to ensure that all metadata for composite data and tabular data provide coherent default values, legal values and indexes.

The developer must also ensure that all MBean components are adequately described in a meaningful way for the intended users. This qualitative requirement cannot be programmatically enforced.

Model MBeans

A *model MBean* is a generic, configurable MBean that anyone can use to instrument almost any resource rapidly. Model MBeans are dynamic MBeans that also implement the interfaces specified in this chapter. These interfaces define structures that, when implemented, provide an instantiable MBean with default and configurable behavior.

Further, the Java Management extensions specify that a model MBean implementation must be supplied as part of all conforming JMX agents. This means that resources, services and applications can rely on the presence of a generic template for creating manageable objects on-the-fly. Users only need to instantiate a model MBean, configure the exposure of the default behavior, and register it in a JMX agent. This significantly reduces the programming burden for gaining manageability. Developers can instrument their resources according to the JMX specification in as little as three to five lines of code.

Instrumentation with model MBeans is universal because instrumentors are guaranteed that there will be a model MBean appropriately adapted to all environments that implement the Java Management extensions.

4.1 Overview

The model MBean specification is a set of interfaces that provides a management template for managed resources. It is also a set of concrete classes provided in conjunction with the JMX agent. The JMX agent must provide an implementation class named `javax.management.modelmbean.RequiredModelMBean`. This model MBean implementation is intended to provide ease of use and extensive default management behavior for the instrumentation.

The MBean server is a repository and a factory for the model MBean, so the managed resource obtains its model MBean object from the JMX agent. Managed resource developers do not have to supply their own implementation of this class. Instead, the resource is programmed to create and configure its model MBean at runtime, dynamically instrumenting the management interface it needs to expose.

Resources to be managed add custom attributes, operations, and notifications to the basic model MBean object by interfacing with the JMX agent and model MBeans that represent the resource. There can be one or more instances of a model MBean for each instance of a resource (application, device, and so forth) to be managed in the system. The model MBean is a dynamic MBean, meaning that it implements the `DynamicMBean` interface. As such, the JMX agent delegates all management operations to the model MBean instances.

The model MBean instances are created and maintained by the JMX agent, like other MBean instances. The managed resource instantiating the model MBean does not have to be aware of the specifics of the implementation of the model MBean. Implementation differences between environments include the JVM, persistence, transactional behavior, caching, scalability, throughput, location transparency, remoteability, and so on. The `RequiredModelMBean` implementation will always be available, but there can be other implementations of the model MBean available, depending on the needs of the environment in which the JMX agent is installed.

For example, a JMX agent running on a Java 2 Platform, Micro Edition (J2ME™) environment can provide a `RequiredModelMBean` with no persistence or remoteability. A JMX agent running in an application server's JVM supporting Java 2 Platform, Enterprise Edition (J2EE™) technologies can provide a `RequiredModelMBean` that handles persistence, transactions, remote access, location transparency, and security. In either case, the instrumentation programmer's task is the same. MBean developers do not have to provide different versions of their MBeans for different Java environments, nor do they have to program to a specific Java environment.

The model MBean, in cooperation with its JMX agent, will be implemented to support its own persistence, transactionality, location transparency, and locatability, as applicable in its environment. Instrumentation developers do not need to develop MBeans with their own transactional and persistence characteristics. They merely instantiate model MBeans in the JMX agent and trust that the model MBean implementation is appropriate for the environment in which the JMX agent currently exists.

Any implementation of the model MBean must implement the `ModelMBean` interface that extends the `DynamicMBean`, `PersistentMBean` and `ModelMBeanNotificationBroadcaster` interfaces. The model MBean must expose its metadata in a `ModelMBeanInfoSupport` object that extends `MBeanInfo` and implements the `ModelMBeanInfo` interface. A model MBean instance sends attribute change notifications and generic notifications for which management applications can listen. The model MBean has both a default constructor and a constructor that takes a `ModelMBeanInfo` instance.

The model MBean information includes a *descriptor* for each attribute, constructor, operation, and notification in its management interface. A descriptor is an essential component of the model MBean. It contains dynamic, extensible, and configurable behavior information for each MBean component. This includes, but is not limited

to, logging policy, notification responses, persistence policy, value caching policy. Most importantly, the descriptors of a model MBean provide the mapping between the attributes and operations in the management interface and the actual methods that need to be called to satisfy the `get`, `set`, or `invoke` request.

As of version 1.3 of this specification, descriptors are present in all MBean types, not just Model MBeans.

Allowing methods to be associated with the attribute allows for dynamic, runtime delegation. For example, a `getAttribute("myApp1Status")` call can actually invoke the `myApp1.StatusChecker` method on another object that is part of the managed resource. The object `myApp1` can be in this JVM, or it can be in another JVM on this host or another host, depending on how the model MBean has been configured through its descriptors. In this way, distributed, dynamic, and configurable model MBeans are supported.

The `ModelMBean` interface extends the `DynamicMBean` interface. The implementation of the `DynamicMBean` methods uses the policy in the descriptors to guide how the requests are satisfied. How to do this is described in greater detail in “`DynamicMBean Implementation`” on page 93.

The `ModelMBean` interface also extends the `PersistentMBean` interface specific to model MBeans. The `load` and `store` methods of this interface are responsible for analyzing and complying with the persistence policy in the descriptors. The persistence policy can be specified at both the MBean level and at the attribute level. These methods are called when appropriate by the model MBean implementation itself and not necessarily by the managed resource or a management application. The implementation can choose to not support any actual, direct persistence, in which case these methods will do nothing. However, if persistence is not implemented, an exception will be thrown.

4.1.1 Generic Notifications

The `ModelMBean` interface extends the `ModelMBeanNotificationBroadcaster` interface. This interface defines a `sendNotification` method that sends any `Notification` object to all registered listeners. It also overloads the `sendNotification` method to accept a text message and wraps it in a notification called `Generic` of type `jmx.modelmbean.generic`. This makes it easier for managed resources to signal important events as well as informational events. Finally, this interface also provides methods for sending the attribute change notifications for which the model MBean’s implementation is responsible.

4.1.2 Interaction with Managed Resources

When a managed resource is instrumented through a model MBean, it uses the `ModelMBeanInfo` interface to expose its intended management interface. At initialization, the managed resource obtains access to the JMX agent through the static `findMBeanServer` method of the `MBeanServerFactory` class (see “MBean Server Factory” on page 127). The managed resource will then create or find and reference one or more instances of the model MBean using the `instantiate`, `createMBean`, `getObjectInstance`, or `queryMBeans` methods. The predefined attributes that are part of the model MBean’s name are meant to establish a unique managed resource (MBean) identity.

The managed resource then configures the model MBean object with its management interface. This includes the custom attributes, operations, and notifications that it needs management applications to access through the JMX agent. The resource specific information can thus be dynamically determined at execution time. The managed resource sets and updates any type of data as an attribute in the model MBean whenever necessary with a single `setAttribute` method invocation. The attribute is now published for use by any management system.

The model MBean has an internal caching mechanism for storing attribute values that are provided by the management resource. Maintaining values of fairly static attributes in the model MBean allows it to return that value without calling the managed resource. The resource can also set its model MBean to disable caching, meaning that the resource will be called whenever an attribute is accessed. In this case, the managed resource is invoked and it returns the attribute values to the model MBean. In turn, the model MBean returns these values to the MBean server, that returns them to the request originator, usually a management application. Because the model MBean can be persistent and is locatable, critical but transient managed resources can retain any required counters or state information within the JMX agent. Likewise, if persistence is supported, the managed resource’s data survives if the JMX agent is recycled.

The model MBean implements the `NotificationBroadcaster` interface. One `sendNotification` API call on the model MBean by the managed resource sends notifications to all “interested” management systems. Predefined or unique notifications can be sent for any significant event defined by a managed resource or management system. These notifications must be documented in the `ModelMBeanNotificationInfo` object. Notifications are typically sent by a managed resource when operator intervention is required or the application’s state is unacceptable. Notifications can also be sent based on MBean life cycle, attribute changes, or for informative reasons. The model MBean sends attribute change notifications whenever a custom attribute is set through the model MBean. The managed resource can capture change requests initiated by the management system by listening for the attribute change notification as well. The managed resource can then choose to implement the attribute change from the model MBean into the resource.

4.1.3 Interaction with Management Applications

Management applications access model MBeans in the same way as they access dynamic or standard MBeans. However, if the manager understands model MBeans it will be able to get additional information out of the descriptors that are part of the model MBean. This additional metadata makes it easier for an arbitrary management console to understand and treat managed resources that are instrumented as model MBeans. As with any MBean, the management application will “find” the JMX agent and model MBean objects through the methods of the MBean server.

The manager can then interact with the model MBean through the JMX agent. It finds the available attributes and operations through the `MBeanInfo` provided by the managed resource. For model MBeans, the manager finds out behavior details about supported attributes, operations, and notifications through the `ModelMBeanInfo` and `Descriptor` interfaces. Like any other MBean, attributes are accessed through the getter and setter methods of the MBean server, and operations through its `invoke` method. Because the model MBean is a notification broadcaster, management notification can be added as listeners for any notifications or attribute change notifications from the managed resource.

4.2 Model MBean Metadata Classes

The management interface of a model MBean is described by its `ModelMBeanInfo` instance. The `getMBeanInfo` method of a model MBean (specified by the `DynamicMBean` interface) must return an extension of `MBeanInfo` that also supports the `ModelMBeanInfo` interface. The `ModelMBeanInfo` interface returns arrays of `ModelMBeanAttributeInfo`, `ModelMBeanOperationInfo`, `ModelMBeanConstructorInfo`, and `ModelMBeanNotificationInfo` instances. These classes extend the MBean metadata classes of the same name without the `Model` prefix.

The model MBean extensions of the MBean metadata classes implement the `DescriptorAccess` interface. This allows replacing the `Descriptor` for each attribute, constructor, operation, and notification in the management interface. The descriptor is accessed through the metadata object for each component.

4.2.1 Descriptor Interface

A descriptor defines behavioral and runtime metadata that is specific to model MBeans. The descriptor data is kept as a set of fields, each consisting of a name-value pair. The `Descriptor` interface must be implemented by the class representing a descriptor. The `DescriptorAccess` interface defines how to get and set the `Descriptor` from within the model MBean metadata classes. The

Descriptor interface describes how to interact with a descriptor instance returned by the DescriptorAccess interface. See “Predefined Descriptor Fields” on page 102 for a discussion of the valid field names and values that must be supported.

The JMX specification includes two standard implementations of this interface called ImmutableDescriptor and DescriptorSupport. Most applications will use one of these rather than implementing the Descriptor interface themselves.

«Interface» Descriptor
clone(): Object getFieldNames(): String[] getFieldValue(fieldName: String): Object getFieldValues(fieldNames: String[]): Object[] getFields(): String[] setField(fieldName: String, fieldValue: Object) setFields(fieldNames: String[], fieldValues: Object[]) removeField(fieldName: String) isValid(): boolean

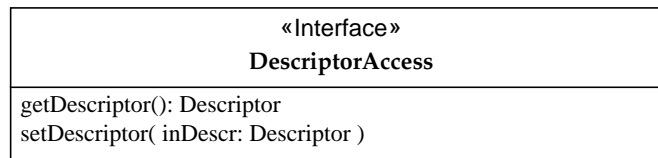
The meaning of these methods is explained in the API documentation generated by the Javadoc tool, that accompanies this specification. A brief summary is presented in the following table.

TABLE 4-1 Descriptor Interface Methods

Method	Description
<code>getFieldNames</code>	Returns all the field names of the descriptor in a <code>String</code> array
<code>getFieldValue(s)</code>	Finds the given field name(s) in a descriptor and returns its (their) value.
<code>setField(s)</code>	Finds the given field name(s) in a descriptor and sets it (them) to the provided value.
<code>getFields</code>	Returns the descriptor information as an array of strings, each with the <code>fieldName=fieldValue</code> format. If the field value is null then the field is defined as <code>fieldName=</code> .
<code>removeFields</code>	Removes a descriptor field from the descriptor.
<code>clone</code>	Returns a new <code>Descriptor</code> instance which is a duplicate of the descriptor.
<code>isValid</code>	Returns <code>true</code> if this descriptor is valid for its <code>descriptorType</code> field.
<code>toString</code>	Returns a human-readable string containing the descriptor information.

4.2.2 DescriptorAccess Interface

This interface must be implemented by the `ModelMBeanAttributeInfo`, `ModelMBeanConstructorInfo`, `ModelMBeanOperationInfo`, and `ModelMBeanNotification` classes.



The meaning of these methods is explained in the API documentation generated by the Javadoc tool, that accompanies this specification. A brief summary is presented in the following table.

TABLE 4-2 DescriptorAccess Interface Methods

Method	Description
<code>getDescriptor</code>	Returns a copy of the descriptor associated with the metadata class
<code>setDescriptor</code>	Replaces the descriptor associated with the metadata class with a copy of the one passed in. This is a full replacement, not a merge.

4.2.3 ModelMBeanInfo Interface

The `ModelMBeanInfo` interface was originally defined to allow the association of a descriptor with the model `MBean`, attribute, constructor, operation, and notification metadata classes. This descriptor is used to define behavioral characteristics of the model `MBean` instance. Now that descriptors are present in all types of `MBean`, the principal interest of the `ModelMBeanInfo` interface is that it adds methods to retrieve particular kinds of descriptors from the contained metadata objects. When the `getModelBeanInfo` method of the `DynamicMBean` interface is invoked on a model `MBean`, it must return an instance of a class that implements the `ModelMBeanInfo` interface.

The JMX specification includes a standard implementation of this interface called `ModelMBeanInfoSupport`. Most applications will use this rather than implementing the `ModelMBeanInfo` interface themselves.

«Interface» ModelMBeanInfo
<pre> clone(): Object getMBeanDescriptor(): Descriptor setMBeanDescriptor(inDescriptor: Descriptor) getDescriptor(inDescriptorName: String, inDescriptorType: String): Descriptor getDescriptors(inDescriptorType: String): Descriptor[] setDescriptor(inDescriptor: Descriptor, inDescriptorType: String) setDescriptors(inDescriptors: Descriptor[]) getAttribute(inAttrName: String): ModelMBeanAttributeInfo getNotification(inNotifName: String): ModelMBeanNotificationInfo getOperation(inOperName: String): ModelMBeanOperationInfo getAttributes(): MBeanAttributeInfo[] getNotifications(): MBeanNotificationInfo[] getOperations(): MBeanOperationInfo[] getConstructors(): MBeanConstructorInfo[] getClassName(): String getDescription(): String </pre>

4.2.4 ModelMBeanInfo Implementation

The requirements of the ModelMBeanInfo implementation are the following:

- It must extend the MBeanInfo class.
- It must implement the ModelMBeanInfo interface.
- Its getAttributes, getConstructors, getOperations, and getNotifications methods must return ModelMBeanAttributeInfo, ModelMBeanConstructorInfo, ModelMBeanOperationInfo, and ModelMBeanNotificationInfo arrays, respectively.
- The ModelMBeanAttributeInfo, ModelMBeanConstructorInfo, ModelMBeanOperationInfo, and ModelMBeanNotificationInfo classes it returns must extend their respective MBeanAttributeInfo, MBeanConstructorInfo, MBeanOperationInfo, and MBeanNotificationInfo classes.
- The ModelMBeanAttributeInfo, ModelMBeanConstructorInfo, ModelMBeanOperationInfo, and ModelMBeanNotificationInfo classes it returns must implement the DescriptorAccess interface. This interface associates a configurable Descriptor object with the metadata class. The descriptor allows the definition of behavioral policies for the MBean component.

- It is recommended that it implement the following constructors, though implementations of the JMX specification do not have to check this:

TABLE 4-3 ModelMBeanInfo Constructors

Constructor	Description
ModelMBeanInfo	The default constructor that constructs a ModelMBeanInfo with empty component arrays and a default MBean descriptor.
ModelMBeanInfo (with ModelMBeanInfo)	Constructs a ModelMBeanInfo that is a duplicate of the one passed in.
ModelMBeanInfo (with className, description, ModelMBeanAttributeInfo[], ModelMBeanConstructorInfo[], ModelMBeanOperationInfo[], ModelMBeanNotificationInfo[])	Creates a ModelMBeanInfo with the provided information, but the MBean descriptor is a default one constructed by the ModelMBeanInfo implementation. The constructed MBean descriptor must not be null. It contains at least the name and descriptorType fields. The name should be the MBean class, as returned by the getClassName method inherited from MBeanInfo.
ModelMBeanInfo (with className, description, ModelMBeanAttributeInfo[], ModelMBeanConstructorInfo[], ModelMBeanOperationInfo[], ModelMBeanNotificationInfo[], MBeanDescriptor)	Creates a ModelMBeanInfo with the provided information. The MBean descriptor is verified: if it is not valid, an exception will be thrown and a default MBean descriptor will be set.

- It must implement the following model MBean-specific methods:

TABLE 4-4 ModelMBeanInfo Methods

Method	Description
<code>getMBeanDescriptor</code>	Returns the MBean descriptor. This descriptor contains default configuration and policies that apply to the whole MBean and to its components by default. The <code>descriptorType</code> field will be "MBean".
<code>setMBeanDescriptor</code>	Sets the MBean descriptor. This descriptor contains MBean-wide default configuration and policies. This is a full replacement, no merging of fields is done. The descriptor is verified before it is set: if it is not valid, the change will not occur.
<code>getDescriptor(s)</code>	Returns a descriptor from a model MBean metadata object by name and descriptor type (as found in the <code>descriptorType</code> field on the descriptor).
<code>setDescriptor(s)</code>	Sets a descriptor in the model MBean in a model MBean metadata object by name and descriptor type (found in the <code>descriptorType</code> field on the descriptor). Replaces the descriptor in its entirety.
<code>getAttribute</code>	Returns a <code>ModelMBeanAttributeInfo</code> by name.
<code>getOperation</code>	Returns a <code>ModelMBeanOperationInfo</code> by name.
<code>getNotification</code>	Returns a <code>ModelMBeanNotificationInfo</code> by name.

- It must implement the following methods specified in the `ModelMBeanInfo` interface but identical to those of the `MBeanInfo` class (see "MBeanInfo Class" on page 61):

TABLE 4-5 ModelMBeanInfo Interface Method

Method	Description
<code>getAttributes</code>	Returns an array of all <code>ModelMBeanAttributeInfo</code> objects.
<code>getNotifications</code>	Returns an array of all <code>ModelMBeanNotificationInfo</code> objects.
<code>getOperations</code>	Returns an array of all <code>ModelMBeanOperationInfo</code> objects.

TABLE 4-5 ModelMBeanInfo Interface Method

Method	Description
<code>getConstructors</code>	Returns an array of all <code>ModelMBeanConstructorInfo</code> objects.
<code>getClassName</code>	Returns the name of the managed resource class.
<code>getDescription</code>	Returns the description of this model MBean instance.

4.2.5 ModelMBeanAttributeInfo Implementation

The `ModelMBeanAttributeInfo` must extend the `MBeanAttributeInfo` class and implement the `DescriptorAccess` interface. The `DescriptorAccess` interface adds the ability to replace the `Descriptor` to the base functionality from the `MBeanAttributeInfo` class.

This descriptor must have a `name` field that matches the name given by the `getName` method of the corresponding metadata object. It must have a `descriptorType` with the value "attribute". It can also contain the following defined fields: `value`, `default`, `displayName`, `getMethod`, `setMethod`, `protocolMap`, `persistPolicy`, `persistPeriod`, `currencyTimeLimit`, `lastUpdatedTimeStamp`, `visibility`, and `presentationString`. See "Attribute Descriptor Fields" on page 104 for a detailed description of each of these fields.

The `ModelMBeanAttributeInfo` class must have the following constructors:

- A constructor accepting a `name`, `description`, `getter Method`, and `setter Method` that sets the descriptor to a default value with at least the `name` and `descriptorType` fields set.
- A constructor accepting a `name`, `description`, `getter Method`, `setter Method`, and a `Descriptor` instance that has at least its `name` and `descriptorType` fields set.
- A constructor accepting a `name`, `type`, `description`, `isReadable`, `isWritable`, and `isIs` boolean parameters that sets the descriptor to a default value with at least the `name` and `descriptorType` fields set.
- A constructor accepting a `name`, `description`, `isReadable`, `isWritable`, and `isIs` boolean parameters, and a `Descriptor` instance that has at least its `name` and `descriptorType` fields set.
- A copy constructor accepting a `ModelMBeanAttributeInfo` object.

4.2.6 ModelMBeanConstructorInfo Implementation

The `ModelMBeanConstructorInfo` must extend the `MBeanConstructorInfo` class and implement the `DescriptorAccess` interface. The `DescriptorAccess` interface adds the ability to replace the `Descriptor` instance to the base functionality of the `MBeanConstructorInfo` class.

This descriptor must have a `name` field that matches the name given by the `getName` method of the corresponding metadata object. It must have a `descriptorType` with the value `"operation"` and a role of `"constructor"`. It can also contain the defined fields `displayName`, `visibility`, and `presentationString`. See `"Operation Descriptor Fields"` on page 105 for a detailed description of each of these fields.

The `ModelMBeanConstructorInfo` class must have the following constructors:

- A constructor accepting a description and `Constructor` object that sets the descriptor to a default value with at least `name` and `descriptorType` fields set.
- A constructor accepting a description, a `Constructor` object, and a `Descriptor` instance that has at least the `name` and `descriptorType` fields set.
- A constructor accepting a name, a description, and an `MBeanParameterInfo` array that sets the descriptor to a default value with at least the `name` and `descriptorType` fields set.
- A constructor accepting a name, description, `MBeanParameterInfo` array, and a `Descriptor` instance that has at least its `name` and `descriptorType` fields set.
- A copy constructor accepting a `ModelMBeanConstructorInfo` object.

4.2.7 ModelMBeanOperationInfo Implementation

The `ModelMBeanOperationInfo` must extend the `MBeanOperationInfo` class and implement the `DescriptorAccess` interface. The `DescriptorAccess` interface adds the ability to replace the `Descriptor` instance to the base functionality of the `MBeanOperationInfo` class.

This descriptor must have a `name` field that matches the name given by the `getName` method of the corresponding metadata object. It must have a `descriptorType` with the value `"operation"`. If the `role` field is present, it must have a value of `"operation"`, `"getter"`, or `"setter"`. It can also contain the defined fields `displayName`, `targetObject`, `targetType`, `value`, `currencyTimeLimit`, `lastUpdatedTimeStamp`, `visibility`, and `presentationString`. See `"Operation Descriptor Fields"` on page 105 for a detailed description of each of these fields.

The `ModelMBeanOperationInfo` class must have the following constructors:

- A constructor accepting a description and a Method object that sets the descriptor to a default value with at least its name and descriptorType fields set.
- A constructor accepting a description, a Method object, and a Descriptor instance that at least has its name and descriptorType fields set.
- A constructor accepting a name, description, MBeanParameterInfo array, type, and an impact that sets the descriptor to a default value with at least the name and descriptorType fields set.
- A constructor accepting a name, description, MBeanParameterInfo array, type, impact and a Descriptor instance that has at least its name and descriptorType fields set.
- A copy constructor accepting a ModelMBeanOperationInfo object.

4.2.8 ModelMBeanNotificationInfo Implementation

The ModelMBeanNotificationInfo must extend the MBeanNotificationInfo class and implement the DescriptorAccess interface. The DescriptorAccess interface adds the ability to replace the Descriptor instance to the base functionality of the MBeanNotificationInfo class.

This descriptor must have a name field that matches the name given by the getName method of the corresponding metadata object. It must have a descriptorType with the value "notification". It can also contain the defined fields displayName, severity, messageID, log, logfile, visibility, and presentationString. See "Notification Descriptor Fields" on page 106 for a detailed description of each of these fields.

The ModelMBeanNotificationInfo class must have the following constructors:

- A constructor accepting an array of notification types, a name and a description that sets the descriptor to a default value with at least its name and descriptorType fields set.
- A constructor accepting an array of notification types, a name, a description, and a Descriptor instance that has at least its name and descriptorType fields set.
- A copy constructor accepting a ModelMBeanNotificationInfo.

4.3 Model MBean Specification

All JMX agents must have an implementation class of a model MBean called javax.management.modelmbean.RequiredModelMBean. The RequiredModelMBean and any other compliant model MBean must comply with the following requirements:

- Implement the `ModelMBean` interface that extends the following interfaces:
 - `DynamicMBean`
 - `PersistentMBean`
 - `ModelMBeanNotificationBroadcaster`
- Return an object from the `getMBeanInfo` method of the `DynamicMBean` interface that:
 - Implements the `ModelMBeanInfo` interface
 - Extends `MBeanInfo`
 - Returns `ModelMBeanAttributeInfo` objects from the `getAttributes` method
 - Returns `ModelMBeanConstructorInfo` objects from the `getConstructors` method
 - Returns `ModelMBeanOperationInfo` objects from the `getOperations` method
 - Returns `ModelMBeanNotificationInfo` objects from the `getNotifications` method
- Have the following constructors:
 - A default constructor having an empty parameter list
 - A constructor accepting a `ModelMBeanInfo`

4.3.1 ModelMBean Interface

Java technology-based resources that need to be manageable instantiate the `RequiredModelMBean` or another compliant model MBean using the MBean server's `createMBean` method, passing as a parameter the `ModelMBeanInfo` (including its descriptors) for the `ModelMBean` instance. The attributes and operations exposed via the `ModelMBeanInfo` for the model MBean are accessible to other MBeans, and to management applications. Through the `ModelMBeanInfo` descriptors, values and methods in the managed application can be defined and mapped to attributes and operations of the model MBean. This mapping can be defined during development in a file, or dynamically and programmatically at runtime.

The `ModelMBean` interface extends `DynamicMBean`, `PersistentMBean`, and `ModelMBeanNotificationBroadcaster` and its unique methods are defined by the following UML diagram.

«Interface» ModelMBean
setModelMBeanInfo(mbi: MBeanInfo) setManagedResource(mr: Object, mr_type: String)

4.3.2 ModelMBean Implementation

The following sections describe how the `ModelMBean` interface must be implemented by compliant model MBeans and in particular how it is implemented by the `RequiredModelMBean` class. This combines both the meaning of the methods and the implementation details.

setModelMBeanInfo (with ModelMBeanInfo)

This method creates the model MBean to reflect the given `ModelMBeanInfo` interface. Sets the `ModelMBeanInfo` object for the model MBean to the provided `ModelMBeanInfo` object. Initializes a `ModelMBean` instance using the `ModelMBeanInfo` passed in.

The model MBean must be instantiated, but not yet registered with the MBean server. Only after the model MBean's `ModelMBeanInfo` and its `Descriptor` objects are customized, should the model MBean be registered with the MBean server.

setManagedResource (with ManagedResourceObject, Type)

This method sets the managed resource attribute of the model MBean to the supplied object. Sets the instance of the object against which to execute all operations in this model MBean management interface (metadata and descriptors). The `String` field encodes the target object type of reference for the managed resource. This can be:

`ObjectReference`, `Handle`, `IOR`, `EJBHandle`, or `RMIRReference`. An implementation must support `ObjectReference`, but need not support the other types. It can also define implementation-specific types.

If the MBean server cannot process the given target object type, this method will throw an `InvalidTargetException`. If the `targetObject` field of an operation's descriptor is set and is valid, then it overrides the managed resource setting for that operation's invocation.

4.3.3 DynamicMBean Implementation

The DynamicMBean interface defines the following methods:

- getMBeanInfo
- getAttribute and getAttributes
- setAttribute and setAttributes
- invoke

The description of these methods is given in “DynamicMBean Interface” on page 47. Here, we define how the model MBean implementation expresses the functionality of each method of the interface.

getMBeanInfo

This method returns the ModelMBeanInfo object that implements the ModelMBeanInfo interface for the ModelMBean. Valid attributes, constructors, operations, and notifications defined by the managed resource can be retrieved from the ModelMBeanInfo with the getOperations, getConstructors, getAttributes, and getNotifications methods.

The ModelMBeanInfo instance returns ModelMBeanOperationInfo, ModelMBeanConstructorInfo, ModelMBeanAttributeInfo, and ModelMBeanNotificationInfo arrays, respectively. These classes extend MBeanOperationInfo, MBeanConstructorInfo, MBeanAttributeInfo, and MBeanNotificationInfo, respectively. These extensions must implement the DescriptorAccess interface that sets and returns the descriptor associated with each of these metadata classes. The ModelMBeanInfo also maintains a descriptor for the model MBean, referred to as the *MBean descriptor*.

getAttribute and getAttributes

These methods are invoked to get attribute information from this instance of the ModelMBean implementation synchronously. Model MBeans that support attribute value caching will perform cache checking and refreshing in this method. Model MBean caching policy is set and values are cached in the descriptor for each attribute. If the model MBean supports the getMethod field of the descriptor (assignment of an operation to be invoked when a get is requested for an attribute) then this method will invoke that operation and return its results as the attribute value. Otherwise, if a value field is defined in the descriptor and it is not “stale” as described below, its contents are returned. Otherwise, if no value or getMethod descriptor fields are defined the default field is returned. If no default value is defined then null will be returned.

If caching is supported, then the following algorithm will be used. The model MBean will check for attribute value staleness. Staleness is determined from the `currencyTimeLimit` and `lastUpdatedTime` fields in the descriptor for the attribute in its `ModelMBeanAttributeInfo` object. If `currencyTimeLimit` is 0, then the value will never be stale. If `currencyTimeLimit` is -1, then the value will always be stale.

If the value in the model MBean is set and not stale, then it will return this value without invoking any methods on the managed resource. If the attribute value is stale, then the model MBean will invoke the operation defined in the `getMethod` field of the attribute descriptor. The returned value from this invocation will be stored in the model MBean as the current value. The `lastUpdatedTime` will be reset to the current time. If a `getMethod` is not defined and the value is stale, then the default from the `Descriptor` for the attribute will be returned.

setAttribute and setAttributes

These methods are invoked to set information for an attribute of this instance of the `ModelMBean` implementation synchronously. The model MBean will invoke the operation defined in the `setMethod` field of the attribute descriptor. If no `setMethod` operation is defined then only the `value` field of the attribute's descriptor will be set. Invocation of this method where the new attribute value does not match the current attribute value causes an `AttributeChangeNotification` to be generated.

If caching is supported by the model MBean, the new attribute value will be cached in the `value` field of the descriptor if the `currencyTimeLimit` field of the descriptor is not -1. The `lastUpdatedTime` field will be set whenever the `value` field is set.

invoke

The `invoke` method will execute the operation name passed in with the parameters passed in, according to the `DynamicMBean` interface. The method will be invoked on the model MBean's managed resource (as set by the `setManagedResource` method). If the `targetObject` field of the descriptor is set and the value of the `targetType` field is valid for the implementation, then the method will be invoked on the value of the `targetObject` instead. Valid values for `targetType` include, but are not limited to, `ObjectReference`, `Handle`, `IOR`, `EJBHandle`, and `RMIRReference`.

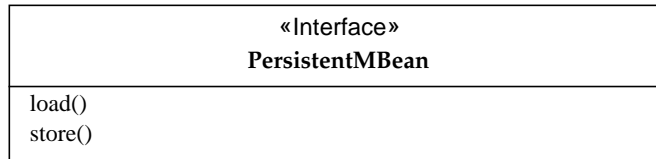
If operation caching is supported, the response from the operation will be cached in the `value` and `lastUpdatedTimeStamp` fields of the operation's descriptor if the `currencyTimeLimit` field in the operation's descriptor is not -1. If `invoke` is executed for a method and the `value` field does not contain a stale value then it will

be returned and the associated method will not actually be executed. This is true even if the `invoke` parameters are not the same as the parameters that produced the cached value. If this is not appropriate for the operation, caching must not be used.

The `RequiredModelMBean` class extends these semantics. If the method name and signature supplied to `invoke` correspond to a public method of the `RequiredModelMBean` class itself, and that method is listed in the `MBeanInfo`, then that method is invoked. Otherwise, the behaviour is as explained above.

4.3.4 PersistentMBean Interface

This interface is implemented by all model MBeans. If the model MBean is not persistent or not responsible for its own persistence, then these methods might do nothing. If the model MBean implementation does not support persistence, then these methods will throw an exception. The methods of the `PersistentMBean` interface are not intended to be called directly by management applications. Rather, they are called by the required model MBean to implement the persistence policy advertised by the MBean descriptor, to the level that it is supported by the JMX agent's runtime environment.



- **load**

Locates the MBean in a persistent store and primes this instance of the MBean with the stored values. Any currently set values are overwritten. This should only be called by an implementation of the `ModelMBean` interface.

- **store**

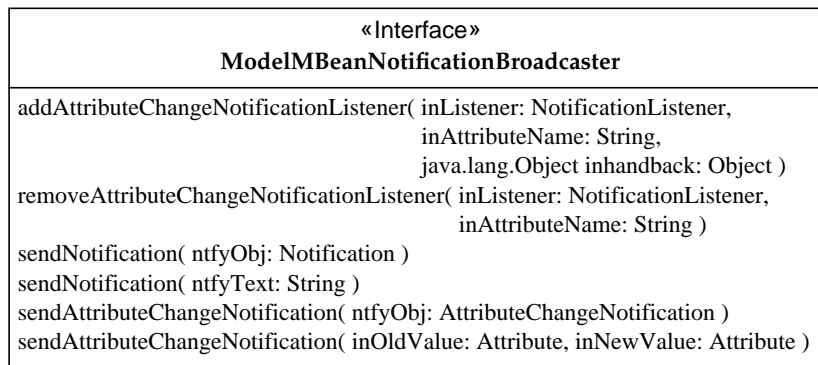
Writes the MBean in a persistent store. It is only called by an implementation of the `ModelMBean` interface to store itself according to persistence policy for the MBean. When used, it can be called with every invocation of `setAttribute`, or on a periodic basis.

4.3.5 ModelMBeanNotificationBroadcaster Interface

This interface extends the `NotificationBroadcaster` interface and must be implemented by any MBean needing to broadcast custom, generic, or attribute change notifications to listeners. Model MBeans must implement this interface.

In the model MBean, `AttributeChangeNotifications` are sent to a different set of listeners to those to which other notifications would go. All other notifications go to listeners who registered using the methods defined in the `NotificationBroadcaster` interface. `AttributeChangeNotifications` are also sent to those listeners, but in addition they are sent to listeners added using `addAttributeChangeNotificationListener`.

The model MBean sends an `AttributeChangeNotification` to all registered notification listeners whenever a value change for the attribute in the model MBean occurs. By default, no `AttributeChangeNotification` will be sent unless a listener is explicitly registered for them. Normally, the `setAttribute` on the model MBean invokes the `set` method defined for the attribute on the managed resource directly. Alternatively, managed resources can use the attribute change notification to trigger internal actions that implement the intended effect; namely, they change the attribute value on the model MBean.



4.3.6 ModelMBeanNotificationBroadcaster Implementation

The `ModelMBeanNotificationBroadcaster` interface extends the `NotificationBroadcaster` interface for its `addNotificationListener` and `removeNotificationListener` methods. The following methods are specific to open MBeans.

- *addAttributeChangeNotificationListener*:
Registers an object that implements the `NotificationListener` interface as a listener for `AttributeChangeNotifications` from this MBean.
- *removeAttributeChangeNotificationListener*
Removes a listener for `AttributeChangeNotifications` from the MBean.
- *sendAttributeChangeNotification* (with *AttributeChangeNotification*)
Sends the given `AttributeChangeNotification` object to all registered listeners.
- *sendAttributeChangeNotification* (with new and old Attributes)
Creates and sends an `AttributeChangeNotification` to all registered listeners.
- *sendNotification* (with *Notification*)
Sends the given `Notification` object to all registered listeners.
- *sendNotification* (with *String*)
Creates a `Notification` called “generic” of type `jmx.modelmbean.generic` and sends it to all registered listeners. The source of the notification is this `ModelMBean` instance, sequence 1, and severity of 5 (informative).

4.4 Descriptors

The `ModelMBeanInfo` interface publishes metadata about the attributes, operations, and notifications in the management interface. The model MBean *descriptors* contain behavioral information and policies about the same management interface. A descriptor consists of a set of fields, each of which is a `String` name and `Object` value pair. They can be used to store any additional metadata about the management information. The managed resource or management applications can add, modify, or remove fields in any model MBean descriptor at run time.

Some standard field names are reserved and predefined in this specification to handle common data management policies such as caching and persistence. The descriptors also contain the names for the getter and setter operations for attributes. This allows applications to distribute attribute support naturally across the application, regardless of class, and to change that responsibility at runtime.

Descriptors are objects that implement the `Descriptor` interface. They are accessible through the methods defined in the `DescriptorAccess` interface and implemented in the `ModelMBeanAttributeInfo`, `ModelMBeanOperationInfo`, `ModelMBeanConstructorInfo`, and `ModelMBeanNotificationInfo` classes. Arrays of these classes are accessed through the `ModelMBeanInfo` instance. Each of these returns a descriptor that contains information about the component it describes. A managed resource can define the values in the descriptors by constructing a `ModelMBeanInfo` object and using it to define its model MBean through the `setModelMBeanInfo` method or through the `ModelMBean` constructor.

4.4.1 Attribute Behavior

For an attribute, if the descriptor in the `ModelMBeanAttributeInfo` for it has no method signature associated with it, then no managed resource method can be invoked to satisfy it. This means that for `setAttribute` the value is simply recorded in the descriptor, and any attribute change notification listeners are sent an `AttributeChangeNotification`. For `getAttribute`, the current value for the attribute in the model MBean is simply returned from the descriptor and its value cannot be refreshed from the managed resource. This can be useful to minimize managed resource interruption for static resource information. The attribute descriptor also includes policy for managing its persistence, caching, and protocol mapping. For operations, the method signature must be defined. For notifications, the type, identity, severity, and logging policy are defined optionally.

4.4.2 Notification Logging Policy

The model MBean will log notifications if the `log` field of the MBean descriptor or of the `ModelMBeanNotificationInfo` descriptor is set to true. A `logfile` field must also be defined with a fully qualified file name at one of these levels to indicate where the notifications should be logged. The setting at the `ModelMBeanNotificationInfo` level will take precedence over the setting at the MBean descriptor level. If the `ModelMBean` implementation or the JMX agent does not support logging, then the `log` and `logfile` fields are ignored.

4.4.3 Persistence Policy

Persistence policies can be implemented as an option. Persistence is handled within the model MBean. However, this does not mean that a model MBean *must* implement persistence itself. Different implementations of the JMX agent can have different levels of persistence. When there is no persistence, objects will be completely transient in nature. In a simple implementation, the `ModelMBeanInfo` can be serialized into a flat file. In a more complex environment, persistence can be handled by the JMX agent in which the model MBean has been instantiated. If the JMX agent is not transient and the model MBean is persistable it should support persistence policy at the attribute level and model MBean level.

The persistence policy can switch persistence off, force persistence on checkpoint intervals, allow it to occur whenever the model MBean is updated, or throttle the update persistence so that it does not write out the information any more frequently than a certain interval. If the model MBean is executing in an environment where management operations are transactional, this should be shielded from the managed resource. If the managed resource must be aware of the transaction, then this will mean that the managed resource depends on a proprietary version of the JMX agent and model MBean, for the resource to be accessible.

A `ModelMBean` implementation that supports persistence will attempt to prime itself when it is registered in the MBean server, by calling the `ModelMBean.load` method. This method must determine where the persistent representation of the MBean is located, retrieve it, and initialize the model MBean. For simpler representations, the directory and filename to be used for persistence can be defined directly in the MBean descriptor's `persistLocation` and `persistName` fields. The model MBean can, through JDBC™ (Java Database Connectivity) operations, write data to and populate the model MBeans from any number of data storage options such as an LDAP server, a database application, a flat file, an NFS file, an FAS file, or an internal high performance cache.

The `load` method allows the JMX agent to be independent and ignorant of data locale information and knowledge. This allows the data location to vary from one installation to another depending on how the JMX agent and managed resource are installed and configured. It also permits managed resource configuration data to be defined within the directory service for use by multiple managed resource instances or JMX agent instances. In this way, data locale has no impact on the interaction between the managed resource, its model MBean, the JMX agent, the adaptor or the management system. As with all data persistence issues, the platform data service characteristics can have an impact upon performance and security.

Because the persistence policy can be set at the model MBean attribute level, all or some of the model MBean attributes can be stored by the `ModelMBean`. The model MBean will detect that it has been updated and invoke its own `store` method. If the model MBean service is configured to checkpoint model MBeans periodically, it will

do so by invoking the `ModelMBean.store` method. Like the `load` method, the `store` method must determine where the data should reside and store it there appropriately.

The JMX agent's persistence setting will apply to all its model MBeans unless one of them defines overriding policies. The model MBean persistence policy provides a specified persistence event (update/checkpoint) and timing granularity concerning how the designated attributes, if any, are stored. The model MBean persistence policy will allow persistence on a "whenever updated" basis, a "periodic checkpoint" basis, or a "never persist" basis. If no persistence policy for a model MBean is defined, then its instance will be transient.

4.4.4 Behavior of Cached Values

The descriptor for an attribute or operation contains the cached value and default value for the data along with the caching policy. In general, the adaptors access the application's `ModelMBean` as it is returned by the JMX agent. If the data requested by the adaptor is current, the managed resource is not interrupted with a data retrieval request. Therefore, direct interaction with the managed resource is not required for each interaction with the management system. This helps minimize the impact of management activity on runtime application resources and performance.

The attribute descriptor contains `currencyTimeLimit` and `lastUpdatedTimeStamp` fields that are expressed in units of seconds. If the current time is past `lastUpdateTimeStamp + currencyTimeLimit`, then the attribute value is *stale*. If the `currencyTimeLimit` is `-1`, then the attribute value is always stale. If the `currencyTimeLimit` is `0`, then the attribute value is never stale.

If a `getAttribute` is received for an attribute with a stale value (or no value) in the descriptor, then:

- If there is a `getMethod` for the attribute, it will be invoked and the returned value will be recorded in the `value` field in the descriptor for the attribute. The `lastUpdatedTimeStamp` will be reset, and the caller will be handed the new value.
- If there is no `getMethod` defined, then the default value from the `default` field in the descriptor for the attribute will be returned.

4.4.5 Protocol Map Support

The model MBean's default behavior and simple APIs satisfy the management needs of most applications. However, the interfaces of a model MBean also allow complex managed resource management scenarios. The model MBean APIs allow mapping of

the application's model MBean attributes to existing management data models, for example, specific MIBs or CIM objects through the `protocolMap` field of the descriptor. Conversely, the managed resource can take advantage of generic mappings to MIBs and CIM objects generated by tools interacting with the JMX agent. For example, a MIB generator can interact with the JMX agent and create a MIB file that is loaded by an SNMP management system. The generated MIB file can represent the resources known by the JMX agent. The applications represented by those resources do not have to be cognizant of how the management data is mapped to the MIB. This scenario will also work for other definition files required by management systems.

The `protocolMap` field of an attribute's descriptor must contain a reference to an instance of a class that implements the `Descriptor` interface. The contents (or mappings) of the `protocolMap` must be appropriate for the attribute. The entries in the `protocolMap` can be updated or augmented at runtime.

4.4.6 Export Policy

If the JMX agent implementation supports operation in a multi-JMX agent environment, then the JMX agent will need to advertise its existence and availability with the appropriate directory or lookup service. The JMX agent might also need to register MBeans that need to be locatable from other JMX agents without advance knowledge about which JMX agent the MBean is currently registered with. MBeans that need to be locatable in this type of environment define an `export` field in the MBean descriptor in its `ModelMBeanInfo` object.

The value of the `export` field is the external name or object required to export the MBean appropriately. If the JMX agent does not support interoperation with a directory or lookup service and the `export` field is defined, then the field will be ignored. If the value of the `export` field is `F` or `false`, or the `export` field is undefined or null, then the MBean will not be exported.

4.4.7 Visibility Policy

Model MBeans in the JMX specification provide developers of managed resources with the ability to instrument manageability that supports both their custom, stand-alone, domain manager as well as interchangeable enterprise managers. However, the level of detail that is available from these types of managers can be significantly different. Enterprise managers might want to interact with higher level management objects. Domain managers generally manage all details of the application. Most management systems show large grain objects on a user interface screen and show small grain objects on a detailed or advanced screen. The `visibility` field in the descriptor is a hint about the level of granularity an MBean, attribute, or operation

represents. The `visibility` field can be used by a custom implementation of a protocol adaptor or connector or by a management system to filter out MBeans, attributes, or operations that it doesn't need to represent.

The `visibility` field's value is an integer ranging from 1 to 4. The largest grain is 1, for an MBean or a component that is nearly always visible. The smallest grain is 4, for an MBean or a component that is only visible in special cases. The JMX specification does not further define these levels.

4.4.8 Presentation Behavior

A `PresentationString` field can be defined in any descriptor. This string is an XML formatted string meant to provide hints to a console so that it can generate user interfaces for a management object. A standard set of presentation fields have not yet been defined.

4.5 Predefined Descriptor Fields

The fields in each descriptor describe standard and custom information about model MBean components. All predefined fields for each of the descriptors are specified below. The fields defined here are standardized so that the management instrumentation is portable between implementations of model MBeans. More fields can be defined in a management solution to store custom information as needed.

Field names are not case sensitive. The field `descriptorType` can also be referred to as `DescriptorType` or `DESCRIPTORTYPE`. The case used when a descriptor is created or updated is preserved. It is recommended that the form shown here be used consistently.

Certain field values are also case insensitive. This is true for the values of the `descriptorType`, `persistPolicy`, `targetType`, and `log` fields.

4.5.1 MBean Descriptor Fields

These are the predefined fields for the MBean descriptor. These values are valid for the entire model MBean. These values can be overridden by descriptor fields with the same name defined at the attribute, operation, or notification level. Optional fields are in italics:

`name` - The case-sensitive name of the MBean.

`descriptorType` - String that always contains the value "MBean".

displayName - Displayable attribute name. In the absence of a value, the value of the name field should be used instead.

persistPolicy - Defines the default persistence policy for attributes in this MBean that do not define their own `persistPolicy`. Takes on one of the following values:

- **Never** - The attribute is never stored. This is useful for highly volatile data or data that only has meaning within the context of a session or execution period.
- **OnTimer** - The attribute is stored whenever the model MBean's persistence timer, as defined in the `persistPeriod` field, expires.
- **OnUpdate** - The attribute is stored every time the attribute is updated.
- **OnUnregister** - The attribute is stored when the MBean is unregistered from the MBean Server
- **NoMoreOftenThan** - The attribute is stored every time it is updated unless the updates are closer together than the `persistPeriod`. This acts as an update throttling mechanism that helps prevent temporarily highly volatile data from affecting performance.
- **Always** - This is a synonym of `OnUpdate`, which is recognized for compatibility reasons. It is recommended that applications use `OnUpdate` instead. An implementation of the `Descriptor` interface, such as `DescriptorSupport`, can choose to replace a value of "Always" for `persistPolicy` by a value of "OnUpdate".

persistPeriod - Valid only if the `persistPolicy` field's value is `OnTimer` or `NoMoreOftenThan`. For `OnTimer`, the attribute is stored at the beginning of each `persistPeriod` starting from when the value is first set. For `NoMoreOftenThan`, the attribute will be stored every time it is updated unless the `persistPeriod` has not elapsed since the previous storage. The value of this field is a number of seconds, specified as a decimal integer string.

persistLocation - The fully qualified directory where files representing the persistent MBeans are stored (for this reference implementation). For other implementations this value can be a keyword or value to assist the appropriate persistence mechanism.

persistName - The filename in which this MBean is stored. This should be the same as the MBean's name (for this reference implementation). For other implementations, this value can be a keyword or value to assist the appropriate persistence mechanism.

log - A boolean where `true` indicates that all sent notifications are logged to a file, and `false` indicates that no notification logging will be done. This setting can be overridden for a particular notification by defining the `log` field in the notification descriptor.

logFile - The fully qualified file name where notifications are logged. If logging is `true` and the `logFile` is not defined or invalid, no logging will be performed.

currencyTimeLimit - Time period in seconds from when an attribute value is current and not stale. If the saved value is current then that value is returned and the `getMethod` (if defined) is not invoked. If the `currencyTimeLimit` is -1, then the value must be retrieved on every request. If `currencyTimeLimit` is 0, then the value is never stale. The value of this field is a number of seconds, specified as a decimal integer string.

export - Its value can be any object that is serializable and contains the information necessary to make the MBean locatable. A value of `null`, or a `String` value of `F` or `false`, indicates that the MBean should not be exposed to other JMX Agents. A defined value indicates that the MBean should be exposed to other JMX Agents and also be findable when the JMX agent address is unknown. If exporting MBeans and MBean servers is not supported, then this field is ignored.

visibility - Integer set from 1 to 4, indicating a level of granularity for the MBean. A value of 1 is for the large grain and most frequently viewed MBeans. A value of 4 is the smallest grain and possibly the least frequently viewed MBeans. This value can be used by adaptors or management applications.

presentationString - XML-encoded string that describes how the attribute will be presented.

4.5.2 Attribute Descriptor Fields

An attribute descriptor represents the metadata for one of the attributes of a model MBean. Optional fields are in italics:

name - The case-sensitive name of the attribute.

descriptorType - A string that always contains the value "attribute".

value - The value of this field is the object representing the current value of attribute, if set. This is, in effect, the cached value of the attribute that will be returned if the `currencyTimeLimit` is not stale.

default - An object that is to be returned if the `value` is not set and the `getMethod` is not defined.

displayName - The displayable name of the attribute.

getMethod - Operation name from the operation descriptors to be used to retrieve the `value` of the attribute from the managed resource. The returned object is saved in the `value` field.

setMethod - Operation name from the operation descriptors to be used to set the `value` of the attribute in the managed resource. The new value will also be saved in the `value` field.

protocolMap - The value of this field must be a `Descriptor` object. It contains the set of protocol name and mapped protocol value pairs. This allows the attribute to be associated with a particular identifier (CIM schema, SNMP MIB Oid, etc.) for a particular protocol. This descriptor is set by the managed resource and used by the adaptors as hints for representing this attribute to management applications.

persistPolicy - Defines the persistence policy for this attribute. If defined, this overrides a `persistPolicy` in the MBean descriptor. The possible values and their meanings are the same as for the `persistPolicy` in the MBean descriptor, described on page 103.

persistPeriod - The meaning of this field is the same as for the `persistPeriod` in the MBean descriptor, described on page 103.

currencyTimeLimit - The meaning of this field is the same as for the `currencyTimeLimit` in the MBean descriptor, described on page 104.

lastUpdatedTimeStamp - Time stamp from when the value field was last updated. The value of this field is a string created by code equivalent to `Long.toString(System.currentTimeMillis())`.

visibility - Integer set from 1 to 4 indicating a level of granularity for the MBean attribute. A value of 1 is for the large grain and most frequently viewed MBean attributes. A value of 4 is the small grain and the least frequently viewed MBean attributes. This value can be used by adaptors or management applications.

presentationString - XML-encoded string that describes how the attribute is presented.

4.5.3 Operation Descriptor Fields

The operation descriptor represents the metadata for operations of a model MBean. Optional fields are in italics:

name - The case-sensitive operation name.

descriptorType - A string that always contains the value "operation".

displayName - Display name of the operation.

value - The value that was returned from the operation the last time it was executed. This allows the caching of operation responses. Operation responses are only cached if the `currencyTimeLimit` field is not -1.

currencyTimeLimit - The period of time in seconds that the `value` is current and not stale. If the `value` is current then it is returned without actually invoking the method on the managed resource. If the `value` is stale then the method is invoked.

If `currencyTimeLimit` is `-1`, then the value is always stale and is not cached. If the `currencyTimeLimit` is `0`, then the value is never stale. The value of this field is a number of seconds, specified as a decimal integer string.

lastUpdatedTimeStamp - The time stamp of when the value field was updated. The value of this field is a string created by code equivalent to `Long.toString(System.currentTimeMillis())`.

visibility - Integer set from 1 to 4 indicating a level of granularity for the MBean operation. A value of 1 is for the large grain and most frequently viewed MBean operations. A value of 4 is the smallest grain and the least frequently viewed MBean operations. This value can be used by adaptors or management applications.

presentationString - XML-encoded string that defines how to present the operation, parameters, and return type to a user.

targetObject - a resource to which invocations of this method are directed. This overrides the managed resource specified by the `ModelMBean.setManagedResource` method for the MBean as a whole.

targetType - the type of the resource defined by the `targetObject`. Every implementation must recognize the type `ObjectReference`, where calling the MBean operation results in calling a method with the same name and parameter types on the `targetObject`. Implementations can also recognize the predefined types `ObjectReference`, `Handle`, `IOR`, `EJBHandle`, and `RMIRReference`, as well as implementation-defined types.

4.5.4 Notification Descriptor Fields

`NotificationDescriptor` represents the metadata for the notifications of a model MBean. Optional fields are in italics:

name - The case-sensitive name of the notification.

descriptorType - A string that always contains the value "notification".

severity - Integer range of 0 to 6 interpreted as follows:

- 0 • Unknown, Indeterminate
- 1 • Non recoverable
- 2 • Critical, Failure
- 3 • Major, Severe

- 4 • Minor, Marginal, or Error
- 5 • Warning
- 6 • Normal, Cleared, or Informative

messageId - ID for the notification. Usually used to retrieve text to match the ID to minimize message size or perform client-side translation.

log - A boolean that is `true` if this notification is logged to a file and `false` if not. There can be a default value for all notifications of an MBean by defining the `log` field in the MBean descriptor.

logFile - The fully qualified file name where notifications are logged. If `log` is `true` but the `logFile` is not defined or invalid, no logging will be performed. This setting can also have an MBean-wide default by defining the `logFile` field in the MBean descriptor.

presentationString - XML-encoded string that describes how to present the notification to a user.

II JMX Agent Specification

Agent Architecture

This chapter gives an overview of the Java Management extensions (JMX) agent architecture and its basic concepts. It serves as an introduction to the JMX agent specification.

5.1 Overview

A JMX agent is a management entity that runs in a Java Virtual Machine (JVM) and acts as the liaison between the MBeans and the management application. A JMX agent is composed of an *MBean server*, a set of MBeans representing *managed resources*, a minimum number of *agent services* implemented as MBeans, and typically at least one *protocol adaptor or connector*.

The key components in the JMX agent architecture can be further defined as follows:

- MBeans that represent managed resources, as specified in Part I “JMX Instrumentation Specification”
- The MBean server, the key-stone of this architecture and the central registry for MBeans. All management operations applied to MBeans need to go through the MBean server.
- Agent services that can either be components defined in this specification or services developed by third parties. The agent service MBeans defined by the JMX specification provide:
 - *Dynamic loading* services that allow the agent to instantiate MBeans using Java classes and native libraries dynamically downloaded from the network
 - *Monitoring* capabilities for attribute values in MBeans; the service notifies its listeners upon detecting certain conditions
 - A *timer* service that can send notifications at predetermined intervals and act as a scheduler
 - A *relation* service that defines associations between MBeans and maintains the consistency of the relation

Remote management applications can access an agent through different protocol adaptors and connectors. These objects are part of the agent application but they are not part of the JMX agent specification.

FIGURE 5-1 shows how the agent's components relate to each other and to a management application.

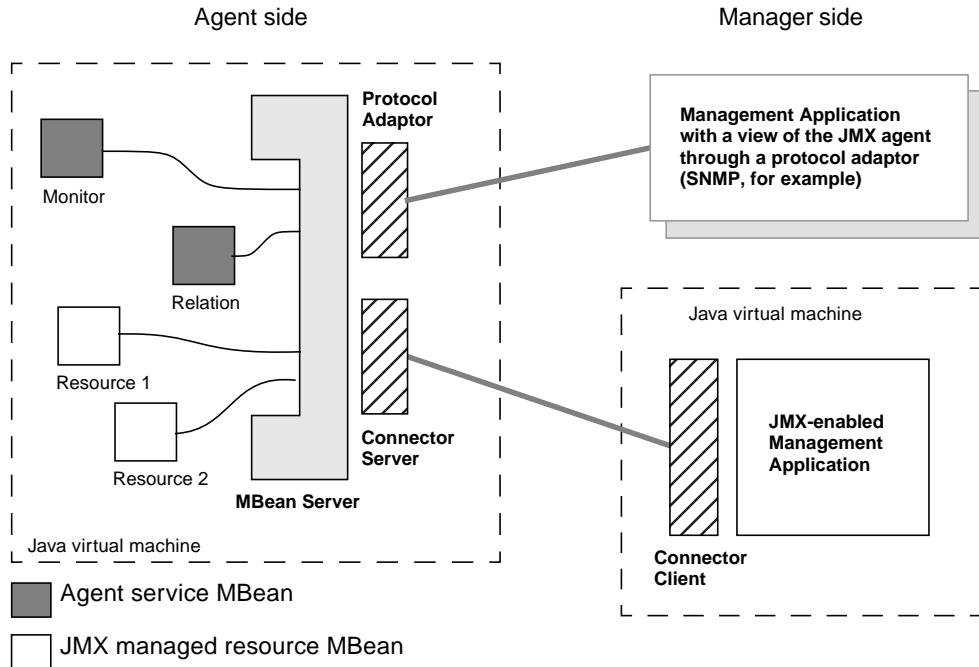


FIGURE 5-1 Key Concepts of the JMX Agent Architecture

The JMX architecture allows objects to perform the following operations on a JMX agent. These objects can either be in the agent-side application or in a remote management application. They can:

- Manage existing MBeans by:
 - Getting their attribute values
 - Changing their attribute values
 - Invoking operations on them
- Get notifications emitted by any MBean
- Instantiate and register new MBeans from:
 - Java classes already loaded into the agent JVM
 - New classes downloaded from the local machine or from the network

- Use the agent services to implement management policies involving existing MBeans

In the JMX architecture, all these operations are performed, either directly or indirectly, through the MBean server of the JMX agent.

5.2 JMX Compliant Agent

All the agent components and classes described in the agent specification are mandatory. To conform to the agent specification, a JMX agent implementation must provide the following components:

- The MBean server implementation
- All the agent services:
 - Dynamic class loading
 - Monitoring
 - Timer
 - Relation

All these components are specified in this document and in the associated API documentation generated by the Javadoc tool. The Agent Compatibility Test Suite will check that all components are actually provided by an implementation of the specification.

5.3 Protocol Adaptors and Connectors

Protocol adaptors and *connectors* make the agent accessible from remote management applications. They provide a view through a specific protocol of the MBeans instantiated and registered in the MBean server. They enable a management application outside the JVM to:

- Get or set attributes of existing MBeans
- Perform operations on existing MBeans
- Instantiate and register new MBeans
- Register for and receive notifications emitted by MBeans

Connectors are used to connect an agent with a remote JMX-enabled management application, namely, a management application developed using the distributed services of the JMX specification. This kind of communication involves a connector server in the agent and a connector client in the manager.

These components convey management operations transparently point-to-point over a specific protocol. The distributed services on the manager side provide a remote interface to the MBean server through which the management application can

perform operations. A connector is specific to a given protocol, but the management application can use any connector indifferently because they have the same remote interface.

Protocol adaptors provide a management view of the JMX agent through a given protocol. They adapt the operations of MBeans and the MBean server into a representation in the given protocol, and possibly into a different information model, for example SNMP.

Management applications that connect to a protocol adaptor are usually specific to the given protocol. This is typically the case for legacy management solutions that rely on a specific management protocol. They access the JMX agent not through a remote representation of the MBean server, but through operations that are mapped to those of the MBean server.

Both connector servers and protocol adaptors use the services of the MBean server to apply the management operation they receive to the MBeans, and to forward notifications to the management application.

For an agent to be manageable, it must include at least one protocol adaptor or connector server. However, an agent can include any number of these, allowing it to be managed remotely through different protocols simultaneously.

The adaptors and connectors provided by an implementation of the JMX specification should be implemented as MBeans. This allows them to be managed as well as to be loaded and unloaded dynamically, as needed.

6

Foundation Classes

The foundation classes describe objects that are used as argument types or returned values in methods of various Java Management extensions (JMX) APIs. The foundation classes described in this chapter are:

- `ObjectName`
- `ObjectInstance`
- `Attribute` and `AttributeList`
- JMX exceptions

The following classes are also considered as foundation classes; they are described in “MBean Metadata Classes” on page 60:

- `MBeanInfo`
- `MBeanFeatureInfo`
- `MBeanAttributeInfo`
- `MBeanOperationInfo`
- `MBeanConstructorInfo`
- `MBeanParameterInfo`
- `MBeanNotificationInfo`

All foundation classes are included in the JMX instrumentation API so that MBeans can be developed solely from the instrumentation specification, yet be manipulated by a JMX agent.

6.1 ObjectName Class

An object name uniquely identifies an MBean within an MBean server. Management applications use this object name to identify the MBean on which to perform management operations. The class `ObjectName` represents an object name that consists of two parts:

- A domain name
- An unordered set of one or more key properties

The components of the object name are described below.

6.1.1 Domain Name

The domain name is a case-sensitive string. It provides a structure for the naming space within a JMX agent or within a global management solution. The domain name part can be omitted in an object name, as the MBean server is able to provide a *default domain*. When an exact match is required (see “Pattern Matching” on page 117), omitting the domain name will have the same result as using the default domain defined by the MBean server.

How the domain name is structured is application-dependent. The domain name string can contain any characters except the colon (:), the asterisk (*), and the question mark (?), that are wildcard characters. JMX always handles the domain name as a whole, therefore any semantic subdefinitions within the string are opaque to a JMX implementation.

To avoid collisions between MBeans supplied by different vendors, a useful convention is to begin the domain name with the reverse DNS name of the organization that specifies the MBeans, followed by a period and a string whose interpretation is determined by that organization. For example, MBeans specified by Sun Microsystems Inc., DNS name `sun.com`, would have domains such as `com.sun.MyDomain`. This is essentially the same convention as for Java-language package names.

It is recommended that the domain should not contain the string `///`, which is reserved for future use.

6.1.2 Key Property List

The key property list allows you to assign unique names to the MBeans of a given domain. A key property is a property-value pair, where the property does not need to correspond to an actual attribute of an MBean.

The key property list must contain at least one key property. It can contain any number of key properties, the order of which is not significant.

The value in a key property is an arbitrary string, except that it cannot contain any of these characters:

`:" , = * ?`

If strings with these special characters are required, a quoting mechanism exists. Use `ObjectName.quote` to convert any string into a quoted form that is usable as a key property value, and `ObjectName.unquote` to convert back to the original string.

A useful convention is to include a `type` property in every object name. Thus, the set of all MBeans of type `user` can be matched with the pattern `*:type=user,*`.

6.1.3 String Representation of Names

Object names are usually built and displayed using their string representation, that has the following syntax:

```
[domainName]:property=value[ ,property=value]*
```

The domain name can be omitted to designate the default domain.

The *canonical name* of an object is a particular string representation of the object's name, in which the key properties are sorted in lexical order. This representation of the object name is used in lexicographic comparisons performed to select MBeans based on their object name.

6.1.4 Pattern Matching

Most of the basic MBean operations (for example, *create*, *get* and *set* attributes) need to identify one MBean uniquely by its object name. In that case, *exact matching* of the name is performed.

On the other hand, for query operations, it is possible to select a range of MBeans by providing an object name expression. The MBean server will use *pattern matching* on the names of the objects. The matching features for the name components are described in the following sections.

Domain Name

The matching syntax is consistent with standard file globbing, namely:

- An asterisk (***) matches any character sequence, including an empty one
- A question mark (*?*) matches any one single character

Key Property List

Wildcard matching can also be performed on the values of key properties using the same matching syntax (*** and *?* characters). Additionally, the list of key properties can be incomplete and used as a pattern.

The *** is also the wildcard for key properties as a whole; it replaces any number of key properties that can take on any value. If the whole key property list is given as ***, this will match all the objects in the selected domain(s). If at least one key property is given in the list pattern, the wildcard can be located anywhere in the

given pattern, provided it is still a comma-separated list: `":property=value,*"` and `":*,property=value"` are both valid patterns. In this case, objects having the given key properties as subsets of their key property list will be selected.

If no wildcard is used, only object names matching the complete key property list will be selected. Again, the list is unordered, so the key properties in the list pattern can be given in any order.

6.1.4.1 Pattern Matching Examples

If the example MBeans with the following names are registered in the MBean server:

```
MyDomain:description=Printer,type=laser
MyDomain:description=Disk,capacity=2
DefaultDomain:description=Disk,capacity=1
DefaultDomain:description=Printer,type=ink
DefaultDomain:description=Printer,type=laser,date=1993
Socrates:description=Printer,type=laser,date=1993
```

Here are some examples of queries that can be performed using pattern matching:

- `"*:*"` will match all the objects of the MBean server. A null string object or empty string (`"`) name used as a pattern is equivalent to `"*:*"`.
- `":*"` will match all the objects of the default domain
- `"MyDomain:*"` will match all objects in MyDomain
- `"??Domain:*"` will also match all objects in MyDomain
- `"*Dom*:*"` will match all objects in MyDomain and DefaultDomain
- `"*:description=Printer,type=laser,*"` will match the following objects:

```
MyDomain:description=Printer,type=laser
DefaultDomain:description=Printer,type=laser,date=1993
Socrates:description=Printer,type=laser,date=1993
```
- `"*Domain:description=Printer,*"` will match the following objects:

```
MyDomain:description=Printer,type=laser
DefaultDomain:description=Printer,type=ink
DefaultDomain:description=Printer,type=laser,date=1993
```
- `"*Domain:description=P*,*"` will match the same objects as the preceding, since `P*` matches `Printer` but not `Disk`.

6.2 ObjectInstance Class

The `ObjectInstance` class is used to represent the link between an MBean's object name and its Java class. It is the full description of an MBean within an MBean server, though it does not allow you to access the MBean by reference.

The `ObjectInstance` class contains the following elements:

- The Java class name of the corresponding MBean
- The `ObjectName` registered for the corresponding MBean
- A test for equality with another `ObjectInstance`

An `ObjectInstance` is returned when an MBean is created and is used subsequently for querying.

6.3 Attribute and AttributeList Classes

These classes are used to represent MBean attributes and their value. They contain the attribute name string and its value cast as an `Object` instance.

JMX defines the following classes:

- The `Attribute` class represents a single attribute-value pair
- The `AttributeList` class represents a list of attribute-value pairs

The `Attribute` and `AttributeList` objects are typically used to convey the attribute values of an MBean, as the result of a getter operation, or as the argument of a setter operation.

6.4 JMX Exceptions

The JMX exceptions are the set of exceptions that are thrown by different methods of the JMX interfaces. This section describes what error cases are encapsulated by these exceptions.

JMX exceptions mainly occur:

- While the MBean server or JMX agent services perform operations on MBeans
- When the MBean code raises user defined exceptions

The organization of the defined JMX exceptions is based on the nature of the error case (runtime or not) and on the location where it was produced (manager, agent, or during communication).

Only exceptions raised by the agent are within the scope of this release of the specification. This section only describes exceptions that are thrown by the MBean server. Agent services also define and throw particular exceptions, these are described in their respective API documentation generated by the Javadoc tool.

6.4.1 JMException Class and Subclasses

As shown in FIGURE 6-1 the base exception class is named `JMException` and it extends the `java.lang.Exception` class. The `JMException` represents all the exceptions thrown by methods of a JMX agent implementation.

To characterize the `JMException` and to give information for the location of the exception's source, some subclass exceptions are defined. They are grouped by exceptions thrown while performing operations in general (`OperationsException`), exceptions thrown during the use of the reflection API for invoking MBean methods (`ReflectionException`) and exceptions thrown by the MBean code (`MBeanException`).

The `ReflectionException` wraps the actual core Java exception thrown when using the reflection API. The `MBeanException` also wraps the actual exception defined by the user and thrown by an MBean method.

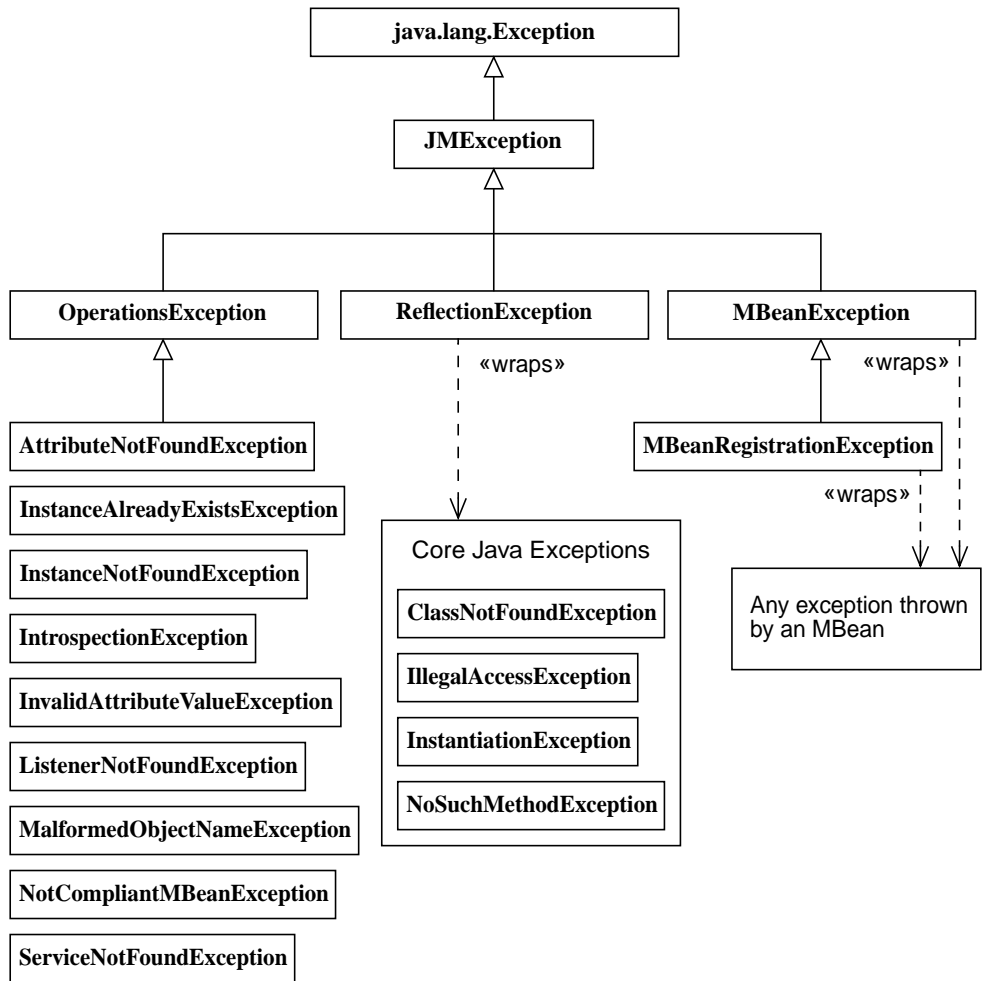


FIGURE 6-1 The JMX Exceptions Object Model

6.4.2 JMRuntimeException Class and Subclasses

As shown in FIGURE 6-2 the base JMX runtime exception defined is named `JMRuntimeException` and it extends the `java.lang.RuntimeException` class. The `JMRuntimeException` represents all the runtime exceptions thrown by methods of a JMX implementation. Like the `java.lang.RuntimeException`, a

method of a JMX implementation is not required to declare in its throws clause any subclasses of `JMRuntimeException` that might be thrown during the execution of the method but not caught.

The `JMRuntimeException` has three subclasses to wrap different sorts of exceptions. The `RuntimeOperationsException` class wraps runtime exceptions thrown while performing operations in the agent. The `RuntimeMBeanException` class wraps runtime exceptions thrown by an MBean. Finally, the `RuntimeErrorException` class is used by the MBean server to wrap `Error` objects thrown by an MBean.

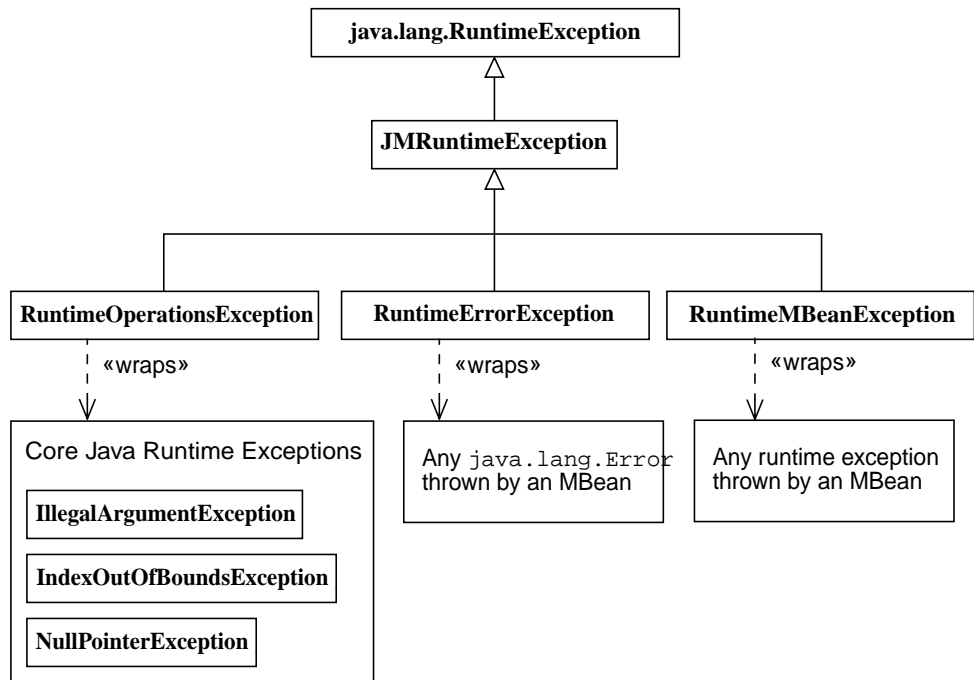


FIGURE 6-2 The JMX Runtime Exceptions Object Model

6.4.3 Description of JMX Exceptions

The following sections describe the exceptions thrown in the JMX specification.

6.4.3.1 JMException Class

This class represents exceptions thrown by JMX implementations. It does not include the runtime exceptions.

6.4.3.2 ReflectionException Class

This class represents exceptions thrown in the agent when using the `java.lang.reflect` classes to invoke methods on MBeans. It “wraps” the actual `java.lang.Exception` thrown.

The exception classes that can be “wrapped” in a `ReflectionException` include the following:

- `ClassNotFoundException` - Thrown when an application tries to load in a class through its string name using the `forName` method in class “`Class`”.
- `InstantiationException` - Thrown when an application tries to create an instance of a class using the `newInstance` method in class “`Class`”, but the specified class object cannot be instantiated because it is an interface or an abstract class.
- `IllegalAccessException` - Thrown when an application tries to load in a class through its string name using the `forName` method in class “`Class`”.
- `NoSuchMethodException` - Thrown when a particular method cannot be found.

6.4.3.3 MBeanException Class

This class represents “user defined” exceptions thrown by MBean methods in the agent. It “wraps” the actual “user defined” exception thrown. This exception will be built by the MBean server when a call to an MBean method results in an unknown exception.

6.4.3.4 OperationsException Class

This class represents exceptions thrown in the agent when performing operations on MBeans. It is the superclass for all the following exception classes, except for the runtime exceptions.

6.4.3.5 InstanceAlreadyExistsException Class

The MBean is already registered in the repository.

6.4.3.6 InstanceNotFoundException Class

The specified MBean does not exist in the repository.

6.4.3.7 InvalidAttributeValueException Class

The specified value is not a valid value for the attribute.

6.4.3.8 AttributeNotFoundException Class

The specified attribute does not exist or cannot be retrieved.

6.4.3.9 IntrospectionException Class

An exception occurred during introspection of the MBean, when trying to determine its management interface.

6.4.3.10 MalformedObjectNameException Class

The format or contents of the information passed to the constructor does not allow a valid `ObjectName` instance to be built.

6.4.3.11 NotCompliantMBeanException Class

This exception occurs when trying to register an object in the MBean server that is not an MBean that is compliant with the JMX specification.

6.4.3.12 ServiceNotFoundException Class

This class represents exceptions raised when a requested service is not supported.

6.4.3.13 MBeanRegistrationException Class

This class wraps exceptions thrown by the `preRegister` and `preDeregister` methods of the `MBeanRegistration` interface.

6.4.3.14 JMRuntimeException Class

This class represents runtime exceptions emitted by JMX implementations.

6.4.3.15 RuntimeOperationsException Class

This class represents runtime exceptions thrown in the agent when performing operations on MBeans. It wraps the actual `java.lang.RuntimeException` thrown.

The exception classes that can be “wrapped” in a `RuntimeOperationsException` include the following:

- `IllegalArgumentException` - Thrown to indicate that a method has been passed an illegal or inappropriate argument.
- `IndexOutOfBoundsException` - Thrown to indicate that an index of some sort (such as to an array, to a string, or to a vector) is out of range.
- `NullPointerException` - Thrown when an application attempts to use null in a case where an object is required.

If a method in an MBean itself throws a runtime exception, that exception will be wrapped in a `RuntimeMBeanException`, not a `RuntimeOperationsException`. The `RuntimeOperationsException` is used in two cases: when the runtime exception occurs before the MBean is invoked (for example, an attribute name in `getAttribute` is null), and by Model MBeans to wrap runtime exceptions coming from methods invoked on the Managed Resource.

6.4.3.16 RuntimeMBeanException Class

This class represents runtime exceptions thrown by MBean methods in the agent. It “wraps” the actual `java.lang.RuntimeException` exception thrown. This exception is built by the MBean server when a call to an MBean method throws a runtime exception. However, if the exception is already a `RuntimeOperationsException` it is not wrapped further.

6.4.3.17 RuntimeErrorException Class

When a `java.lang.Error` occurs in the agent it must be caught and thrown again as a `RuntimeErrorException`.

MBean Server

This chapter describes the Managed Bean server, or MBean server, that is the core component of the Java Management extensions (JMX) agent infrastructure.

7.1 Role of the MBean Server

The MBean server is a registry for MBeans in the agent. The MBean server is the component that provides the services for manipulating MBeans. All management operations performed on the MBeans are done through the `MBeanServer` interface.

In general, the following kinds of MBeans are registered in an MBean server:

- MBeans that represent managed resources for management purposes. These resources can be of any kind: application, system, or network resources that provide a Java interface or a Java wrapper.
- MBeans that add management functionality to the agent. This functionality can be fully generic, for example, providing a logging or a monitoring capability, or it can be specific to a technology or to a domain of application. Some of these MBeans are defined by the JMX specification, others will be provided by management application developers.
- Some components of the infrastructure, such as the connector servers and protocol adaptors, can be implemented as MBeans. This allows such components to benefit from the dynamic management infrastructure.

7.1.1 MBean Server Factory

A JMX agent has a factory class for finding or creating an MBean server through the factory's static methods. This allows more flexible agent applications and possibly more than one MBean server in an agent.

The `MBeanServer` interface defines the operations available on a JMX agent. An implementation of the JMX agent specification provides a class that implements the `MBeanServer` interface. Throughout this document, we use the term *MBean server* to refer to the implementation of the `MBeanServer` interface that is available in an agent.

The `MBeanServerFactory` is a class whose static methods return instances of the implementation class. This object is returned as an instance of the `MBeanServer` interface, thereby isolating other objects from any dependency on the MBean server's actual implementation class. When creating an MBean server, the caller can also specify the name of the default domain used in the JMX agent it represents.

An agent application uses these methods to create the single or multiple MBean servers containing its MBeans. The JMX agent specification only defines the behavior of a single MBean server. The additional behavior required in a JMX agent containing multiple MBean servers is outside the scope of this specification.

The factory also defines static methods for finding an MBean server that has already been created. In this way, objects loaded into the JVM can access an existing MBean server without any prior knowledge of the agent application.

Starting with version 5.0 of the Java 2 Platform, Standard Edition (J2SE 5.0 Platform), every Java application has a *platform MBean Server* which can be obtained using `java.lang.management.ManagementFactory.getPlatformMBeanServer()`. This MBean Server contains a certain number of MBeans specified by the `java.lang.management` package and can also be used as a convenient way to share application MBeans between different modules of an application.

7.1.2 MBean Server Permission Checking

Access to the `MBeanServerFactory` class's static methods is controlled by the `MBeanServerPermission` class. `MBeanServerPermission` extends basic Java permissions, and grants access to the following MBean server operations:

- `createMBeanServer`
- `findMBeanServer`
- `newMBeanServer`
- `releaseMBeanServer`

Permission checking is covered further in Chapter 12 "Security".

7.1.3 Registration of MBeans

The first responsibility of the MBean server is to be a *registry* for MBeans. MBeans can be registered either by the agent application, or by other MBeans. The interface of the `MBeanServer` class allows two different kinds of registration:

- Instantiation of a new MBean and registration of this MBean in a single operation. In this case, the loading of the java class of the MBean can be done either by using a default class loader, or by explicitly specifying the class loader to use.
- Registration of an already existing MBean instance.

An *object name* is assigned to an MBean when it is registered. The object name is a string whose structure is defined in detail in “Object Name Class” on page 115. The object name allows an MBean to be identified uniquely in the context of the MBean server. This uniqueness is checked at registration time by the MBean server, which will refuse MBeans with duplicate names.

7.1.3.1 MBean Registration Control

The MBean developer can exercise some control over registering and unregistering of MBeans in the MBean server. This can be done in the MBean by implementing the `MBeanRegistration` interface. Before and after registering and deregistering an MBean, the MBean server checks dynamically whether the MBean implements the `MBeanRegistration` interface. If this is the case, the appropriate callbacks are invoked.

The `MBeanRegistration` interface is actually an API element of the JMX instrumentation specification. It is described here because it is the implementation of the MBean server that defines the behavior of the registration control mechanism.

Implementing this interface is also the only means by which MBeans can get a reference to the `MBeanServer` with which they are registered. This means that they have information about their management environment and become capable of performing management operations on other MBeans.

If the MBean developer chooses to implement the `MBeanRegistration` interface, the following methods must be provided:

- `preRegister` - This is a callback method that the MBean server invokes before registering the MBean. The MBean is not registered if any exception is raised by this method. This method might throw the `MBeanRegistrationException` that will be thrown again unchanged by the MBean server. Any other exception will be caught by the MBean server, encapsulated in an `MBeanRegistrationException` and thrown again.

This method can be used to:

- Allow an MBean to keep a reference on its MBean server.

- Perform any initialization that needs to be done before the MBean is exposed to management operations.
- Perform semantic checking on the object name, and possibly provide a name if the object was created without a name.
- Get information about the environment, for example, check on the existence of services upon which the MBean depends. When such required services are not available, the MBean might either try to instantiate them, or raise a `ServiceNotFoundException` exception.
- `postRegister` - This is a callback method that the MBean server will invoke after registering the MBean. Its boolean parameter will be *true* if the MBean was registered successfully, and *false* if the MBean could not be registered. If registration failed, this method can free resources allocated in preregistration.
- `preDeregister` - this is a callback method that the MBean server invokes before unregistering an MBean.

This method might throw an `MBeanRegistrationException`, that is thrown again unchanged by the MBean server. Any other exception is caught by the MBean server, encapsulated in an `MBeanRegistrationException` and thrown again. The MBean is not unregistered if any exception is raised by this method.

- `postDeregister` - This is a callback method that the MBean server invokes after unregistering the MBean.

FIGURE 7-1 describes the way the methods of the `MBeanRegistration` are called by the MBean server when an MBean registration or a unregistration is performed. The methods illustrated with a thick border are `MBeanServer` methods, the others are implemented in the MBean.

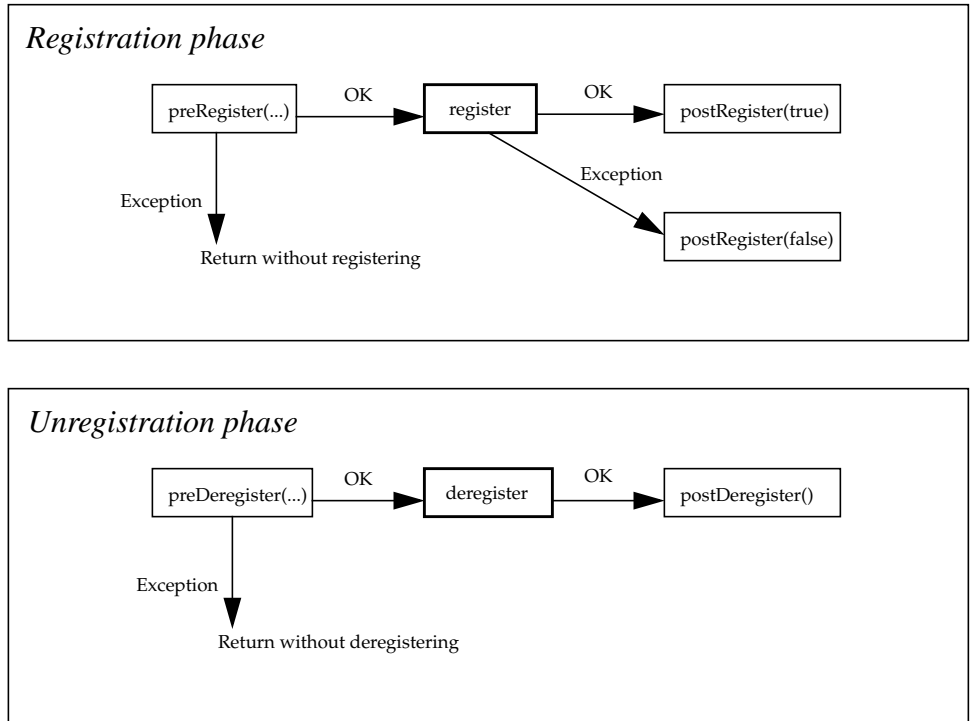


FIGURE 7-1 Calling Sequence for the MBean Registration Methods

7.1.4 Operations on MBeans

The methods of the `MBeanServer` interface define the following management operations to be performed on registered MBeans:

- Retrieve a specific MBean by its object name.
- Retrieve a collection of MBeans, by means of pattern matching on their names, and optionally by means of a filter applied to their attribute values. Such a filter can be constructed by using the query expressions defined in “Queries” on page 135.
- Get one or several attribute value(s) of an MBean.
- Invoke an operation on an MBean.
- Discover the management interface of an MBean, that is, its attributes and operations. This is what is called the introspection of the MBean.
- Register interest in the notifications emitted by an MBean.

The methods of the MBean server are generic: they all take an object name that determines the MBean on which the operation is performed. The role of the MBean server is to resolve this object name reference, determine if the requested operation

is allowed on the designated object, and if so, invoke the MBean method that performs the operation. If there is a result, the MBean server returns its value to the caller.

Calling a method in the MBean server requires an appropriate permission. Permissions are described in Chapter 12 “Security”.

The detailed description of all MBean server operations is given in the API documentation generated by the Javadoc tool.

7.1.5 MBean Proxies

As an alternative to calling the generic methods of the `MBeanServer` interface directly, code that accesses a specific MBean can construct a *proxy* for it. A proxy is a Java object that implements the same interface as the MBean itself. A method in this interface on the proxy is routed through the MBean server to the MBean.

It is simpler and less error-prone to use proxies where possible rather than calling the methods of the MBean server directly.

Proxies are constructed using the methods `newMBeanProxy` and `newMXBeanProxy` in the class `javax.management.JMX`. The Javadoc for that class explains in detail how to construct and use them.

7.2 MBean Server Delegate MBean

The MBean server defines a domain called “`JMImplementation`” in which one MBean of class `MBeanServerDelegate` is registered. This object identifies and describes the MBean server in which it is registered. It is also the broadcaster for notifications emitted by the MBean server. In other words, this MBean acts as a delegate for the MBean server that it represents.

The complete object name of this delegate object is specified by the JMX specification, as follows: “`JMImplementation:type=MBeanServerDelegate`”.

The delegate object provides the following information about the MBean server, all of which is exposed as read-only attributes of type `String`:

- The `MBeanServerId` identifies the agent. The format of this string is not specified, but it is intended to provide a unique identifier for the MBean server, for example, based on the host name and a time stamp.
- The `SpecificationName` indicates the full name of the specification on which the MBean server implementation is based. The value of this attribute must be “`Java Management Extensions`”.

- The `SpecificationVersion` indicates the version of the JMX specification on which the MBean server implementation is based. For this release, the value of this attribute must be “1.4”.
- The `SpecificationVendor` indicates the name of the vendor of the JMX specification on which the MBean server implementation is based. The value of this attribute must be “Sun Microsystems”.
- The `ImplementationName` gives the implementation name of the MBean server. The format and contents of this string are given by the implementor.
- The `ImplementationVersion` gives the implementation version of the MBean server. The format and contents of this string are given by the implementor.
- The `ImplementationVendor` gives the vendor name of the MBean server implementation. The contents of this string are given by the implementor.

The `MBeanServerDelegate` class implements the `NotificationBroadcaster` interface and sends the `MBeanServerNotifications` that are emitted by the MBean server. For objects to receive these notifications, they must register with the delegate object (see “MBean Server Notifications” on page 134).

Note – The “`JMImplementation`” domain name is reserved for use by JMX Agent implementations. The `MBeanServerDelegate` MBean cannot be unregistered from the MBean server.

7.3 Remote Operations on MBeans

Using an appropriate connector server in the agent, a remote management application is able to perform operations on the MBeans through the corresponding connector client, once a connection is established.

Typically, a remote client is able to perform a subset of the operations in the `MBeanServer` interface, through that interface’s parent `MBeanServerConnection`. Because remote connections can fail, each method in `MBeanServerConnection` declares `IOException` in its throws clause. See “`MBeanServerConnection` Interface” on page 140.

FIGURE 7-2 shows how a management operation can be propagated from a remote management application to the MBean on the agent side. The example illustrates the propagation of a method for getting the “State” attribute of a standard MBean, in the following cases:

- The management application invokes a generic `getValue` method on the connector client, that acts as a remote representation of the MBean server. This type of dynamic invocation is typically used in conjunction with the MBean introspection functionality that dynamically discovers the management interface of an MBean, even from a remote application.

- The management application invokes the `getState` method directly on a proxy object that is typically generated automatically from the MBean class (in the case of a Java application). The proxy object relies on the interface of the connector client to transmit the request to the agent and ultimately to the MBean. The response follows the inverse return path.

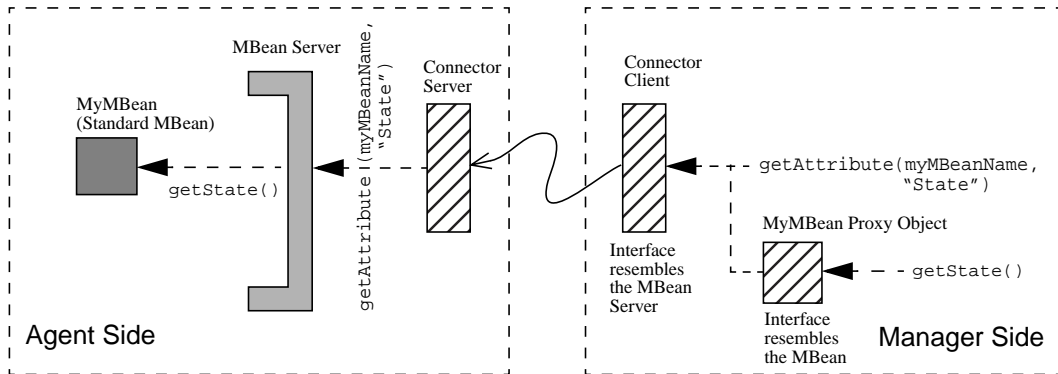


FIGURE 7-2 Propagation of a Remote Operation to an MBean.

7.4 MBean Server Notifications

The MBean server will always emit notifications when MBeans are registered or deregistered. A specific subclass of the `Notification` class is defined for this purpose: the `MBeanServerNotification` class, that contains a list of object names involved in the operation.

The MBean server object does not broadcast notifications itself: its unique delegate MBean implements the `NotificationBroadcaster` interface to broadcast the notifications in its place.

To register for MBean server notifications, the listener will call the `addNotificationListener` method of the MBean server, as when registering for MBean notifications, but it will provide the standardized object name of the MBean server delegate object (see “MBean Server Delegate MBean” on page 132).

As when receiving MBean notifications, an object must implement the `NotificationListener` interface to receive MBean server notifications.

Through its delegate, the MBean server emits the following two types of notifications:

- `JMX.mbean.registered` - This notification indicates that one or more MBeans have been registered. The notification will convey the list of object names of these MBeans.

- `JMX.mbean.unregistered` - This notification indicates that one or more MBeans have been unregistered. The notification conveys the list of these MBeans' object names .

Note – The MBean server does not send notifications when attributes of registered MBeans change values. When implemented, this type of notification is handled directly by the MBean, as described in “Attribute Change Notifications” on page 58.

7.5 Queries

Queries retrieve sets of MBeans from the MBean server, according to their object name, their current attribute values, or both. The JMX specification defines the classes that are used to build query expressions. These objects are then passed to methods of the `MBeanServer` interface to perform the query.

The methods of the `MBeanServer` interface that perform queries are:

- `queryMBeans(ObjectName name, QueryExp query)` - Returns a `Set` containing object instances (object name and class name pairs) for MBeans matching the name and query.
- `queryNames(ObjectName name, QueryExp query)` - Returns a `Set` containing object names for MBeans matching the name and query.

The meaning of the parameters is the same for both methods. The object name parameter defines a pattern: the *scope* of the query is the set of MBeans whose object name satisfies this pattern. The query expression is the user-defined criteria for filtering MBeans within the scope, based on their attribute values. If either query method finds no MBeans that are in the given scope, or that satisfy the given query expression, or both, the returned `Set` will contain no elements.

When the object name pattern is `null`, the scope is equivalent to all MBeans in the MBean server. When the query expression is `null`, MBeans are not filtered and the result is equivalent to the scope. When both parameters are `null`, the result is the set of all MBeans registered in the MBean server.

The set of all MBeans registered in the MBean server always includes the delegate MBean, as does any count of the registered MBeans. Other queries can also return the delegate MBean if its object name is within the scope and if it satisfies the query expression, if any (see “MBean Server Delegate MBean” on page 132).

7.5.1 Scope of a Query

The scope is defined by an object name pattern: see “Pattern Matching” on page 117. Only those MBeans whose object name matches the pattern are considered in the query. The query expression must then be applied to each MBean in the scope to

filter the final result of the query. If the query mechanism is properly implemented and the user gives a relevant object name pattern, the scope of the query can greatly reduce the execution time of the query.

It is possible for the pattern to be a complete object name, meaning that the scope of the query is a single MBean. In this case, the query is equivalent to testing the existence of a registered MBean with that name, or, if the query expression is not `null`, testing the attribute values of that MBean.

7.5.2 Query Expressions

A query expression is built up from constraints on attribute values (such as “equals” and “less-than” for numeric values and “matches” for strings). These constraints can then be associated by relational operators (and, or, and not) to form complex expressions involving several MBean attributes.

For example, the agent or the manager should be able to express a query such as: “Retrieve the MBeans for which the attribute `age` is at least 20 and the attribute name starts with `G` and ends with `ling`”.

A query expression is evaluated on a single MBean at a time, and if and only if the expression is true, that MBean is included the query result. The MBean server tests the expression individually for every MBean in the scope of the query. It is not possible for a query expression to apply to more than one MBean: there is no mechanism for defining cross-MBean constraints.

If the evaluation of the query expression for a given MBean in the scope results in an exception, that MBean is omitted from the query result. The exception is not propagated to the caller of `queryMBeans` or `queryNames`. Errors (subclasses of `java.lang.Error`) can be propagated, however.

The following classes and interfaces are defined for developing query expressions:

- The `QueryExp` interface identifies objects that are complete query expressions. These objects can be used in a query or composed to form more complex queries.
- The `ValueExp` and `StringValueExp` interfaces identify objects that represent numeric and string values, respectively, for placing constraints on attribute values.
- The `AttributeValueExp` interface identifies objects that represent the attribute involved in a constraint.
- The `Query` class supports the construction of the query. It contains static methods that return the appropriate `QueryExp` and `ValueExp` objects.

- The `ObjectName` class (see “`ObjectName Class`” on page 115) implements the `QueryExp` interface and can be used within queries. Usually, an `ObjectName` in a query will be a pattern. When an `ObjectName` query expression is being evaluated for a given `MBean`, the expression is true if the `MBean`’s name matches the `ObjectName` pattern.

In practice, users do not instantiate the `ValueExp` and `QueryExp` implementation classes directly. Instead, they rely on the methods of the `Query` class to return the values and expressions, composing them together to form the final query expression.

7.5.2.1 Methods of the Query Class

The static methods of the `Query` class are used to construct the values, constraints, and subexpressions of a query expression.

The following methods return a `ValueExp` instance that can be used as part of a constraint, as described:

- `classattr` - The result represents the class name of the `MBean` and can only be used in a string constraint.
- `attr` - The result represents the value of the named attribute. This result can be used in boolean, numeric or string constraints, depending upon the type of the attribute. Attributes can also be constrained by the values of other attributes of an equivalent type. This method is overloaded to take a class name too: this is equivalent to setting a constraint on the name of the `MBean`’s class.

If an `MBean` in the scope does not have an attribute with the given name, or if there is a class name parameter and it does not match the `MBean`’s class, then the `MBean` is omitted from the query result.

- `value` - The result represents the value of the method’s argument, and it is used in a constraint. This method is overloaded to take any one of the following types:
 - `java.lang.String`
 - `java.lang.Number`
 - `int`
 - `long`
 - `float`
 - `double`
 - `boolean`

In all these cases, the resulting value must be used in a constraint on an equivalent attribute value.

- `plus`, `minus`, `times`, `div` - These methods each take two `ValueExp` arguments and return a `ValueExp` object that represents the result of the operation. These operations only apply to numeric values. These methods are useful for constructing constraints between two attributes of the same `MBean`.

The following methods represent a constraint on one or more values. They take `ValueExp` objects and return a `QueryExp` object that indicates if the constraint is satisfied at runtime. This return object can be used as the query expression, or it can be composed into a more complex expression using the logical operators.

- `gt`, `geq`, `lt`, `leq`, `eq` - These methods represent the standard relational operators between two numeric values, respectively: greater than, greater than or equals, less than, less than or equals, and equals. The constraint is satisfied if the relation is true with the arguments in the given order.
- `between` - This method represents the constraint where the first argument is strictly within the range defined by the other two arguments. All arguments must be numeric values.
- `in` - This method is equivalent to multiple “equals” constraints between a numeric value argument and an array of numeric values. The constraint is satisfied (`true`) if the numeric value is equal to any one of the array elements.
- `match` - This method represents the equality between an attribute’s value and a given string value or string pattern. The pattern admits wildcards (`*` and `?`), character sets (`[Aa]`), and character ranges (`[A-Z]`) with the standard meaning. The attribute must have a string value, and the constraint is satisfied if it matches the pattern.
- `initialSubString`, `finalSubString`, `anySubString` - These methods represent substring constraints between an attribute’s value and a given substring value. The constraint is satisfied if the substring is a prefix, suffix or any substring of the attribute string value, respectively.
- `isInstanceOf` - This method represents the constraint that the MBean is an instance of a given class, named by a string. This query type did not exist in versions of this specification before version 1.3, so it should not be used when interacting remotely with an agent that implements an earlier version.

A constraint can be seen as computing a boolean value and can be used as a subexpression to the following methods. Constraints also return a `QueryExp` object that can either be used in a query or as a subexpression of an even more complex query using the same methods:

- `and` - The resulting expression is the logical AND of the two subexpression arguments. The second subexpression is not evaluated if the first one is false.
- `or` - The resulting expression is the logical OR of the two subexpression arguments. The second subexpression is not evaluated if the first one is true.
- `not` - The resulting expression is the logical negation of the single subexpression argument.

7.5.2.2 Query Expression Examples

Using these methods, the sample query mentioned at the beginning of this section is built as follows. When constructing constraints on string values, the asterisk (*) is a wildcard character that can replace any number of characters, including zero. Alternatively, the programmer can use the substring matching methods of the `Query` class.

CODE EXAMPLE 7-1 Building a Query

```
QueryExp exp = Query.and(  
    Query.geq(Query.attr("age"),  
        Query.value(20)),  
    Query.match(Query.attr("name"),  
        Query.value("G*ling")));
```

Most queries follow the above pattern: the named attributes of an MBean are constrained by programmer-defined values and then composed into a query across several attributes. All exposed attributes can be used for filtering purposes, provided that they can be constrained by numeric, boolean or string values.

It is also possible to perform a query based on the name of the Java class that implements the MBean, using the `classattr` method of the `Query` class. (This functionality is mostly replaced by the `Query.isInstanceOf` query, however.) CODE EXAMPLE 7-2 shows how to build a query for filtering all MBeans of the fictional class `managed.device.Printer`. This constraint can also be composed with constraints on the attribute values to form a more selective query expression.

CODE EXAMPLE 7-2 Building a Query Based on the MBean Class

```
QueryExp exp = Query.eq(  
    Query.classattr(),  
    Query.value("managed.device.Printer"));
```

7.5.3 Query Exceptions

Performing queries can result in some exceptions that are specific to the filtering methods. If the evaluation of a query for a given MBean produces one of these exceptions, the MBean is omitted from the query result. Application code will not see these exceptions in usual circumstances. Only if the application itself throws the exception, or if it calls `QueryExp.apply`, will it see these exceptions.

7.5.3.1 `BadAttributeValueExpException` Class

The `BadAttributeValueExpException` is thrown when an invalid name for an MBean attribute is passed to a query constructing method.

7.5.3.2 `BadStringOperationException` Class

This exception is thrown when an invalid string operation is passed to a method for constructing a query.

7.5.3.3 `BadBinaryOpValueExpException` Class

This exception is thrown when an invalid expression is passed to a method for constructing a query.

7.5.3.4 `InvalidApplicationException` Class

This exception is thrown when an attempt is made to apply a constraint with a class name to an MBean of the wrong class.

7.6 `MBeanServerConnection` Interface

The JMX 1.2 specification introduced a new interface `MBeanServerConnection`, the parent interface of `MBeanServer`. The purpose of this interface is to provide a common type to be used for access to an MBean server regardless of whether it is remote, namely, accessed through a connector, or local, and accessed directly as a Java object.

The `MBeanServerConnection` interface is similar to `MBeanServer`, but with two key differences:

- It omits the following methods that are only appropriate for local access to the MBean server:
 - `instantiate`. This method is useful to create instances of parameters to MBean methods or constructors when they are of classes unknown to the caller's class loader. But a remote client's class loader must know the classes to be able to deserialize them.
 - `registerMBean`. This method registers a local object as an MBean within the MBean server. It does not make sense to register a remote object in this way.
 - `getClassLoader`, `getClassLoaderFor`, `getClassLoaderRepository`. These methods are useful for the server end of a connector. (See "Using the Correct Class Loader for Parameters" on page 152.) Class loaders and the Class

Loader Repository are not serializable in general, so they could not be transmitted to a remote client. In any case, it is not appropriate for a remote client to be able to access this information.

- `deserialize`. This method returns an `ObjectInputStream`, that is not a serializable class, so it could not be transmitted to a remote client. The method is only of use to the server end of a connector, and even there it is superseded by the `getClassLoader` (etc) methods.
- Each remaining method includes `java.io.IOException` in its `throws` clause.

Application code that interacts with `MBeanServerConnection` works with a local `MBean` server or with the client end of a connector, regardless of whether it is connected to the server or the connector.

Because all the methods of `MBeanServerConnection` can throw `IOException`, application code that calls them must be prepared to deal with this exception and handle it appropriately. In the case of a local `MBean` server, these exceptions cannot happen, but the code must handle them anyway. This is the price to pay for operating the same way in both the local and remote cases.

7.7 Changing the MBean Server Implementation

As of version 1.2 of the JMX specification, the system property `javax.management.builder.initial` can be set to replace the default implementation of the `MBeanServer` interface with a different implementation. When the `createMBeanServer` or `newMBeanServer` method of the `MBeanServerFactory` class is called, it consults this property. If a value exists, then it must name a public class that is a subclass of `javax.management.MBeanServerBuilder`. The class is instantiated and used to create an `MBeanServer` instance.

An `MBeanServerBuilder` must be able to create an instance of `MBeanServerDelegate` and an instance of `MBeanServer`. The `MBeanServerDelegate` can be the standard `javax.management.MBeanServerDelegate`, or a custom subclass, for example, to override the `ImplementationName` attribute. The `MBeanServer` can be a complete reimplement of the `MBeanServer` interface, or it can build on the standard implementation by instantiating `javax.management.MBeanServerBuilder`, calling its `newMBeanServer` method, and wrapping the resulting object in another `MBeanServer` object.

Advanced Dynamic Loading

This chapter describes the dynamic loading services that build on Java's class loader functionality to provide the ability to retrieve and instantiate MBeans using new Java classes and possibly native libraries. The origin of these classes and libraries is not necessarily known when the MBean server is deployed, and can include code loaded from a remote server.

Dynamic loading is usually performed by the management applet (m-let) service that is used to instantiate MBeans obtained from a remote URL (Universal Resource Locator) on the network.

The Java Management extensions (JMX) specification also defines lower-level mechanisms for class loading, that allow developers to extend the functionality of the m-let service or to load classes without it.

This chapter describes mandatory functionality for all compliant JMX agents.

8.1 Overview of M-Lets

The m-let service allows you to instantiate and register one or more MBeans from a remote URL, in the MBean server. The m-let service does this by loading an m-let text file, that specifies information on the MBeans to be obtained. The information on each MBean is specified in a tag similar to those used in XML, called the MLET tag. The location of the m-let text file is specified by a URL. When an m-let text file is loaded, all classes specified in MLET tags are downloaded, and an instance of each MBean specified in the file is created and registered.

The m-let service is itself implemented as an MBean and registered in the MBean server, so it can be used by other MBeans, by the agent application, or by remote management applications.

The operation of the m-let service is illustrated in FIGURE 8-1.

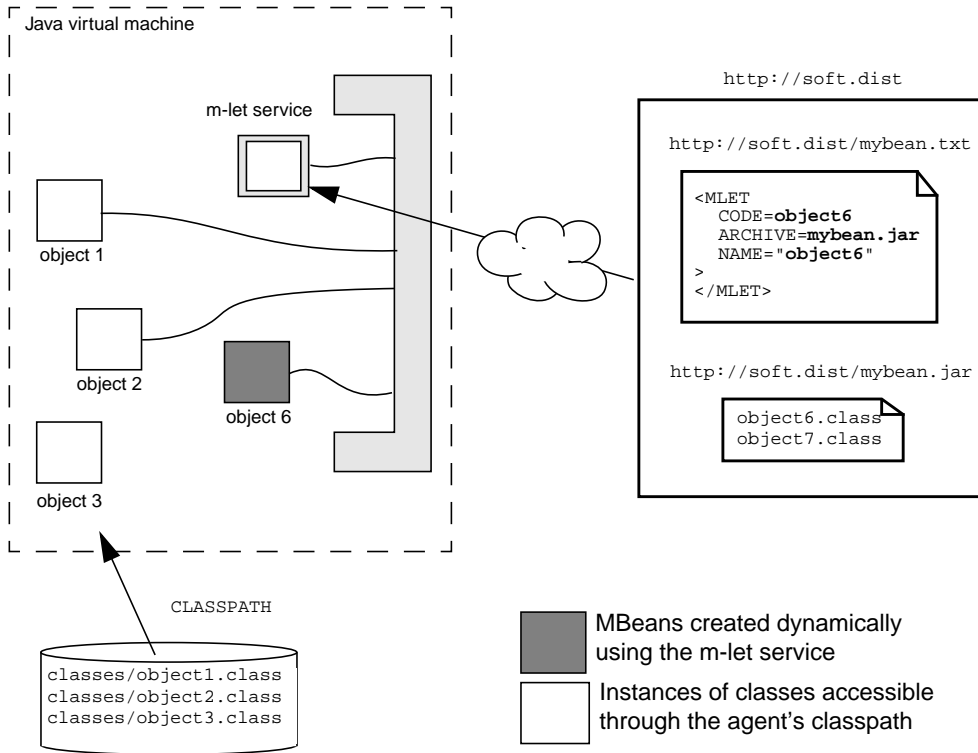


FIGURE 8-1 Operation of the M-Let Service

8.2 The MLET Tag

The m-let file can contain any number of MLET tags, each for instantiating a different MBean in a JMX agent. The MLET tag has the following syntax:

```
<MLET
  CODE = class | OBJECT = serfile
  ARCHIVE = "archivelist"
  [CODEBASE = codebaseURL]
  [NAME = MBeanName]
  [VERSION = version]
>
  [arglist]
</MLET>
```


The elements of this tag are explained below:

- `CODE = class`

This attribute specifies the full Java class name, including package name, of the MBean to be obtained. The compiled `.class` file of the MBean must be contained in one of the JAR files specified by the `ARCHIVE` attribute. Either the `CODE` or the `OBJECT` attribute must be present.

- `OBJECT = serfile`

This attribute specifies the `.ser` file that contains a serialized representation of the MBean to be obtained. This file must be contained in one of the JAR files specified by the `ARCHIVE` attribute. If the JAR file contains a directory hierarchy, this attribute must specify the path of the file within this hierarchy, otherwise a match will not be found.

- `ARCHIVE = archiveList`

This mandatory attribute specifies one or more JAR files containing MBeans or other resources used by the MBean to be obtained. One of the JAR files must contain the file specified by the `CODE` or `OBJECT` attribute. If archive list contains more than one file:

- Each file must be separated from the next one it by a comma (,)
- The whole list must be enclosed in double quote marks (" ")

All JAR files in the archive list must be stored in the directory specified by the code base URL, or in the same directory as the m-let file, that is the default code base when none is given.

- `CODEBASE = codebaseURL`

This optional attribute specifies the code base URL of the MBean to be obtained. It identifies the directory that contains the JAR files specified by the `ARCHIVE` attribute. This attribute is used when the JAR files are not in the same directory as the m-let text file. If this attribute is not specified, the base URL of the m-let text file is taken as the code base URL.

- `NAME = MBeanName`

This optional attribute specifies the string format of an object name to be assigned to the MBean instance when the m-let service registers it in the MBean server.

- `VERSION = version`

This optional attribute specifies the version number of the MBean and associated JAR files to be obtained.

This version number can be used to specify whether or not the JAR files need to be loaded from the server to update those already loaded by the m-let service. The `version` must be a series of non-negative decimal integers each separated by a decimal point (.), for example `2.14`.

- `arglist`

The optional contents of the `MLET` tag specify a list of one or more arguments to pass to the constructor of the MBean to be instantiated. The m-let service looks for a constructor with a signature that matches the types of the arguments specified in the `arglist`. Instantiating objects with a constructor other than the default constructor is limited to constructor arguments for which there is a string representation.

Each item in the `arglist` corresponds to an argument in the constructor. Use the following syntax to specify the `argList`:

```
<ARG TYPE=argumentType VALUE=argumentValue>
```

where:

- `argumentType` is the class of the argument (for example `Integer`)
- `argumentValue` is the string representation of the value of the argument

8.3 The M-Let Service

The classes of the m-let service are members of the `javax.management.loading` package. The `MLet` class implements the `MLetMBean`, that contains the methods exposed for remote access. This implies that the m-let service is itself an MBean and can be managed as such.

The `MLet` class also extends the `java.net.URLClassLoader` object, meaning that it is itself a class loader. This allows several shortcuts for loading classes without requiring an m-let file.

8.3.1 Loading MBeans From a URL

The `getMBeansFromURL` methods of the m-let service perform the class loading based on the m-let text file on a remote server. The m-let file and the class files need to be available on the server as described in “The MLET Tag” on page 144. The two overloaded versions of this method take the URL argument as a string or as a `java.net.URL` object.

Each `MLET` tag in the m-let file describes one MBean to be downloaded and created in the MBean server. When the call to a `getMBeansFromURL` method is successful, the newly downloaded MBeans are instantiated in the JMX agent and registered with the MBean server. The methods return the object instance of the MBeans that were successfully created and a throwable object for those that were not.

Other methods of the `MLet` class manage the directory for native libraries downloaded in JAR files and used by certain MBeans. See the API documentation generated by the Javadoc tool for more details.

8.3.2 Class Loader Functionality

The m-let service uses its class loader functionality to access the code base given in an m-let file or given by the URL itself. This code base is then available in the m-let service for downloading other MBeans from the same code base.

For example, an m-let file can specify a number of MLET tags to populate all the MBeans in a JMX agent. Once the `getMBeansFromURL` method has been invoked to do this, the m-let service can be used to instantiate any one of those MBeans again, or any other class at the same code base.

This is done by passing the m-let service's object name as a class loader parameter to the `createMBean` method of the MBean server (see the corresponding API documentation generated by the Javadoc tool). Because the code base has already been accessed by the m-let service, its class loader functionality can access the code base again. In this case, the information in the MLET tag is no longer taken into account, although the parameters of the `createMBean` method can be used to specify the parameters to the class constructor.

Because the `createMBean` methods of the `MBeanServer` interface take the object name of the class loader, this functionality is also available to remote management applications that do not have direct object references in the JMX agent.

The m-let service MBean also exposes the `addURL` methods for specifying a code base without needing to access any m-let file. These methods add the code base designated by the given URL to the class loader of the m-let service. MBean classes at this code base can be downloaded and created in the MBean server directly through the `createMBean` method, again with the m-let service given as the class loader object.

Note – Using the class loader of the m-let service to load create classes from arbitrary code bases or to reload classes from m-let code bases implies that the agent application or the MBean developer has some prior knowledge of the code base contents at runtime.

8.3.2.1 Native libraries

The m-let service acts as the class loader for any MBeans it loads. This means that if the MBeans contain native methods, and they load a native library containing the code for those methods using `System.loadLibrary`, then the m-let class loader's `findLibrary` method will be called to find the library. This method is overridden from `java.lang.ClassLoader`. It will attempt to find a resource (typically an entry in a JAR file) whose name is the name of the library, modified in a system-dependent way. If it does find one, it will copy the contents to a file in the directory returned by the `Mlet.getLibraryDirectory()` method, and return the name of the file as the result of `findLibrary`. This is described further in the API specification for `Mlet.findLibrary`.

Not all systems support native libraries in this way. A system that does not will throw `UnsupportedOperationException` from the `getLibraryDirectory` and `setLibraryDirectory` methods in the `MLet` class.

Even on systems that do support this functionality, it is better not to rely on it because of the portability problems it poses.

8.4 The Class Loader Repository

The MBean server maintains a list of class loaders in the *class loader repository*. The class loader repository is also sometimes referred to as the default loader Repository.

The class loader repository is used in the following circumstances:

- In the `createMBean` and `instantiate` methods from the `MBeanServer` interface. The class loader repository is used to find and load the class named by the `className` parameter to these methods.

These methods exist in several overloaded forms. Some of the forms have an `ObjectName` parameter specifying an MBean that is a class loader. The class loader repository is not used by those forms.

- When an m-let does not find a class in its URLs, it tries to load the class through the class loader repository. This behavior can be disabled when the m-let is created.
- The method `getClassLoaderRepository` from the `MBeanServer` interface provides a way for clients of the MBean server to access its class loader repository directly.

If several MBean servers are created within the same Java Virtual Machine, for example by a program that calls `MBeanServerFactory.createMBeanServer` several times, each one has its own class loader repository, independently of the others.

8.4.1 How to Add Loaders to the Class Loader Repository

When an MBean server is created, its class loader repository contains the class loader that was used to load the `MBeanServer` implementation class. Thereafter, a class loader is added to the repository if it is registered as an MBean. If the MBean is subsequently unregistered, it is removed from the repository.

Put another way, if an MBean is registered that is a descendant of `java.lang.ClassLoader`, it is added to the class loader repository.

If an MBean is a descendant of `java.lang.ClassLoader` but implements the interface `javax.management.loading.PrivateClassLoader`, then it is never added to the class loader repository.

Because the class `javax.management.loading.MLet` is a descendant of `java.lang.ClassLoader`, m-lets are added to the class loader repository when they are registered in the MBean server. The JMX specification includes a class `PrivateMLet` that subclasses `MLet` and implements `PrivateMLet`. A `PrivateMLet` behaves like an `MLet` in every way except that it is never added to the class loader repository.

8.4.2 Order of Loaders in the Class Loader Repository

The order of class loaders in the repository is significant. When a class is loaded using the repository, each class loader in turn is asked to load the class. If a loader successfully loads the class, the search stops. If a loader throws `ClassNotFoundException`, the search continues with the next loader in the list. If no loader succeeds in loading the class, the attempt results in a `ClassNotFoundException`.

The first loader in the class loader repository is the one that was used to load the `MBeanServer` implementation class. Thereafter, each entry is an MBean that is a descendant of `java.lang.ClassLoader`. The order of these loaders is the order in which the MBeans were registered.

More formally, an MBean *m1* appears before an MBean *m2* if the `createMBean` or `registerMBean` operation that registered *m1* completed before the operation that registered *m2* started. If neither operation completed before the other started, both MBeans were registered at the same time in different threads, and the order between *m1* and *m2* is indeterminate.

8.4.3 M-Let Delegation to the Class Loader Repository

An m-let is a class loader, and as such follows the standard behaviour for a class loader when it loads a class using its `loadClass` method:

- First, it sends a request to its *parent class loader* to load the class. The parent class loader is specified when the m-let is created. By default, it is the *system class loader*.
- If the parent class loader is unable to load the class, the m-let attempts to load it itself through its list of URLs. The `MLet` class is a subclass of `java.net.URLClassLoader`, and the behavior for loading a class through a list of URLs is inherited from `URLClassLoader`.

If neither of these two attempts finds the class, the m-let attempts to load the class through the class loader repository. We say that it *delegates* to the class loader repository. Only if that attempt also fails does the m-let throw a `ClassNotFoundException`.

When an m-let delegates to the class loader repository, each loader in the repository is asked in turn to load the class. However, if the m-let is itself in the class loader repository, the search stops as soon as the m-let is reached. That is, the m-let only delegates to loaders that precede it in the repository.

The class loader repository can be used as a way to make common classes available to MBeans from different sources. The common classes are placed in the repository, and m-lets that delegate to the repository can find them. Because m-lets only delegate to loaders that precede them in the repository, the order in which loaders are registered is important. If m-let *m1* defines classes that are used by classes in m-let *m2*, then *m1* must be registered before *m2*.

When an m-let is created, it is possible to control both whether it delegates to other loaders via the repository, and whether other loaders delegate to it:

- If the m-let is constructed with the Boolean *delegateToCLR* parameter false, then it will not delegate to the class loader repository.
- If the m-let is an instance of `PrivateMlet`, then it will not be added to the class loader repository, so other loaders will not delegate to it.

8.4.3.1 New Semantics in the JMX 1.2 Specification

In versions of the JMX specification prior to 1.2, m-lets delegated to the complete list of loaders in the class loader repository. That is, if an m-let did not find a class itself, every other loader in the repository was consulted. Loaders were consulted regardless of whether they were before or after the m-let in the repository.

This behaviour is open to a subtle problem with certain Java Virtual Machines. Note that a class is not necessarily loaded by an explicit call to the `loadClass` method of some class loader. More often, a class is loaded because it is referred to by another class, for instance because it is the type of a field in that class, or of a parameter or return value in a method, or it is a superclass or superinterface of the class, or one of the methods in the class constructs an instance of it or refers to a static field or method in it. Simplifying slightly, we can say that the exact moment when a class is loaded cannot be predicted.

When a class *c1* refers to another class *A* for the first time, *A* is loaded using *c1*'s class loader. If *c1* was loaded by the m-let *m1*, then *A* will also be loaded using *m1*.

If *m1* does not find the class *A* through its parent class loader, or through its list of URLs, it will delegate to the class loader repository.

Referring to FIGURE 8-2, imagine that at the same time in another thread, a class *c2*, loaded by the m-let *m2*, refers to the class B for the first time. Again, B will be loaded using *m2*, and if *m2* does not find the class itself, it will delegate to the class loader repository.

If *m1* searches through all the loaders in the repository besides itself, and *m2* does likewise, then *m1* will end up sending a request to *m2* to load A and *m2* will end up sending a request to *m1* to load B.

A problem arises with certain Java Virtual Machine implementations that do not allow more than one thread at a time to load a class through a given class loader. Because thread 1 is loading class A through *m1*, thread 2 cannot simultaneously load class B through *m1*. Because thread 2 is loading class B through *m2*, thread 1 cannot simultaneously load class A through *m2*. Each thread must wait for the other to finish before it can proceed, creating a classical deadlock situation.

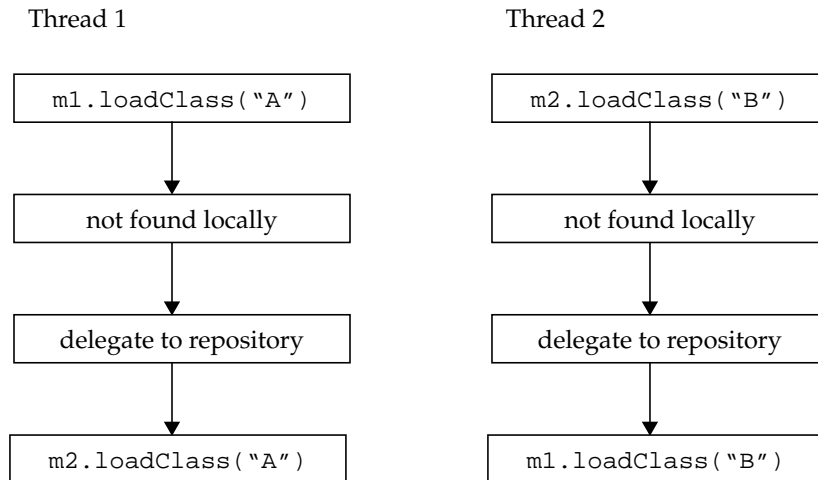


FIGURE 8-2 Deadlock scenario for m-let delegation

The change in semantics avoids this scenario because one of the two m-lets must appear after the other in the class loader repository. If *m2* appears after *m1*, *m1* will never attempt to load a class using *m2*, because it only delegates to loaders that appear earlier than it in the repository. So the deadlock cannot happen.

If you are prepared to run the risk of deadlock, or you are sure that a scenario such as the above cannot happen, it is straightforward to subclass `Mlet` and override its `loadClass` method to restore the previous semantics of delegating to all the loaders in the repository, whether before or after the m-let. However, you should remember

that if a class loaded by such an `Mlet` subclass refers to another class that does not exist, *all* the m-lets in the class loader repository are consulted before `ClassNotFoundException` is thrown.

8.5 Using the Correct Class Loader for Parameters

A subtle pitfall of class loading is that the class `a.b.C` created by the class loader `cl1` is not the same as the class `a.b.C` created by the class loader `cl2`. Here, “created” refers to the class loader that actually creates the class with its `defineClass` method. If `cl1` and `cl2` both find `a.b.C` by delegating to another class loader `cl3`, it is the same class.

A value of type “`a.b.C` created by `cl1`” cannot be assigned to a variable or parameter of type “`a.b.C` created by `cl2`”. An attempt to do so will result in an exception such as `ClassCastException`.

For the JMX specification, this can pose problems for the parameters of the methods `createMBean`, `invoke`, `setAttribute`, and `setAttributes` of the MBean server.

Suppose you have an MBean with the following interface:

CODE EXAMPLE 8-1 Simple MBean interface

```
public interface AnMBean {
    public void m(SomeClass x);
}
```

If the MBean server contains an instance of this MBean that was created by the class loader `cl1`. At some stage, either during loading or the first time it is referenced, `cl1` will load the class `SomeClass`.

Suppose now that you are writing a connector. At the receiving (server) end of the connector, you get a request to invoke `m` on the MBean. The sender will have sent an instance of `SomeClass` that you must recreate, for example, by deserializing it. If you recreate it with any class loader other than `cl1`, you will get an exception when you try to pass it to the method `m`.

This means that your connector server must have a way of instantiating received objects using the correct class loader.

To this end, there are three methods in the `MBeanServer` interface related to class loading:

- `getClassLoaderFor`
- `getClassLoaderRepository`

- `getClassLoader`

These methods are described in the following sections.

8.5.1 `getClassLoaderFor`

The appropriate method for CODE EXAMPLE 8-1 on page 152 is:

```
public ClassLoader getClassLoaderFor(ObjectName name);
```

By calling this method with the `ObjectName` of an MBean, you can obtain the class loader that created the MBean's class, `cl1` in our example. Then you can get the correct class, `SomeClass`, using `cl1`.

The `getClassLoaderFor` method is appropriate for the `invoke`, `setAttribute`, and `setAttributes` operations, because the appropriate class loader for the parameters to these operations is the class loader of the target MBean.

The `getClassLoaderFor` method was introduced in version 1.2 of the JMX specification. Previously, connector servers had to use one of the `deserialize` methods in the `MBeanServer` interface. These methods are now deprecated. Consequently, use `getClassLoaderFor` instead of

```
deserialize(ObjectName name, byte[] data).
```

8.5.2 `getClassLoader` and `getClassLoaderRepository`

For the `createMBean` operation, the target MBean does not exist, because the whole purpose of the operation is to create it. There are two classes of `createMBean` operation, depending on whether there is a `loaderName` parameter that specifies the name of an MBean that is a class loader to be used to load the MBean class.

- For a `createMBean` operation that does not include a `loaderName`, the MBean class is loaded using the class loader repository. If the constructor invoked to create the MBean has parameters, then these should also be loaded using the class loader repository, to avoid the problem that was explained above for `invoke`. Thus, the `MBeanServer` interface contains a method:

```
public ClassLoaderRepository getClassLoaderRepository();
```

The method `loadClass` in the `ClassLoaderRepository` interface can be used to load classes through the class loader repository.

- For a `createMBean` operation that includes a *loaderName*, the MBean class is loaded using the class loader that is registered as an MBean with the given name. If the constructor has parameters, their classes should be loaded by the same class loader. Thus, the `MBeanServer` interface contains a method:

```
public ClassLoader getClassLoader(ObjectName name);
```

Similar considerations apply to the `instantiate` methods of the `MBeanServer` interface. However, these methods are not usually exposed through connectors.

The methods `getClassLoader`, and `getClassLoaderRepository` were introduced in the JMX specification version 1.2. Previously, connector servers had to use one of the three `deserialize` methods in the `MBeanServer` interface. These methods are now deprecated.

Consequently, use `getClassLoaderRepository` instead of

```
deserialize(String className, byte[] data)
```

Also use `getClassLoader` instead of

```
deserialize(String className, ObjectName loaderName, byte[] data)
```

Monitoring

This chapter specifies the family of monitor MBeans that allow you to observe the variation over time of attribute values in other MBeans and emit notifications at threshold events. Collectively they are referred to as the monitoring services.

Monitoring services are a mandatory part of agents that comply with the JMX specification, and they must be implemented in full.

9.1 Overview

Using a monitoring service, an *observed value* from a given attribute in one or more other MBeans (the *observed MBeans*) is monitored at intervals specified by the *granularity period*. This value is either the attribute value, or a value contained within an attribute value of complex type. For each observed MBean, the monitor derives a second value from this observation, called the *derived gauge*. This derived gauge is either the exact observed value, or optionally, the difference between two consecutive observed values of numeric type.

A specific notification type is sent by each of the monitoring services when the value of the derived gauge satisfies one of a set of conditions. The conditions are specified when the monitor is initialized, or dynamically through the monitor MBean's management interface. Monitors can also send notifications when certain error cases are encountered while monitoring an attribute value.

9.1.1 Types of Monitors

Information on the value of an attribute within an MBean is provided by three different types of monitors:

- `CounterMonitor` - Observes values with Java integer types (`Byte`, `Integer`, `Short`, `Long`) that behave like a counter, namely:
 - Their value is always greater than or equal to zero.
 - They can only be incremented.

- They can roll over, and in that case a *modulus* value is defined.
- `GaugeMonitor` - Observes values with Java integer or floating point types (`Float`, `Double`) that behave like a gauge (arbitrarily increasing and decreasing).
- `StringMonitor` - Observes values of type `String`.

All types of monitors extend the abstract `Monitor` class, that defines common attributes and operations. The type of the observed value must be supported by the specific monitor subclass used.

However, monitors verify the type of the object instance that is returned as the attribute's value, not the attribute type declared in the observed `MBean`'s metadata. For example, this allows a string monitor to observe a value declared as an `Object` in its metadata, as long as actual values are `String` instances.

Each of the monitors is also a standard `MBean`, allowing them to be created and configured dynamically by other `MBeans` or by management applications.

9.2 MonitorNotification Class

A specific subclass of the `Notification` class is defined for use by all monitoring services: the `MonitorNotification` class.

This notification is used to report one of the following cases:

- One of the trigger conditions of a monitor is detected, for example, the high threshold of a gauge is reached
- An error occurs during an observation of the attribute, for example, the observed `MBean` is no longer registered

The notification type string within a `MonitorNotification` instance identifies the specific monitor event or error condition, as shown in FIGURE 9-1. The fields of a `MonitorNotification` instance contain the following information:

- The observed `MBean`'s object name
- The observed attribute name, or the attribute name plus the value within a complex-type attribute value to be observed
- The derived gauge, namely, the last value computed from the observation
- The threshold value or string that triggered this notification

The tree representation of all notification types that can be generated by the monitoring services is given in FIGURE 9-1. The error types are common to all monitors and are described below. Each of the threshold events is particular to its monitor and is described in the corresponding section.

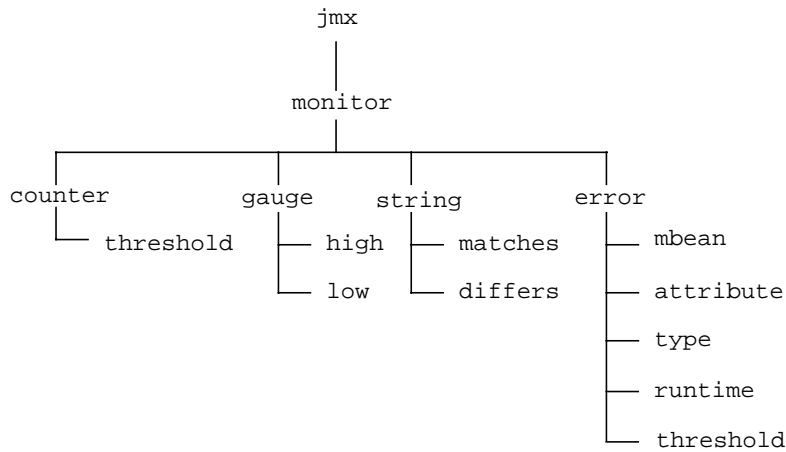


FIGURE 9-1 Tree Representation of Monitor Notification Types

9.2.1 Common Monitor Notification Types

The following notification types are common to all monitors and are emitted to reflect error cases. The first measurement is made when the monitor is started:

- `jmx.monitor.error.mbean` - Sent when one of the observed MBeans is not registered in the MBean server. The *observed object name* is provided in the notification.
- `jmx.monitor.error.attribute` - Sent when the observed attribute does not exist in one of the observed objects. The *observed object name* and *observed attribute name* are provided in the notification.
- `jmx.monitor.error.type` - Sent when the object instance of the observed attribute value is null or not of the appropriate type for the given monitor. The *observed object name* and *observed attribute name* are provided in the notification.
- `jmx.monitor.error.runtime` - All exceptions (except the cases described above) that occur while trying to get the value of the observed attribute are caught by the monitor and will be reported in a notification of this type.

The following notification type is common to the counter and the gauge monitors; it is emitted to reflect specific error cases:

- `jmx.monitor.error.threshold` - Sent in case of any incoherence in the configuration of the monitor parameters:
 - Counter monitor: the threshold, the offset, or the modulus is not of the same type as the observed counter attribute.

- Gauge monitor: the low threshold or high threshold is not of the same type as the observed gauge attribute.

9.3 CounterMonitor Class

A counter monitor sends a notification when the observed counter value reaches or exceeds a comparison level known as the *threshold*.

The counter can *roll over* (also known as *wrapping around*) when it reaches a maximum value. In this case, the notification is triggered every time the counter reaches or exceeds the threshold, provided it has been observed below the threshold since the previous notification. A counter does not necessarily roll over to zero, but this does not affect the monitor that handles the general case.

In addition, an *offset* mechanism can detect counting intervals, as follows:

- The offset mechanism is enabled whenever the monitor's offset value is non-zero.
- Whenever the monitor detects that the counter reaches or exceeds the threshold, a notification is triggered and the threshold is incremented by the offset value. The threshold is incremented by the offset value as many times as necessary for the threshold to exceed the counter value again, but still only one notification is sent.
- If the counter that is monitored rolls over when it reaches a maximum value, then the *modulus* value needs to be set to that maximum value. The threshold will then also "roll over" whenever it strictly exceeds the modulus value. When the threshold "rolls over", it is reset to the value that was specified through the latest call to the monitor's `setInitThreshold` method, before any offsets were applied.
- The `getThreshold` method of the `CounterMonitor` class always returns the current value of the threshold, which includes any offset increments.
- All incrementing or rolling over of the threshold is considered to take place instantaneously, namely, before the count is incremented. Thus, if the granularity period is set appropriately, the monitor triggers a threshold notification every time the count increases by an interval equal to the offset value.

If the counter difference option is used, then the value of the derived gauge is computed as the difference between the observed counter values for two consecutive observations. If the counter will roll over, then the modulus must be defined when counter difference is active. When the counter does roll over, the difference between the observations will be negative and value of the modulus needs to be added.

The derived gauge value ($V[t]$) for the counter difference is calculated at time t using the following algorithm, where GP is the granularity period:

- While t is less than $StartDate+2GP$, $V[t] = (\text{Integer})0$
- If $(\text{counter}[t] - \text{counter}[t-GP])$ is greater than or equal to zero, then $V[t] = \text{counter}[t] - \text{counter}[t-GP]$

- If $(\text{counter}[t] - \text{counter}[t-\text{GP}])$ is negative, then

$$V[t] = \text{counter}[t] - \text{counter}[t-\text{GP}] + \text{MODULUS}$$

The counter monitor has the following constraint:

- The threshold value, the offset value and the modulus value properties must be of the same integer type as the observed attribute.

The operation of a counter monitor with an offset of 2 is illustrated in FIGURE 9-2.

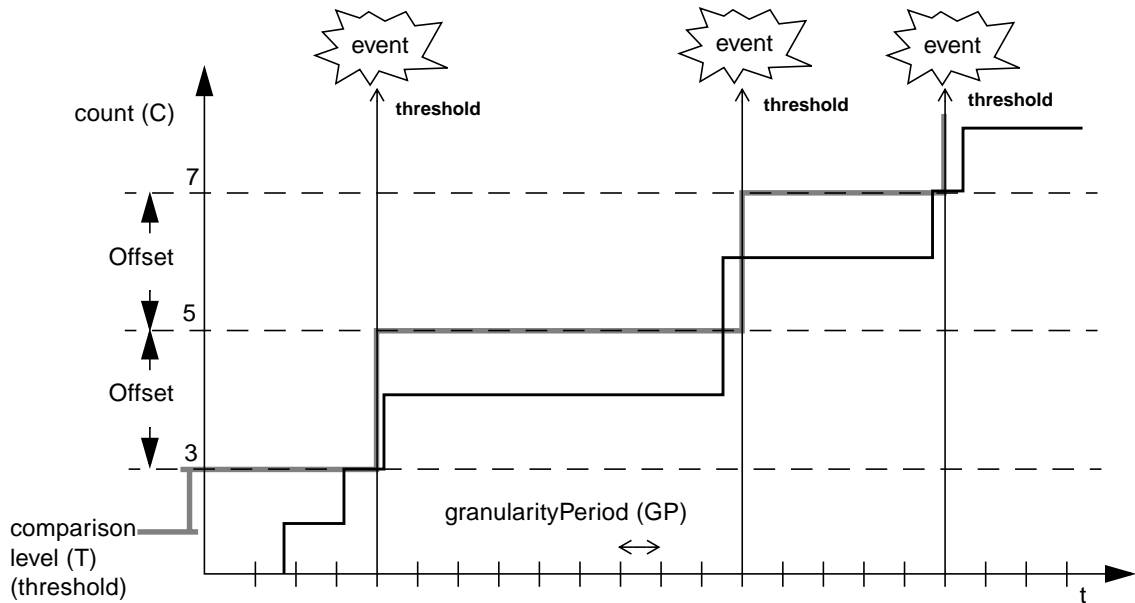


FIGURE 9-2 Operation of the CounterMonitor

The monitor observes a counter $C(t)$ that varies with time t . The granularity period is GP and the comparison level is T . A CounterMonitor sends a notification when the value of the counter reaches or exceeds the comparison (threshold) level. After the notification has been sent, the threshold is incremented by the offset value until the comparison level is greater than the current value of the counter.

9.3.1 Counter Monitor Notification Types

In addition to the monitor error notification types, a CounterMonitor MBean can broadcast the following notification type:

- `jmx.monitor.counter.threshold` - This notification type is triggered when the derived gauge has reached or exceeded the threshold value.

9.4 GaugeMonitor Class

A gauge monitor observes a numerical value that behaves as a gauge. A *hysteresis* mechanism is provided to avoid the repeated triggering of notifications when the gauge makes small oscillations around the threshold value. This capability is provided by specifying threshold values in pairs; one being a *high threshold* value and the other being a *low threshold* value. The difference between threshold values is the hysteresis interval.

The GaugeMonitor MBean has the following structure:

- The `HighThreshold` attribute defines the value that the gauge must reach or exceed to trigger a notification that will be broadcast only if the `NotifyHigh` boolean attribute is `true`.
- The `LowThreshold` attribute defines the value that the gauge must fall to or fall below to trigger a notification that will be broadcast only if the `NotifyLow` boolean attribute is set to `true`.

The gauge monitor has the following constraints:

- The threshold high value and the threshold low value properties are of the same type as the observed attribute.
- The threshold high value is greater than or equal to the threshold low value.

The gauge monitor has the following behavior:

- Initially, if `NotifyHigh` is `true` and the gauge value becomes equal to or greater than the `HighThreshold` value while the gauge is increasing, then the defined notification is triggered. Subsequent crossings of the high threshold value will not trigger further notifications until the gauge value becomes equal to or less than the `LowThreshold` value.
- Initially, if `NotifyLow` is `true` and the gauge value becomes equal to or less than the `LowThreshold` value while the gauge is decreasing, then the defined notification is triggered. Subsequent crossings of the low threshold value will not cause further notifications until the gauge value becomes equal to or greater than the `HighThreshold` value.
- Upon creation of the gauge, if `NotifyHigh` is `true` and the gauge value is already equal to or greater than the `HighThreshold` value, then the defined notification is triggered. Similarly, if `NotifyLow` is `true` and the gauge value is already equal to or less than the `LowThreshold` value, then the defined notification is also triggered.

If the gauge difference option is used, then the value of the derived gauge is calculated as the difference between the observed gauge values for two consecutive observations.

The derived gauge value ($V[t]$) for gauge difference is calculated at time t using the following algorithm, where GP is the granularity period:

- While t is less than $StartDate+2GP$, $V[t] = (\text{Integer})0$
- Otherwise, $V[t] = \text{gauge}[t] - \text{gauge}[t-GP]$

The operation of the GaugeMonitor is illustrated in FIGURE 9-3, assuming both notification switches are true.

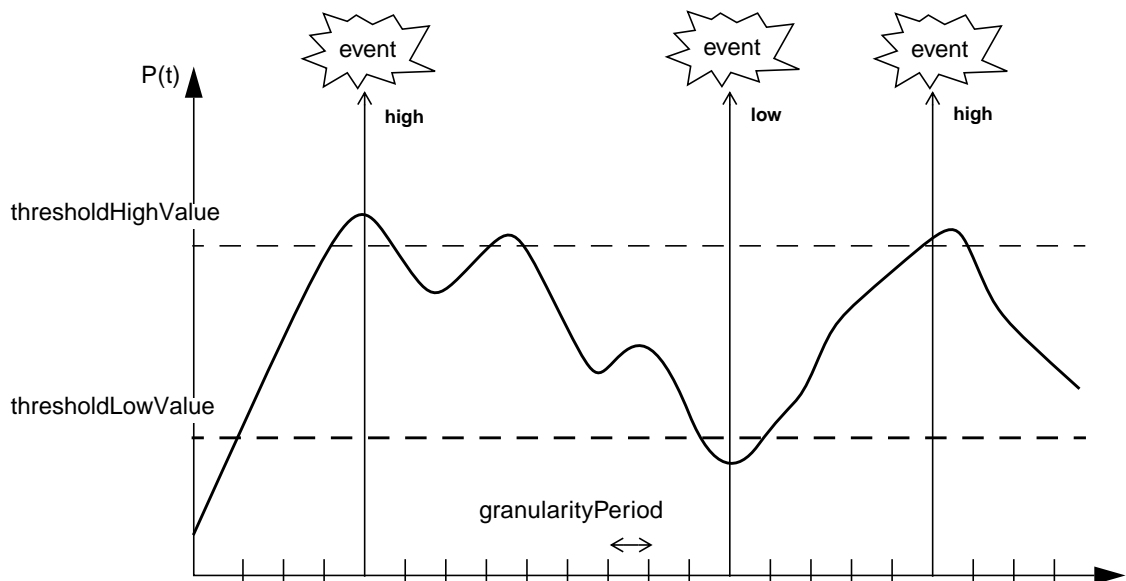


FIGURE 9-3 Operation of the GaugeMonitor

9.4.1 Gauge Monitor Notification Types

In addition to the monitor error notification types, a GaugeMonitor MBean can broadcast the following notification types:

- `jmx.monitor.gauge.high` - This notification type is triggered when the derived gauge has reached or exceeded the high threshold value.
- `jmx.monitor.gauge.low` - This notification type is triggered when the derived gauge has decreased to or below the low threshold value.

9.5 StringMonitor Class

A string monitor observes a value of type `String`. The derived gauge in this case is always the observed value. The string monitor is configured with a value for the string called *string-to-compare*, and is able to detect the following two conditions:

- The derived gauge matches the string-to-compare. If the `NotifyMatch` attribute of the monitor is `true`, then a notification is sent. At the subsequent observation times (defined by the granularity period), no other notification will be sent for as long as the attribute value still matches the string-to-compare.
- The value of the derived gauge differs from the string-to-compare. If the `NotifyDiffer` attribute of the monitor is `true`, then a notification is sent. At the subsequent observation times, no other notification will be sent for as long as the attribute value differs from the string-to-compare.

Assuming both notifications are selected, this mechanism ensures that matches and differs are strictly alternating, each occurring the first time the condition is observed.

The operation of the string monitor is illustrated in FIGURE 9-4. The granularity period is `GP`, and the string-to-compare is `"XYZ"`.

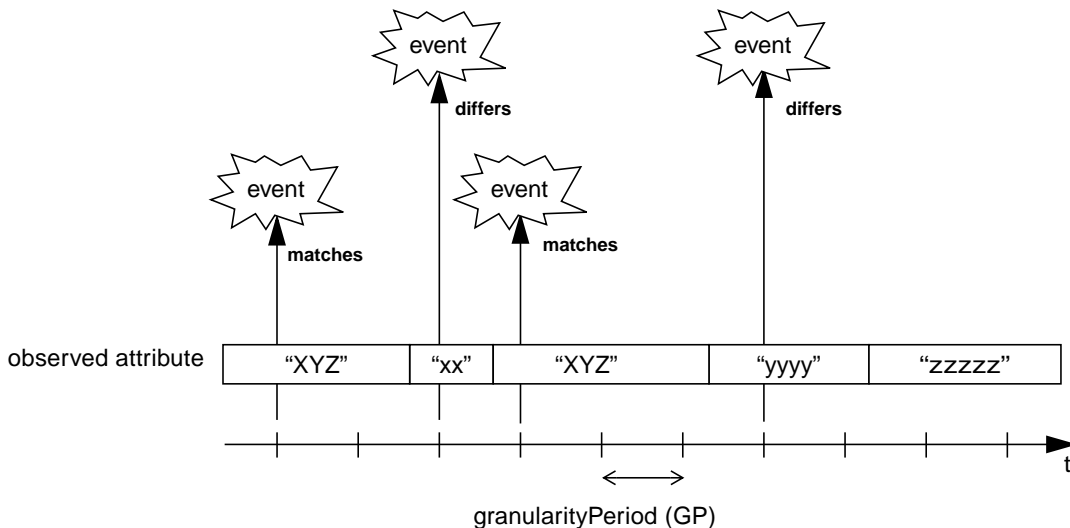


FIGURE 9-4 Operation of the `StringMonitor`

9.5.1 String Monitor Notification Types

In addition to the monitor error notification types, a `StringMonitor` MBean can broadcast the following notification types:

- `jmx.monitor.string.matches` - This notification type is triggered when the derived gauge first matches the string to compare.
- `jmx.monitor.string.differs` - This notification type is triggered when the derived gauge first differs from the string to compare.

9.6 Implementation of the Monitor MBeans

FIGURE 9-5 provides the package diagram of the various monitor MBean classes, with the interfaces they implement. The API documentation generated by the Javadoc tool provides the complete description of all monitoring service interfaces and classes.

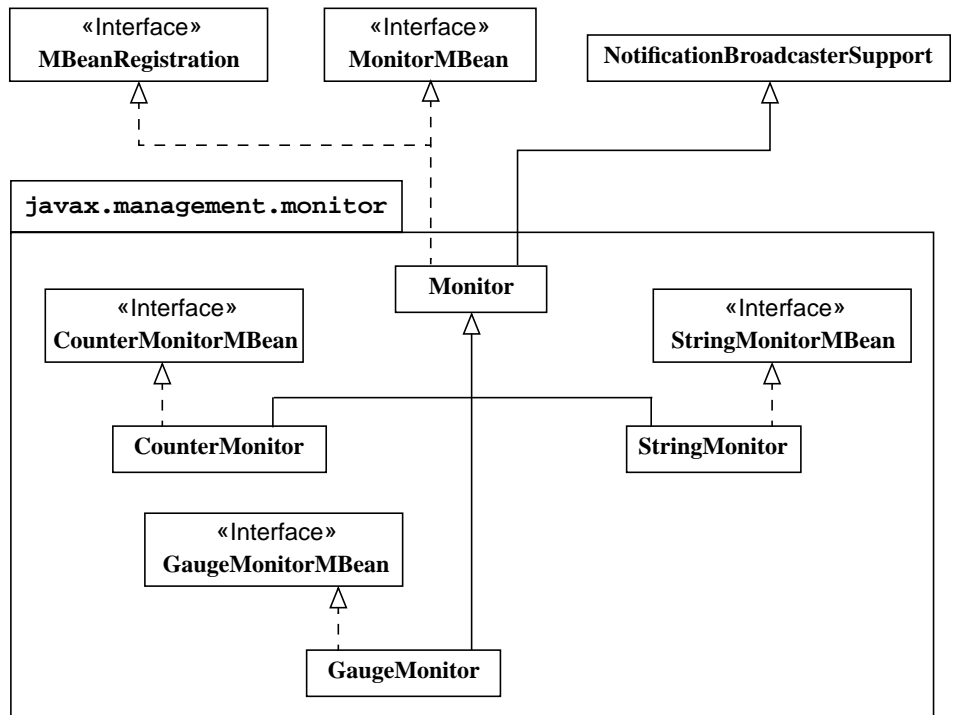


FIGURE 9-5 The Package and Class Diagram of the Monitor MBeans

Timer Service

The timer service triggers notifications at specific dates and times. It can also trigger notifications repeatedly at a constant interval. The notifications are sent to all objects registered to receive notifications emitted by the timer. The timer service is an MBean that can be managed, allowing applications to set up a configurable scheduler.

Conceptually, the `Timer` class manages a list of dated notifications that are sent when their date and time arrives. Methods of this class are provided to add and remove notifications from the list. In fact, the notification *type* is provided by the user, along with the date and optionally a period and the number of repetitions. The timer service always sends the notification instances of its specific `TimerNotification` class.

10.1 Timer Notifications

The timer service can manage notifications in two different ways:

- Notifications that are triggered only once
- Notifications that are repeated with a defined period and/or number of occurrences

This behavior is defined by the parameters passed to the timer when the notification is added into the list of notifications. Each of the notifications added to the timer service is assigned a unique identifier number. Only one identifier number is assigned to a notification, no matter how many times it is triggered.

10.1.1 TimerNotification Class

A specific subclass of the `Notification` class is defined for use by the timer service: the `TimerNotification` class. The notification type contained in instances of the `TimerNotification` class is particular: it is defined by the user when the notification is added to the timer. All notifications broadcast by the timer service are instances of the `TimerNotification` class.

The `TimerNotification` class has a notification identifier field that uniquely identifies the timer notification that triggered this notification instance.

10.1.2 Adding Notifications to the Timer

The timer service maintains an internal list of the dated notifications that it has been requested to send. Notifications are added to this list using the `Timer` class' `addNotification` methods. The methods take the following parameters, used by the timer to create a `TimerNotification` object and then add it to the list:

- `type` - The notification type string.
- `message` - The notification's detailed message string.
- `userData` - The notification's user data object.
- `date` - The date when the notification will occur. The `Timer` class includes integer constants for expressing durations in milliseconds, that can then be used to create `java.util.Date` objects.

The `addNotification` method is overloaded and, in addition to the notification's parameters and `date`, it can take the following optional parameters:

- `period` - The interval in milliseconds between notification occurrences. Repeating notifications are not enabled if this parameter is zero or `null`.
- `nbOccurrences` [sic] - The total number of times that the notification will occur. If the value of this parameter is zero or is not defined (`null`), and if the `period` is not zero or `null`, then the notification will repeat indefinitely.

If the notification to be inserted has a date that is before the current date, the `addNotification` method behaves as if the current date had been specified. Updating the date of a timer notification that is being added *does not* generate any notification events, as opposed to the `sendPastNotifications` mechanism that applies when the timer is started (see "Starting and Stopping the Timer" on page 168).

The `addNotification` method returns the identifier of the new timer notification. This identifier can be used to retrieve information about the notification from the timer or to remove the notification from the timer's list of notifications. However, after a notification has been added to the list of notifications, its associated parameters cannot be updated.

When a one-off notification (period is zero or null) occurs, it is removed from the timer's list of notifications.

10.1.3 Receiving Timer Notifications

The timer service MBean is a standard notification broadcaster with notification types and times defined by the list of notifications built up through the `addNotification` method. All listeners of a given timer MBean will receive all its timer notifications. Listeners configured to listen for a specific timer notification should specify the appropriate filter object when registering as a listener (see "NotificationFilter Interface" on page 58).

When the timer is active and the date of a timer notification comes due, the timer service broadcasts this notification with the given type, message, and user data, along with the notification's identifier within the timer. If a periodic notification has a specified number of occurrences, that number is decremented by one. Accessing the occurrence parameter of a timer notification always returns the remaining number of occurrences at the time of access.

When a notification is not repeating or when it has exhausted its number of occurrences, it is removed from the timer's list of notifications. The methods of the `Timer` class for accessing notification parameters will raise an exception if called with the identifier of a timer notification that has been sent and removed.

10.1.4 Removing Notifications From the Timer

Timer notifications can also be removed from the list of notifications using one of the following methods of the `Timer` class:

- `removeNotification` - Takes a notification identifier as a parameter and removes the corresponding notification from the list. If the specified identifier does not exist in the list, this method throws an `InstanceNotFoundException`.
- `removeNotifications` - Takes a notification type as a parameter and removes all notifications from the list that were added with that type. If the specified notification type does not correspond to any notifications in the list, this method throws an `InstanceNotFoundException`.
- `removeAllNotifications` - Empties the timer's list of notifications. This method also resets the notification identifiers, meaning that all existing identifiers for this timer are invalid and will erroneously refer to new notifications.

10.2 Starting and Stopping the Timer

The timer service, represented by an instance of the `Timer` class, is activated using the `start` method and deactivated using the `stop` method. If the list of notifications is empty when the timer is started, the timer waits for a notification to be added. No timer notifications are triggered before the timer is started or after it is stopped.

You can determine whether the timer is running or not by invoking the timer method `isActive`. The `isActive` method returns `true` if the timer is running.

If any of the notifications in the timer's list have associated dates that have passed when the timer is started, the timer attempts to update them. The dates of periodic notifications are incremented by their interval period until their date is greater than the current date. The number of increments can be limited by their defined number of occurrences. Notifications with one-time dates preceding the start date and notifications with a limited number of occurrences that cannot be updated to exceed the start date are removed from the timer's list of notifications.

When a notification is updated or removed during timer start-up, its notification is either triggered or ignored, depending on the `sendPastNotifications` attribute of the `Timer` class:

- `sendPastNotifications = true` - All one-time notifications with a date before the start date are broadcast, and all periodic notifications will be broadcast as many times as they should have occurred before the start date, including those that are removed because they cannot be updated beyond the start date.
- `sendPastNotifications = false` - Notifications with a date before the start date are ignored; if a notification is periodic, its notification date is updated but no notifications are triggered.

Setting the `sendPastNotifications` flag to `true` can cause a flood of notifications to be broadcast when the timer is started. The default value for this flag is `false`. Setting this flag to `true` ensures that notification dates that occur while the timer is stopped are not lost. The user can choose to receive them when the timer is started again, even though they no longer correspond to their set dates.

Calling `start` on a `Timer` that has already been started, or `stop` on a `Timer` that has already been stopped, has no effect. After a `stop`, the timer is in its initial state, and it can be started again with `start`.

Relation Service

As part of the agent specification, the Java Management extensions (JMX) specification also defines a model for relations between MBeans. A relation is a user defined, n-ary association between MBeans in named roles. The JMX specification defines the classes that are used to construct an object representing a relation, and it defines the relation service that centralizes all operations on relations in an agent.

All relations are defined by a relation type that provides information about the roles it contains, such as their multiplicity, and the class name of MBeans that satisfy the role. Through the relation service, users create new types and then create, update, or remove relations that satisfy these types. The relation service also performs queries among all relations to find related MBeans.

The relation service maintains the consistency of relations, checking all operations and all MBean deregistrations to ensure that a relation always conforms to its relation type. If a relation is no longer valid, it is removed from the relation service, though its member MBeans continue to exist otherwise.

11.1 The Relation Model

A relation is composed of named *roles*, each of which has a value consisting of the list of MBeans in that role. This list must comply with the role information that defines the multiplicity and class of MBeans in the corresponding role. A set of one or more role information definitions constitutes a *relation type*. The relation type is a template for all relation instances that associate MBeans representing its roles. We use the term *relation* to mean a specific instance of a relation that associates existing MBeans according to the roles in its defining relation type.

11.1.1 Terminology

The relation model in the JMX specification relies on the following terms. Here we only define the concepts represented by a term, not the corresponding Java class.

- role information* Describes one of the roles in a relation. The role information gives the name of the role, its multiplicity expressed as a single range, the name of the class that participates in this role, read-write permissions, and a description string.
- relation type* The metadata for a relation, composed of a set of role information. It describes the roles that a relation must satisfy, and it serves as a template for creating and maintaining relations.
- relation* A current association between MBeans that satisfies a given relation type. A relation can only be created and modified such that the roles of its defined type are always respected. A relation can also have properties and methods that operate on its MBeans.
- role value* The list of MBeans that currently satisfies a given role in a relation. The role value must at all times conform to its corresponding role information.
- unresolved role* An unresolved role is the result of an illegal access operation on a role, as defined by its role information. Instead of the resulting role value, the unresolved role contains the reason for the refused operation. For example, setting a role with the wrong class of MBean, providing a list with an illegal cardinality, or attempting to write a read-only role will all return an unresolved role.
- support classes* Internal classes used to represent relation types and relation instances. The support classes are also exposed to simplify user implementations of relation classes. The user's external implementation must still rely on the relation service to maintain the consistency of the relation model.
- relation service* An MBean that can access and maintain the consistency of all relation types and all relation instances within a JMX agent. It provides query operations to find related MBeans and their role in a relation. It is also the sole source of notifications concerning relations.

11.1.2 Example of a Relation

Throughout this chapter we will use the example of a relation between books and their owner.

To represent this relation in the JMX specification model, we say that `Books` and `Owner` are roles. `Books` represents any number of owned books of a given MBean class, and `Owner` is a book owner of another MBean class. We might define a relation type containing these two roles and call it `Personal Library`, representing the concept of book ownership.

The following diagram represents this sample relation, as compared to the UML modeling of its corresponding association.

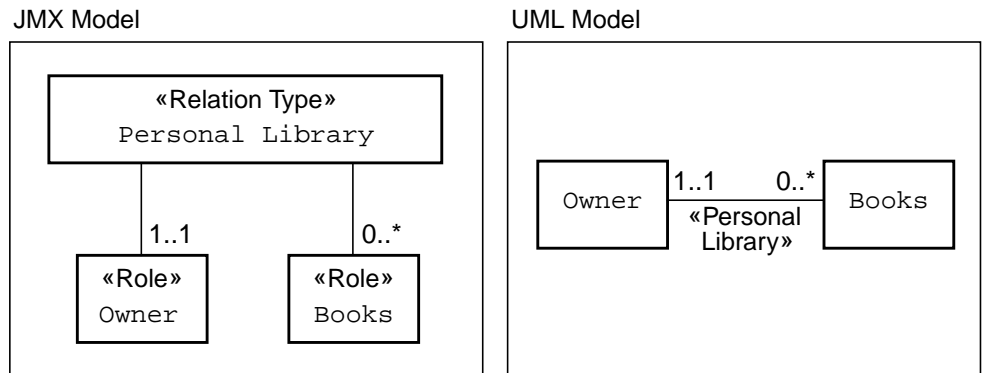


FIGURE 11-1 Comparison of the Relation Models

In the JMX specification model, the relation type is a static set of roles. Relation types can be defined at runtime, but once defined, their roles and the role information cannot be modified. The relation instance of a given type defines the MBeans in each role and provides operations on them, if necessary.

11.1.3 Maintaining Consistency

MBeans are related through relation instances defined by relation types in the relation service, but the MBeans remain completely accessible through the MBean server. Only registered MBeans, identified by their object name, can be members of a relation. The relation service never operates on member MBeans, it only provides their object names in response to queries.

The relation service blocks the creation of invalid relation types, for example if the role information is inconsistent. In the same way, invalid relations cannot be created, either because the relation type is not respected or because the object name of a member MBean does not exist in the MBean server. The modification of a role value is also subject to the same consistency checks.

When a relation is removed from the relation service, its member MBeans are no longer related through the removed instance, but are otherwise unaffected. When a relation type is removed, all existing relations of that type are first removed. The caller is responsible for being aware of the consequences of removing a relation type.

Because relations are defined only between registered MBeans, deregistering a member MBean modifies the relation. The relation service listens for all MBean server notifications that indicate when a member of any relation is deregistered. The

corresponding MBean is then removed from any role value where it appears. If the new cardinality of the role is not consistent with the corresponding relation type, that relation is removed from the relation service.

The relation service sends a notification after all operations that modify a relation instance, either creation, update, or removal. This notification provides information about the modification, such as the identifier of the relation and the new role values. The notification also indicates whether the relation was internally or externally defined (see “External Relations” on page 174).

There is a difference between the two models presented in FIGURE 11-1 on page 171. The UML association implies that each one of the `Books` can only have one owner. The relation type in the JMX specification only models a set of roles, indicating that a relation instance has one `Owner` MBean and any number of MBeans in the `Books` role.

The JMX specification relation model only guarantees that an MBean satisfies its designated role, it does not allow a user to define how many relations an MBean can appear in. This implies that the relation service does not perform inter-relation consistency checks. These are the responsibility of the management application when creating or modifying relation instances.

If this level of consistency is needed, the designer of a management solution must implement the necessary verifications in the objects that use the relation service. In our example, the designer would need to ensure that the same book MBean is not added to more than one `Personal Library` relation. One way to do this is by calling the query methods of the relation service before performing any operation.

11.1.4 Implementation

The JMX specification defines the Java classes the behavior of which implements this relation model. Each of the concepts defined in “Terminology” on page 170 has a corresponding Java class (see FIGURE 11-2 on page 173). Along with the behavior of the relation service object itself, these classes determine how the relation service is used in management solutions.

This section explains the interaction between the relation service and the support classes. The operations and other details of all classes will be covered in further sections. The exception classes are all subclasses of the `RelationException` class and provide only a message string. The API documentation generated by the Javadoc tool for the other classes indicates which exceptions are raised by specific operations.

In practice, role description structures are handled outside of the relation service, and their objects are instantiated directly by the user (see “Role Description Classes” on page 184). Role information objects are grouped into arrays to define a relation

type. Role objects and role lists are instantiated to pass to setters of role values. Role results are returned by getters of role values, and their role lists and unresolved role lists can be extracted for processing.

<code>javax.management.relation</code>	
«relation service»	«exception superclass»
<code>RelationService</code>	<code>RelationException</code>
<code>RelationServiceMBean</code>	«relation type creation errors»
<code>RelationNotification</code>	<code>InvalidRoleInfoException</code>
<code>MBeanServerNotificationFilter</code>	<code>InvalidRelationTypeException</code>
«relation support»	«relation creation errors»
<code>RelationType</code>	<code>InvalidRelationServiceException</code>
<code>RelationTypeSupport</code>	<code>RelationServiceNotRegisteredException</code>
<code>Relation</code>	<code>RoleInfoNotFoundException</code>
<code>RelationSupport</code>	<code>InvalidRoleValueException</code>
<code>RelationSupportMBean</code>	<code>RelationTypeNotFoundException</code>
«role description»	<code>InvalidRelationIdException</code>
<code>RoleInfo</code>	«relation access errors»
<code>Role</code>	<code>RelationNotFoundException</code>
<code>RoleList</code>	<code>RoleNotFoundException</code>
<code>RoleUnresolved</code>	
<code>RoleUnresolvedList</code>	
<code>RoleResult</code>	
<code>RoleStatus</code>	

FIGURE 11-2 Classes of the `javax.management.relation` package

On the other hand, relation types and relation instances are controlled by the relation service to maintain the consistency of the relation model. The implementation of the JMX specification relation model provides a flexible design whereby relation types and instances can be either internal or external to the relation service.

Internal relation types and instances are created by the relation service and can only be accessed through its operations. The objects representing types and relations internally are not accessible to the user. External relation types and instances are objects instantiated outside the relation service and added under its control. Users can access these objects in any manner that has been designed into them, including as registered MBeans.

11.1.4.1 External Relation Types

The relation service maintains a list of relation types that are available for defining new relations. A relation type must be created internally or instantiated externally and added to the relation service before it can be used to define a relation.

Objects representing external relation types must implement the `RelationType` interface. The relation service relies on its methods to access the role information for each of the roles defined by the external object. See “`RelationTypeSupport Class`” on page 181 for the description of a class used to define external relation types.

Relation types are immutable, meaning that once they are added to the relation service, their role definitions cannot be modified. If an external relation type exposes methods for modifying the set of role information, they should not be invoked by its users after the instance has been added under the control of the relation service. The result of doing so is undefined, and consistency within the relation service is no longer guaranteed.

The benefit of using an external relation type class is that the role information can be defined statically, for example, in a class constructor. This allows predefined types to be rapidly instantiated and then added to the relation service.

Once it has been added to the relation service, an external relation type can be used to create both internal and external relations. An external relation type is also removed from the relation service in the same way as an internal relation type, with the same consequences (see “`RelationService Class`” on page 177)

11.1.4.2 External Relations

The relation service also maintains a list of the relations that it controls. Internal relations are created through the relation service and are only accessible through its methods. External relations are MBeans instantiated by the user and added under the control of the relation service. They must be registered in the MBean server before they can be added to the relation service. They are accessible both through the relation service and through the MBean server.

An external relation object must implement the `Relation` interface that defines the methods that the relation service uses to access its role values. An external relation is also responsible for maintaining its own consistency, by only allowing access to its role values as described by its relation type. Finally, an external relation must inform the relation service when any role values are modified.

The relation service object exposes methods for checking role information and updating its internal role values. The external relation object must be designed to call these when appropriate. Failure to do so will result in an inconsistent relation service the behavior of which is thereafter undefined.

The major benefit of external relations is the ability to provide methods that return information about the relation’s members or even operate on the role values. Because the external relation is also an MBean, it can choose to expose these methods as attributes and operations.

Returning to “Example of a Relation” on page 170, the book ownership relation can be represented by a unary relation type containing only the role `Books`. The relation would be implemented by instances of an `Owner` MBean that are external to the relation service. This MBean could have an attribute such as `bookCount` and operations such as `buy` and `sell` that all apply to the current members of the relation.

See “RelationSupport Class” on page 184 for an example of an external relation.

11.2 Relation Service Classes

The relation service is implemented in the `RelationService` object, a standard MBean defined by the `RelationServiceMBean` interface. It can therefore be accessed and managed remotely from a management application.

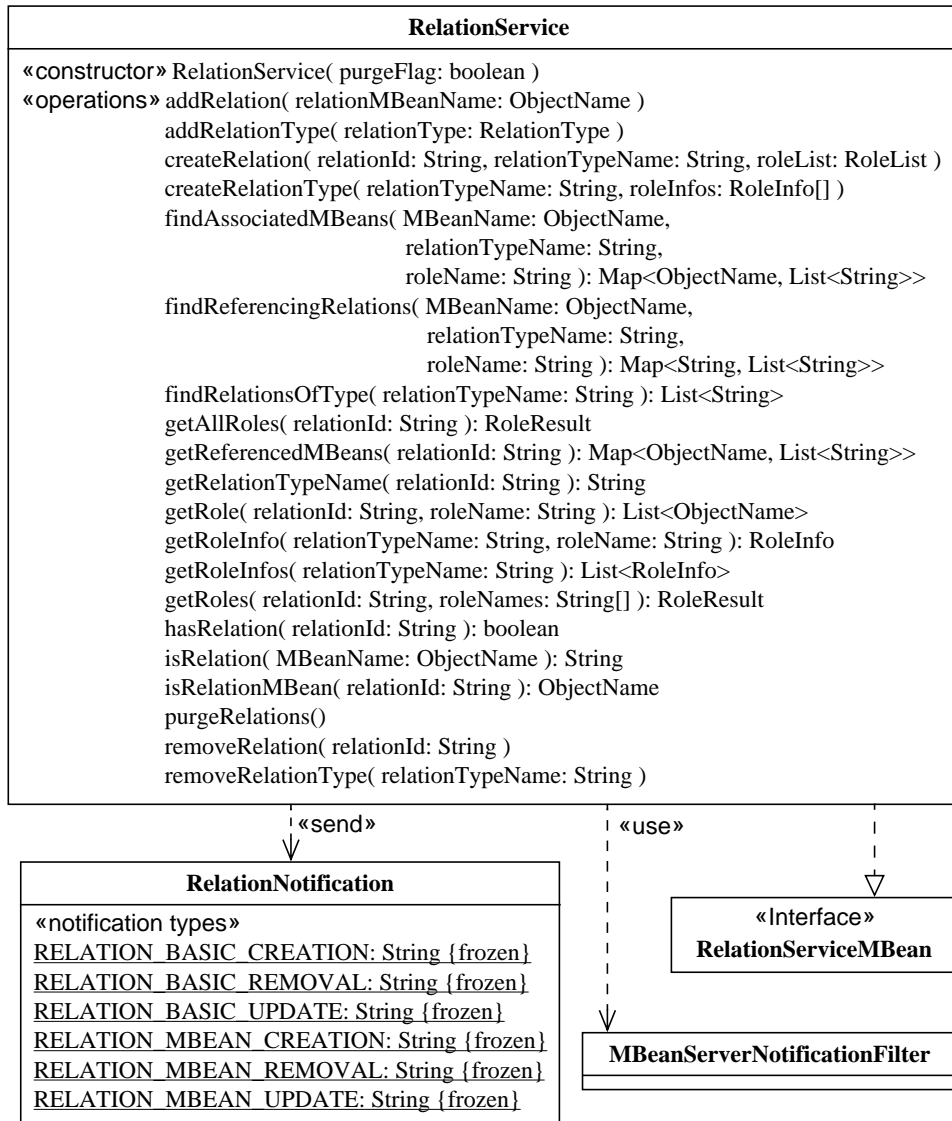


FIGURE 11-3 Relation Service Classes

The relation service MBean is a notification broadcaster and the only object to send RelationNotification objects. To maintain consistency, it also listens for MBean server notifications through an MBeanServerNotificationFilter object.

11.2.1 RelationService Class

The relation service exposes methods for creating and removing relation types and relation instances, and for accessing roles in relations. It also exposes methods for querying the relations and their members to find related MBeans.

There are two methods to define a relation type:

- `createRelationType` - Creates an internal relation type from an array of role information objects; the relation type is identified by a name passed as a parameter and that must be unique among all relation type names.
- `addRelationType` - Makes an externally defined relation type available through the relation service (see “RelationType Interface” on page 181).

There are also two similar methods for defining a relation. Every new relation triggers a `RelationNotification`:

- `createRelation` - Creates an internal relation using the given list of role values; the relation is identified by an identifier passed as a parameter and that must be unique among all relation identifiers.
- `addRelation` - Places an external relation represented by a MBean under the control of the relation service; the MBean must have been previously instantiated and registered in the MBean server.

The method `removeRelationType` removes both internal or external relation types. All relations of that type will be removed with the `removeRelation` method (see “Maintaining Consistency” on page 171).

The `removeRelation` method removes a relation from the relation service, meaning that it can no longer be accessed. Member MBeans in the roles of the relation continue to exist. When an external relation is removed, the MBean that implements it will still be available in the MBean server. Removing a relation triggers a relation notification.

The relation service provides methods to access a relation type, identified by its unique name: `getRoleInfo` and `getRoleInfos`.

It provides methods to access the relation and its role values. All access to roles is subject to the access mode defined in the relation type and to consistency checks, especially for setting role values: `getRelationTypeName`, `getRole`, `getRoles`, `getAllRoles`, `getReferencedMBeans`, `setRole` and `setRoles`. Setting roles will trigger a relation update notification.

There are also methods for identifying internal and external relations:

- `hasRelation` - Indicates if a given relation identifier is defined.
- `isRelation` - Takes an object name and indicates if it has been added as an external relation to the service.

- `isRelationMBean` - Returns the object name of an externally defined relation.

The following query methods retrieve relations where a given MBean is involved:

- `findReferencingRelations` - Retrieves the relations where a given MBean is referenced.

It is possible to restrict the scope of the search by specifying the type of the relations to look for and/or the role where the MBean is expected to be found in the relation.

In the result, relation identifiers are mapped to a list of role names where the MBean is referenced (an MBean can be referenced in several roles of the same relation).

- `findAssociatedMBeans` - Retrieves the MBeans associated to a given MBean in the relation service.

It is possible to restrict the scope of the search by specifying the type of the relations to look for and/or the role in which the MBean is expected to be found in the relation.

In the result, the object names of related MBeans are mapped to a list of relation identifiers where the two are associated.

The method `findRelationsOfType` returns the relation identifiers of all the relations of the given relation type.

To maintain consistency, the relation service listens to the deregistration notifications from the MBean server delegate. It will be informed when an external relation's MBean is unregistered, in which case the relation is removed, or when an MBean that is a member of a relation is unregistered (see "Maintaining Consistency" on page 171). The `purgeRelations` method will check all relation data for consistency and remove all relations that are no longer valid.

Every time a relevant deregistration notification is received, the relation service behavior depends upon the `purge` flag attribute:

- If the `purge` flag is `true`, the `purgeRelations` method will be called automatically.
- When the `purge` flag is `false`, no action is taken and the relation service might be in an inconsistent state until the `purgeRelations` method is called by the user.

The relation service also exposes methods that allow external relation MBeans to implement the expected behavior, or to inform the relation service so that it can maintain consistency:

- `checkRoleReading` and `checkRoleWriting` - Check if a given role can be read and updated by comparing the new value to the role information.
- `sendRelationRemovalNotification`, `sendRoleUpdateNotification`, and `sendRelationCreationNotification` - Trigger a notification for the given event.
- `updateRoleMap` - Informs the relation service that a role value has been modified, so that it can update its internal data.

11.2.2 RelationNotification Class

An instance of this class is created and broadcast as a notification when a relation is created, added, updated, or removed. It defines two separate notification types for each of these events, depending upon whether the event concerns an internal or external relation. The static fields of this class describe all notification type strings that the relation service can send (see FIGURE 11-3 on page 176).

The methods of this class allow the listener to retrieve information about the event:

- `getRelationId` - Returns the identifier of the relation affected by this event.
- `getRelationTypeName` - Returns the relation type identifier of the relation affected by this event.
- `getObjectName` - Returns the object name only if the involved relation was an externally defined MBean.
- `getRoleName`, `getOldRoleValue`, `getNewRoleValue` - Give additional information about a role update event.
- `getMBeansToUnregister` - Returns the list of object names for MBeans expected to be unregistered due to a relation removal.

11.2.3 MBeanServerNotificationFilter Class

This class is used by the relation service to receive only those notifications concerning MBeans that are role members or external relation instances. It filters MBeans based on their object name, ensuring that the relation service will only receive the deregistration notifications for MBeans of interest.

Its methods allow the relation service to update the filter when it must add or remove MBeans in relations or representing external relations.

The filter instance used by the relation service is not exposed for management by the relation service. This class is described here because it is available as part of the `javax.management.relation` package and can be reused elsewhere.

11.3 Interfaces and Support Classes

External relation types and relation instances rely on the interfaces defined in the following figure and can choose to extend the support classes for convenience. Implementations of the JMX specification can also rely on these classes internally.

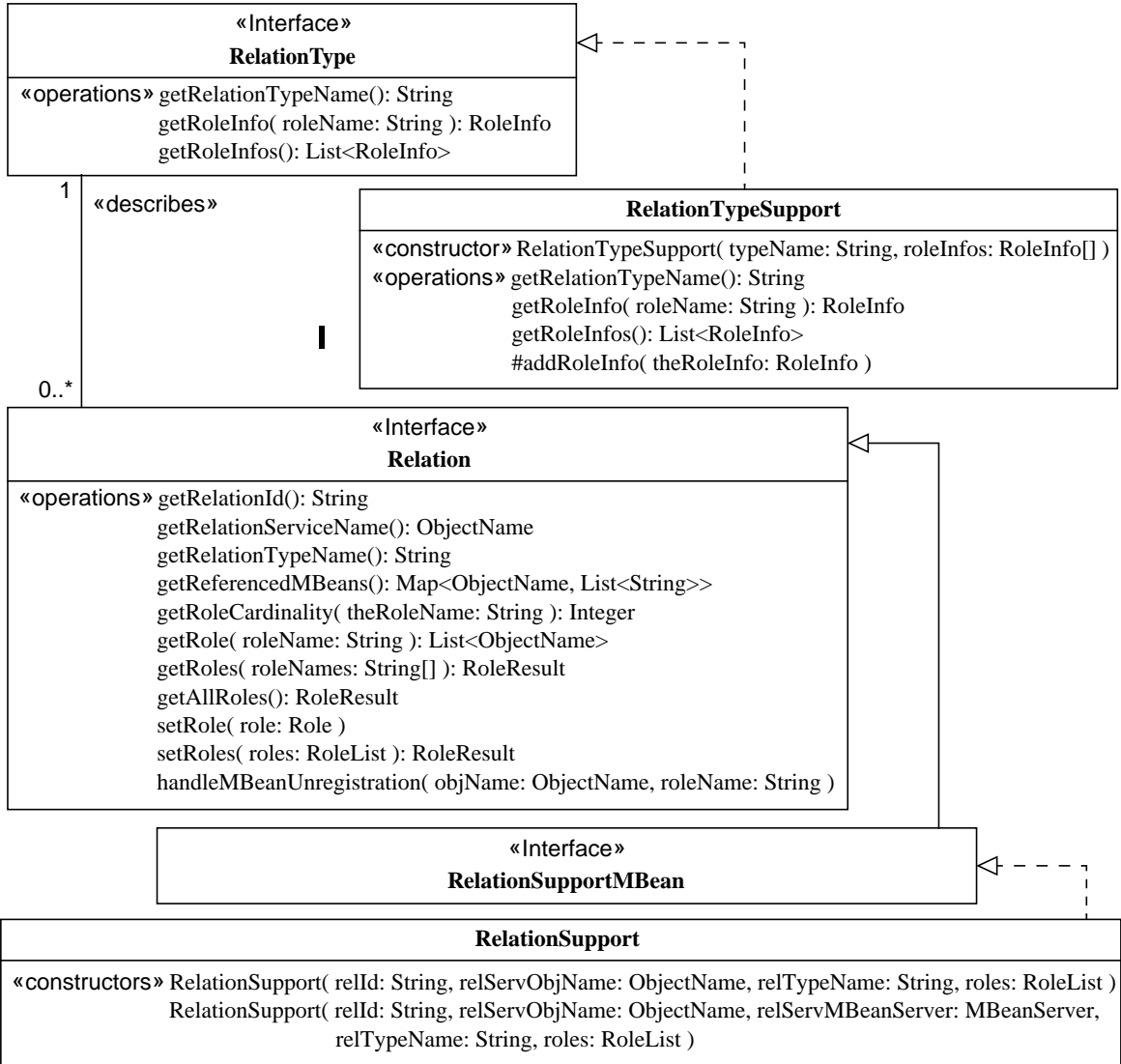


FIGURE 11-4 Interfaces and Support Classes

11.3.1 RelationType Interface

Any external representation of a relation type must implement the `RelationType` interface to be recognized by the relation service. The methods of this interface expose the name of the relation type and its role information (see “`RoleInfo Class`” on page 185).

The relation service invokes the methods of this interface to access the relation type name or the role information. Because a relation type is immutable, the returned values should never change while the relation type is registered with the relation service.

An instance of an object that implements this interface can be added as an external relation type, using the `addRelationType` method of the relation service. Providing its implementation is coherent, it can be accessed through the relation service in the same manner as an internal relation type. In fact, internal relation types are usually represented by an object that also implements this interface

11.3.2 RelationTypeSupport Class

This class implements the `RelationType` interface and provides a generic mechanism for representing any relation type. The name of the relation type is passed as a parameter to the class constructor.

There are two ways to define a specific relation type through an instance of the `RelationTypeSupport` class:

- Its constructor takes an array of `RoleInfo` objects.
- The `addRoleInfo` method takes a single `RoleInfo` object at a time.

Role information cannot be added after an instance of this class has been used to define an external relation type in the relation service.

Users can also extend this class to create custom relation types without needing to rewrite the role information access methods. For example, the constructor of the subclass can determine the `RoleInfo` objects to be passed to the superclass constructor. This effectively encapsulates a relation type definition in a class that can be downloaded and instantiated dynamically.

The implementation of the relation service will usually instantiate the `RelationTypeSupport` class to define internal relation types, but these objects are not accessible externally.

11.3.3 Relation Interface

The `Relation` interface describes the operations to be supported by a class whose instances are expected to represent relations. Through the methods of this interface, the implementing class exposes all the functionality needed to access the relation.

The class that implements the `Relation` interface to represent an external relation must be instrumented as an MBean. The object must be instantiated and registered in the MBean server before it can be added to the relation service. Then, it can be accessed either through the relation service or through whatever management interface it exposes in the MBean server.

11.3.3.1 Specified Methods

Each relation is identified in the relation service by a unique relation identifier that is exposed through the `getRelationId` method. The string that it returns must be unique among all relations in the service at the time it is registered. The relation service will refuse to add an external relation with a duplicate or null identifier.

In the same way, the `getRelationTypeName` method must return a valid relation type name that has already been defined in the relation service. An external relation instance must also know about the relation service object where it will be controlled: this can be verified through the `getRelationServiceName` method. This method returns an object name that is assumed to be valid in the same MBean server as the external relation implementation.

The other methods of the `Relation` interface are used by the relation service to access the roles of a relation under its control. Role values can be read or written either individually or in bulk (see “Role Description Classes” on page 184). Individual roles that cannot be accessed cause an exception whose class indicates the nature of the error (see the exception classes in FIGURE 11-2 on page 173).

The methods for bulk role access follow a “best effort” policy: access to all indicated roles is attempted and roles that cannot be accessed do not block the operation. Those that cannot be accessed, either due to error in the input or due to the access rights of the role, will return an unresolved role object indicating the nature of the error (see “RoleUnresolved Class” on page 187).

The `getReferencedMBeans` method returns a list of object names for all MBeans referenced in the relation, with each object name mapped to the list of roles in which the MBean is a member.

11.3.3.2 Maintaining Consistency

The relation service delegates the responsibility of maintaining role consistency to the relation object. In this way, consistency checks can be performed when the roles are accessed through methods of the external relation. However, the relation service must be informed of any role modifications, so that it can update its internal data structures and send notifications.

When accessing a role, either getting or setting its value, the relation instance must verify that:

- The relation type has the corresponding role information for the named role.
- The role has the appropriate access rights according to its role information.
- The role value provided for setting a role is consistent with that role's information with respect to cardinality and MBean class.

An implementation of the `Relation` interface can rely on the `checkRoleReading` and `checkRoleWriting` methods of the relation service MBean, provided to simplify the above verifications.

After setting a role, an external relation must call the `updateRoleMap` operation of the relation service, providing the old and new role values. This allows the relation service to update its internal data to maintain consistency.

The relation service must be informed of all new role values so that it can listen for a unregistration notification concerning any of the member MBeans. When a member MBean of an external relation is unregistered from the MBean server, the relation service checks the new cardinality of the role it satisfied.

If the cardinality is no longer valid and if the `purge` flag is `true`, the relation service removes this relation instance (see “`RelationService Class`” on page 177). If the external relation is still valid, the relation service calls its `handleMBeanUnregistration` method.

When called, this method removes the MBean from the role where it was referenced (because all role members must be registered MBeans). The guarantee that the relation service will call this method when necessary frees the external relation from having to listen for MBean unregistrations itself. It also allows the relation implementation to define how the corresponding role will be updated. For example, the unregistration of an MBean in a given role could update other roles.

In this case, and in any other case where an exposed method modifies a role value, the implementation uses its own `setRole` method or call the appropriate relation service methods, such as `updateRoleMap`. It is the responsibility of all implementations of the `Relation` interface to maintain the consistency of their relation instance, as well as that of the relation service concerning their role values.

11.3.4 RelationSupport Class

This class is a complete implementation of the `Relation` interface that provides a generic relation mechanism. This class must be instantiated with a valid role list that defines the relation instance it will represent. The constructor also requires a unique relation identifier, and the name of an existing relation type that is satisfied by the given role list.

In fact, the `RelationSupport` class implements the `RelationSupportMBean` that extends the `Relation` interface. This implies that it is also a standard MBean whose management interface exposes all the relation access methods. Because an external relation must first be registered in the MBean server, external instances of the relation support class can be managed by remote applications.

Users can also extend the `RelationSupport` class to take advantage of its implementation when developing a customized external relation. Users can also choose to extend its MBean interface to expose other attributes or operations that access the relation. This customization must still maintain the consistency of role access and role updating, but it can use the consistency mechanism built into the methods of the `RelationSupport` class.

The relation service usually instantiates the `RelationSupport` class to define internal relation instances, but these objects are not accessible externally.

11.4 Role Description Classes

The relation service accesses the roles of a relation for both reading and writing values. The JMX specification defines the classes that are used to pass role values as parameters and receive them as results. These classes are also used by external relation MBeans that implement the behavior of a relation.

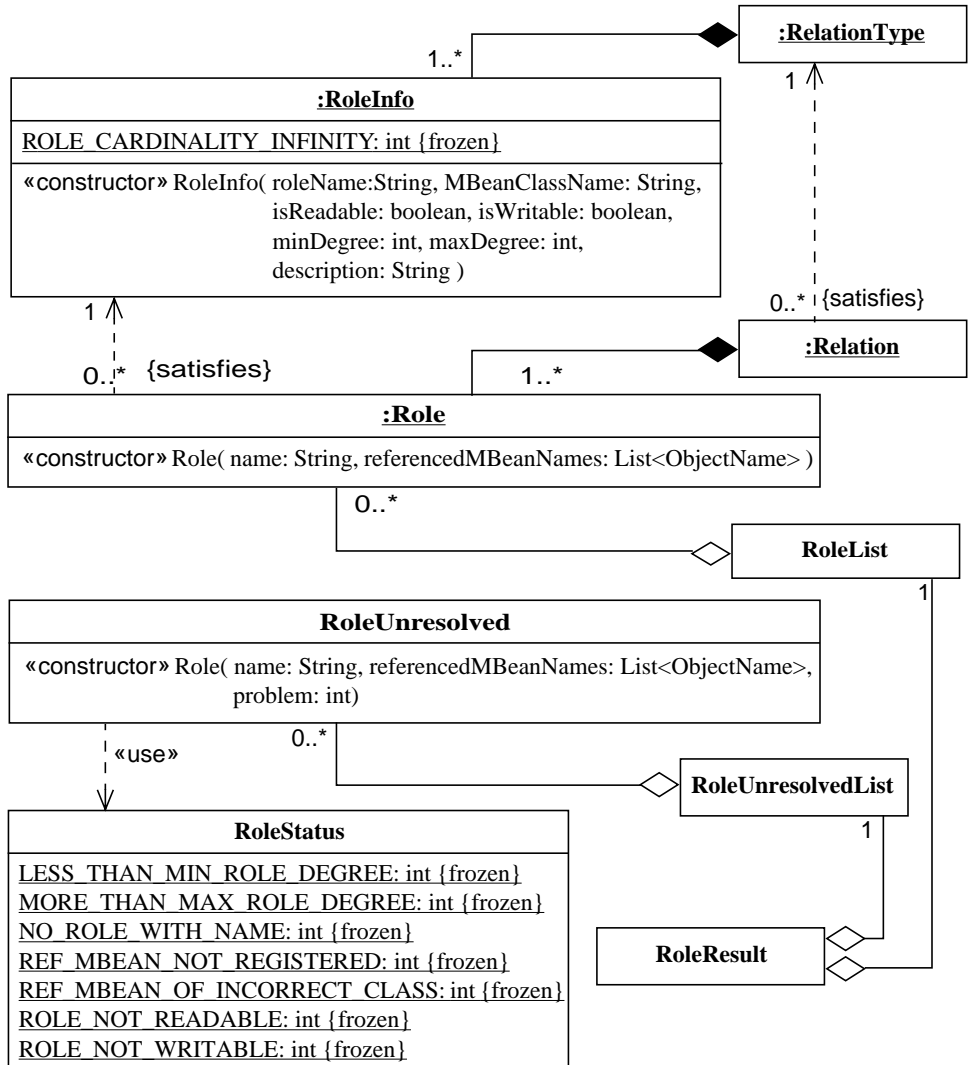


FIGURE 11-5 Role Description Classes

11.4.1 RoleInfo Class

The role information provides a metadata description of a role. It specifies:

- The name of the role.

- The multiplicity of the role, expressed as a single closed interval between the minimum and maximum number of MBeans that can be referenced in that role. The `RoleInfo` constructor verifies that this is a proper, non-empty interval.
- The name of the class or interface of which all members must be instances, as determined by the MBean server's `isInstanceOf` method.
- The role access mode, that is whether the role is readable, writable, or both.

When role information is used as a parameter for a new relation type, it is the defining information for a role. When that relation type is declared in the relation service, for each role, the service will verify that:

- The role information object is not `null`.
- The role name is unique among all roles of the given relation type. The relation service does not guarantee that roles with the same name in other relation types are identical; this is the user's responsibility.

11.4.2 Role Class

An instance of the `Role` class represents the value of a role in a relation. It contains the role name and the list of object names that reference existing MBeans.

A role value must always satisfy the role information of its relation's type. The role name is the key that associates the role value with its defining role information.

The `Role` class is used as a parameter to the `setRole` method of both the relation service and the `Relation` interface. It is also a component of the lists that are used in bulk setter methods and for defining an initial role value. For each role being initialized or updated, the relation service verifies that:

- A role with the given name is defined in the relation type.
- The number of referenced MBeans is greater than or equal to the minimum cardinality and less than or equal to the maximum cardinality.
- Each object name references a registered MBean that is an instance of the expected class or interface.

11.4.3 RoleList Class

This class extends `java.util.ArrayList` to represent a set of `Role` objects.

Instances of the `RoleList` class are used to define initial values for a relation. When calling the `createRelation` method of the relation service, roles that admit a cardinality of 0 can be omitted from the role list. All other roles of the relation type must have a well-formed role value in the initial role list.

Role list objects are also used as parameters to the `setRoles` method of both the relation service and the `Relation` interface. These methods only set the roles for which a valid role value appears in the role list.

Finally, all bulk access methods return a result containing a `RoleList` object representing the roles that were successfully accessed.

11.4.4 RoleUnresolved Class

An instance of this class represents an unsuccessful read or write access to a given role in a relation. It is used only in the return values of role access methods of either the relation service or of an object implementing the `Relation` interface.

The object contains:

- The name of the role that could not be accessed
- The value provided for an unsuccessful write access
- The reason why the attempt failed, encoded as an integer value. The constants for decoding the problem are given in the FIGURE 11-5 on page 185.

11.4.5 RoleUnresolvedList Class

This class extends `java.util.ArrayList` to represent a set of `RoleUnresolved` objects. All bulk access methods return a result containing a `RoleUnresolvedList` object representing the roles that could not be accessed.

11.4.6 RoleResult Class

The `RoleResult` class is the return object for all bulk access methods of both the relation service and implementations of the `Relation` interface. A role result contains a list of roles and their values, and a list of unresolved roles and the reason each could not be accessed.

As the result of a getter, the role values contain the current value of the requested roles. The unresolved list contains the roles that cannot be read, either because the role name is not valid or because the role does not permit reading.

As the result of a setter, the role values contain the new value for those roles where the operation was successful. The unresolved list contains the roles that cannot be written, for any access or consistency reason.

11.4.7 RoleStatus Class

This class contains static fields giving the possible error codes of an unresolved role. The error codes are either related to access permissions or consistency checking. The names of the fields identify the nature of the problem, as given in FIGURE 11-5 on page 185.

Security

A Java Management extensions (JMX) MBean server might have access to sensitive information and might be able to perform sensitive operations. In such cases, it is desirable to control who can access that information and who can perform those operations. The JMX specification builds on the standard Java security model by defining *permissions* that control access to the MBean server and its operations.

The security checks described in this chapter are only performed when there is a *security manager*. That is, if `System.getSecurityManager()` returns `null`, then no checks are performed.

12.1 Permissions

It is assumed that the reader has some familiarity with the Java security model. An excellent reference is *Inside Java™ 2 Platform Security* by Li Gong (Addison Wesley, 1999). Documentation is also available online as part of the Java 2 platform Standard Edition (J2SE) Standard Development Kit (SDK).

Sensitive operations require permissions. Before such an operation is performed, a check is performed to ensure that the caller has the required permission or permissions.

At any given point in the execution of a program, there is a current set of permissions that a thread of execution holds. When such a thread calls a JMX specification operation, we say that these are the *held permissions*.

An operation that performs a security check does so by defining a *needed permission*. The operation is allowed if the held permissions *imply* the needed permission. That is, at least one held permission must imply the needed permission.

A permission is a Java object that is a subclass of `java.security.Permission`. This class defines the following method:

```
public boolean implies(Permission permission);
```

A held permission *held* implies a needed permission *needed* if *held.implies(needed)*.

For example, to call `MBeanServerFactory.createMBeanServer`, a thread needs the permission

```
MBeanServerPermission("createMBeanServer")
```

Here are some permissions a thread can hold that imply this needed permission:

- `MBeanServerPermission("createMBeanServer")`
- `MBeanServerPermission("createMBeanServer, findMBeanServer")`
- `MBeanServerPermission("*")`
- `java.security.AllPermission()`

A thread that does not hold any of these permissions, or any other permission that implies the needed one, will not be able to call `createMBeanServer`. An attempt to do so will result in a `SecurityException`.

The JMX 1.2 specification defines three permissions:

- `MBeanServerPermission`
- `MBeanTrustPermission`
- `MBeanPermission`

These permissions are described in the following sections.

12.1.1.1 MBeanServerPermission

`MBeanServerPermission` controls access to the static methods of the class `javax.management.MBeanServerFactory`. (See “MBean Server Factory” on page 127.) An `MBeanServerPermission` is constructed with a single string argument, and the meaning of the permission object depends on this string, as follows:

- `MBeanServerPermission("createMBeanServer")` controls access to the two overloaded methods `MBeanServerFactory.createMBeanServer`. Holding this permission allows the creation of an `MBeanServer` object that is registered in the list accessible through `MBeanServerFactory.findMBeanServer`.

This permission implies the `newMBeanServer` permission, so holding it also allows the creation of an `MBeanServer` object that is not registered in that list.

- `MBeanServerPermission("newMBeanServer")` controls access to the two overloaded methods `MBeanServerFactory.newMBeanServer`. Holding this permission allows the creation of an `MBeanServer` object that is not registered in the list accessible through `MBeanServerFactory.findMBeanServer`.

- `MBeanServerPermission("releaseMBeanServer")` controls access to the method `MBeanServerFactory.releaseMBeanServer`. Holding this permission allows the removal of an `MBeanServer` object from the list accessible through `MBeanServerFactory.findMBeanServer`.
- `MBeanServerPermission("findMBeanServer")` controls access to the method `MBeanServerFactory.findMBeanServer`. Holding this permission allows you to find an `MBeanServer` object in the `MBeanServerFactory`'s list given its identifier, and to retrieve all `MBeanServer` objects in the list.

As a convenience in defining permissions, two or more of these strings can be combined in a comma-separated list. The resulting permission implies all the operations in the list. Thus, for example, holding `MBeanServerPermission("newMBeanServer,findMBeanServer")` is equivalent to holding both `MBeanServerPermission("newMBeanServer")` and `MBeanServerPermission("findMBeanServer")`.

Holding `MBeanServerPermission("*")` is equivalent to holding all the permissions in the list above.

12.1.2 MBeanPermission

`MBeanPermission` controls access to the methods of an `MBeanServer` object returned by `MBeanServerFactory.createMBeanServer` or `MBeanServerFactory.newMBeanServer`. (See Chapter 7 "MBean Server.")

An `MBeanPermission` is constructed using two string arguments. The first argument is conventionally called the *name* of the permission, but we refer to it here as the *target*. The second argument is the *actions* of the permission.

12.1.2.1 MBeanPermission Target

The target of an `MBeanPermission` groups together three pieces of information, each of which can be omitted:

- The *class name*. For a needed permission, this is the class name of an `MBean` being accessed. Certain methods do not reference a class name, in which case the class name is null.

For a held permission, this is either empty or a *class name pattern*. A class name pattern can be a literal class name such as `javax.management.MBeanServerDelegate` or a wildcard such as `javax.management.*`. If the class name is empty or is an asterisk (*), the permission covers any class name.

- The *member*. For a needed permission, this is the name of the attribute or operation being accessed. For `MBeanServer` methods that do not reference an attribute or operation, the member is null.

For a held permission, this is either the name of an attribute or operation that can be accessed, or it is empty or an asterisk (*), that covers any attribute or operation.

- The *object name*. For a needed permission, this is the `ObjectName` of the MBean being accessed. (See “`ObjectName Class`” on page 115.) For operations that do not reference a single MBean, it is null.

For a held permission, this is the `ObjectName` of the MBean or MBeans that can be accessed. It can be an object name pattern, that covers all MBeans with names matching the pattern; see “`Pattern Matching`” on page 117. It can also be empty, covering all MBeans regardless of their name.

If the domain part of the `ObjectName` in a held permission is empty, it is not replaced by a default domain, because the permission could potentially apply to several MBean servers with different domains.

A held `MBeanPermission` only implies a needed permission if all three items match.

If a needed permission has a null class name, the class name is not relevant for the action being checked, so a held permission will match regardless of its class name.

If a held permission has an empty class name, this means that the permission covers any class name, so a needed permission will match no matter what its class name is.

The same rules apply to the member and the object name.

The three items in the target are written as a single string using the syntax:

```
className#member[objectName]
```

Any of the three items can be omitted, but at least one must be present.

Any of the three items can be the character “-”, representing a null item. A null item is not the same as an empty item. An empty class name, for example, in a held permission is the same as “*” and implies any class name. A null class name in a needed permission is implied by any class name. A needed permission never has an empty class name, and usually a held permission never has a null class name.

The following are some examples of targets with their meanings:

- `com.example.Resource#Name[com.example.main:type=resource]`
This represents access to the attribute or operation called `Name` of the MBean whose object name is `com.example.main:type=resource` and whose class name is `com.example.Resource`.
- `com.example.Resource[com.example.main:type=resource]`
`com.example.Resource#[com.example.main:type=resource]`

These both mean the same thing, namely access to any attribute or operation of the MBean with this object name and class name.

- `#Name[com.example.main:type=resource]`
`*#Name[com.example.main:type=resource]`

These both mean the same thing, namely access to the attribute or operation called `Name` of the MBean with the given object name, regardless of its class name.

- `[com.example.main:type=resource]`

This represents access to the MBean with the given object name, regardless of its class name, and regardless of what attributes or operations can be referenced.

- `[com.example.main:*]`

This represents access to any MBean with an object name that has the domain `com.example.main`.

- `com.example.Resource#Name`

This represents access to the attribute or operation called `Name` in any MBean with a class name of `com.example.Resource`.

12.1.2.2 MBeanPermission Actions

The *actions* string of an `MBeanPermission` represents one or more methods from the `MBeanServer` interface. Not all methods in that interface are possible values for the *actions* string. The complete list is as follows:

- `addNotificationListener`
- `getAttribute`
- `getClassLoader`
- `getClassLoaderFor`
- `getClassLoaderRepository`
- `getMBeanInfo`
- `getObjectInstance`
- `instantiate`
- `invoke`
- `isInstanceOf`
- `queryMBeans`
- `queryNames`
- `registerMBean`
- `removeNotificationListener`
- `setAttribute`
- `unregisterMBean`

For a needed permission, the *actions* string will always contain exactly one of these strings.

For a held permission, it can contain one of these strings, or a comma-separated list of strings. Holding an MBeanPermission with *actions* "invoke, instantiate" is equivalent to holding two MBeanPermissions, one with *actions* "invoke" and the other with *actions* "instantiate", each having the same target as the original.

A held permission can also have "*" as its *actions* string, which covers all *actions*.

The meanings of the different *actions* are summarized in the table below, as well as the risks associated with granting these permissions to potentially malicious code.

TABLE 12-1 MBeanPermission actions

Action	Meaning when held with <i>className</i> , <i>member</i> , <i>objectName</i>
addNotificationListener	Add a notification listener to an MBean with a class name matching <i>className</i> and with an object name matching <i>objectName</i> . Granting this permission to malicious code could alter the behavior of notification broadcasters (see "NotificationBroadcaster and NotificationEmitter Interfaces" on page 56), by adding listeners that block forever or that throw exceptions.
getAttribute	Get the value of an attribute <i>member</i> from an MBean with a class name matching <i>className</i> and with an object name matching <i>objectName</i> .
getClassLoader	Get a class loader object with a class name matching <i>className</i> and that is registered in the MBean server with an object name that matches <i>objectName</i> . Granting this permission to malicious code could alter the behavior of the class loader. For example, if the class loader is an m-let (see "Class Loader Functionality" on page 147), malicious code could add to its list of URLs.
getClassLoaderFor	Get the class loader that was used to load an MBean object with a class name matching <i>className</i> and with an object name matching <i>objectName</i> . Granting this permission to malicious code carries similar risks to those for getClassLoader.
getClassLoaderRepository	Get a reference to the MBean server's class loader repository (see "The Class Loader Repository" on page 148). Granting this permission to malicious code allows it to load classes through these loaders, including over the network if the class loader repository contains URLClassLoaders, or something similar.
getDomains	See ObjectName domains in which MBeans are registered if they match <i>objectName</i> .
getMBeanInfo	Get the MBeanInfo of an MBean with a class name matching <i>className</i> and with an object name matching <i>objectName</i> . (See "MBean Metadata Classes" on page 60.)

TABLE 12-1 MBeanPermission actions

Action	Meaning when held with <i>className</i> , <i>member</i> , <i>objectName</i>
getObjectInstance	Get the <i>ObjectName</i> and class name of an MBean with a class name matching <i>className</i> and with an object name matching <i>objectName</i> . Holding this permission allows the discovery of the class name of any MBean, provided that its <i>ObjectName</i> and class name match <i>objectName</i> and <i>className</i> .
instantiate	Instantiate a Java class whose name matches <i>className</i> , using one of the class loader possibilities offered by the overloaded <i>instantiate</i> methods of the <i>MBeanServer</i> interface. This permission is also needed by the <i>createMBean</i> methods. Granting this permission to malicious code allows it to load classes through those loaders, including over the network if there is a <i>URLClassLoader</i> or something similar.
invoke	Invoke the method <i>member</i> from an MBean with a class name matching <i>className</i> and with an object name matching <i>objectName</i> .
isInstanceOf	Determine whether an MBean with a class name matching <i>className</i> and with an object name matching <i>objectName</i> is an instance of any named Java class.
queryMBeans	Discover the names and classes of MBeans whose class names match <i>className</i> and whose object names match <i>objectName</i> , and apply queries to them. (See “Queries” on page 135.) Holding this permission implies the corresponding <i>queryNames</i> permission.
queryNames	Discover the names of MBeans whose class names match <i>className</i> and whose object names match <i>objectName</i> .
registerMBean	Register MBeans whose class names match <i>className</i> under object names that match <i>objectName</i> . This permission is needed for the <i>registerMBean</i> and <i>createMBean</i> methods of the MBean server. Granting this permission to malicious code could allow it to register a rogue MBean in the place of a legitimate one, especially if it also has the <i>unregisterMBean</i> permission.
removeNotificationListener	Remove a notification listener from an MBean with a class name matching <i>className</i> and with an object name matching <i>objectName</i> . The impact of granting this permission is limited, because malicious code can only remove listeners it references. But the forms of <i>removeNotificationListener</i> that identify the listener with an <i>ObjectName</i> would be vulnerable to malicious code with this permission.
setAttribute	Set the value of an attribute <i>member</i> in an MBean with a class name matching <i>className</i> and with an object name matching <i>objectName</i> .
unregisterMBean	Unregister an MBean with a class name matching <i>className</i> and with an object name matching <i>objectName</i> .

12.1.2.3 Unchecked MBean Server Methods

The following MBean server methods are not subject to permission checks:

- ***isRegistered*** - Code can always discover whether an MBean with a given name exists. Without the `queryMBeans` or `queryNames` permission, however, it cannot find out the names of MBeans it does not already know about.

The reason that this operation is not subject to a permission check is that it would generate a `SecurityException` if the MBean existed but its class name was not covered by the user's permissions, while it would generate an `InstanceNotFoundException` if the MBean did not exist, regardless of what class names are covered by the user's permissions. Generating a `SecurityException` would therefore be equivalent to admitting that the MBean does indeed exist, so the permission checking would serve no purpose.

Though it is possible to refine the permission checking semantics for this case, the `isRegistered` method is not considered sufficiently sensitive to justify it.

- ***getMBeanCount*** - Code can always discover how many MBeans there are. Again, this is not considered sufficiently sensitive to justify defining a permission check for it.
- ***getDefaultDomain*** - Code can always discover the MBean server's default domain.

12.1.2.4 Permission Checking for Queries

The `queryMBeans` and `queryNames` actions for `MBeanPermission` allow control of which MBeans are visible to queries. A `queryMBeans` operation proceeds as follows:

1. The held permissions are checked to see if they imply `MBeanPermission("-#-[-]", "queryMBeans")`. If not, a `SecurityException` is thrown.

If the held permissions include *any* `queryMBeans` permission, this implies the permission shown here. The exception will only be thrown if there are no `queryMBeans` permissions in the caller's set.

Without this check, if the policy that grants permissions is accidentally configured without `queryMBeans` permissions, then all queries would return an empty set, with no indication that the reason had anything to do with security. The check described here helps avoid this confusion.

2. The `ObjectName` parameter to `queryMBeans`, that is typically an object name pattern, is used to select a set of MBeans to which the query applies. If the parameter is `null`, all MBeans are selected.

3. For each MBean in the set, an `MBeanPermission` is constructed where the *actions* parameter is `"queryMBeans"` and the target parameter contains the class name and object name of the MBean. If the held permissions do not imply this permission, the MBean is eliminated from the set.
4. For each MBean in the remaining set, the `QueryExp` parameter to `queryMBeans` is used to decide whether it is included in the final set.

The rules for the `queryNames` operation are exactly the same as just stated, but with `queryMBeans` replaced by `queryNames`.

With these rules in place, the permissions held by a thread completely govern the set of MBeans that thread can see through queries.

It is important that MBeans that are not covered by the held permissions be eliminated from the set *before* the query is executed. In other words, step 3 must happen before step 4. Otherwise, malicious code could implement the `QueryExp` interface to save each MBean in the selected set somewhere.

12.1.2.5 Permission Checking for `getDomains`

The `getDomains` permission filters the information about MBean names that is visible to a thread, in a similar fashion to `queryMBeans` and `queryNames`. The thread's held permissions should imply :

```
MBeanPermission("-#-[-]", "getDomains")
```

Otherwise, the `MBeanServer.getDomains()` method throws a `SecurityException`. Otherwise, the MBean server first gets the list of domains that would be returned if there were no security checks, and for each domain *d* in the list, it checks that the held permissions imply:

```
MBeanPermission("-#-[d:x=x]", "getDomains")
```

Otherwise, the domain is eliminated from the list.

The `x=x` is an artifact of the way `ObjectName` works. An implementation can use any other *key=value* possibility instead, but there must be one.

When defining held permissions, for instance in a security policy file, the `getDomains` permission should always either omit the `ObjectName` or supply an `ObjectName` pattern with just a `*` in the key properties, such as `"*:*"`, `"com.example.*:*"`, or `"com.example.visible:*"`.

12.1.2.6 Permission Checking for `getAttributes` and `setAttributes`

A similar scheme to the one for queries is used for the `getAttributes` and `setAttributes` operations. A `getAttributes` operation proceeds as follows:

1. The held permissions are checked to see if they imply
`MBeanPermission("className#[objectName]", "getAttribute")`
where `className` and `objectName` are the class name and object name of the MBean being accessed. If not, a `SecurityException` is thrown.

If the held permissions allow `getAttribute` on *any* attribute of the MBean, they will imply the permission shown here. Only if `getAttribute` is not allowed for any attributes in the MBean will the exception be thrown.

Without this check, if no attributes are accessible to the caller, an empty `AttributeList` would be returned, with no indication that the reason had anything to do with security.
2. For each attribute `attr` in the list given to the `getAttributes` operation, the permission
`MBeanPermission("className#attr[objectName]", "getAttribute")`
is constructed. If the held permissions do not imply this permission, the attribute is eliminated from the list.
3. The `getAttributes` operation then works on the attributes remaining in the list.

The rules for the `setAttributes` operation are exactly the same as just stated, but with `getAttribute(s)` replaced by `setAttribute(s)`.

12.1.1.3 MBeanTrustPermission

This permission represents "trust" in a signer or codesource. If a signer or codesource is granted this permission, it is considered a trusted source for MBeans. Only MBeans from trusted sources can be registered in the MBean server.

In conjunction with `MBeanPermission`, `MBeanTrustPermission` enables fine-grained control of which MBeans are registered in the MBean server. The `registerMBean` action of `MBeanPermission` controls what entities can register MBeans. `MBeanTrustPermission` controls what MBeans they can register.

An `MBeanTrustPermission` is constructed with a single string argument. In this version of the JMX specification, the argument can have two possible values:

- "register"
- "*"

Both values have the same meaning, but if in a future version of the JMX specification other possibilities are added, "*" will cover all of them.

The details of the `MBeanTrustPermission` check are illustrated in the following example.

Let `c` be the Java class of an MBean to be registered in the MBean server via its `createMBean` or `registerMBean` methods, and let `p` be a permission constructed as follows:

```
p = new MBeanTrustPermission("register");
```

Then, for the `createMBean` or `registerMBean` to succeed, the following expression must be true:

```
c.getProtectionDomain().implies(p)
```

Otherwise, a `SecurityException` is thrown.

12.2 Policy File Examples

The following are some examples of how the permissions described in the previous sections can be granted using the standard Java policy file syntax.

The simplest MBean access policy is to grant all signers and codebases access to all MBeans:

```
grant {
    permission javax.management.MBeanPermission "*", "*";
};
```

Here is a more restrictive policy that grants the code in `app11.jar` the permission to get the MBean server's class loader repository:

```
grant codeBase "file:${user.dir}${/}app11.jar" {
    permission javax.management.MBeanPermission "",
        "getClassLoaderRepository";
};
```

Here is a policy that grants the code in `app12.jar` the permission to call the `isInstanceOf` and `getObjectInstance` operations for MBeans from any class, provided they are registered in the domain `"d1"`:

```
grant codeBase "file:${user.dir}${/}app12.jar" {
    permission javax.management.MBeanPermission "[d1:*]",
        "isInstanceOf, getObjectInstance";
};
```

Here is a policy that grants the code in `app13.jar` the permission to find MBean servers, and to call the `queryNames` operation but restricting the returned set to MBeans in the domain `"JMImplementation"`:

```
grant codeBase "file:${user.dir}${/}app13.jar" {
    permission javax.management.MBeanServerPermission
        "findMBeanServer";
    permission javax.management.MBeanPermission
        "JMImplementation:*", "queryNames";
};
```

If the MBean server has MBeans with names in other domains, for example an MBean registered as `"com.example.main:type=user,name=gorey"`, they will never appear in the result of a `queryNames` executed by code in `app13.jar`.

Here is a policy that grants the code in `app14.jar` the permission to create and manipulate MBeans of class `"com.example.Foo"` under any object name:

```
grant codeBase "file:${user.dir}${/}app14.jar" {
    permission javax.management.MBeanPermission
        "com.example.Foo", "instantiate, registerMBean";
    permission javax.management.MBeanPermission
        "com.example.Foo#doIt",
        "invoke, addNotificationListener, removeNotificationListener";
};
```

The first permission ignores the object name. The operation or attribute name is not required by these two actions.

The second permission, however, uses the member part for the `"invoke"` action and ignores it for the `"add/removeNotificationListener"` actions.

Here is a policy that allows MBeans to be registered no matter where they come from. (A thread that registers MBeans must also have the appropriate MBeanPermissions.)

```
grant {  
    permission javax.management.MBeanTrustPermission "register";  
};
```

Here is a policy that only trusts MBeans signed by "Gorey":

```
grant signedBy "Gorey" {  
    permission javax.management.MBeanTrustPermission "register";  
};
```


III JMX Remote API Specification

Connectors

The JMX specification defines the notion of *connectors*. A connector is attached to a JMX API MBean server and makes it accessible to remote Java technology-based clients. The client end of a connector exports essentially the same interface as the MBean server.

A connector consists of a *connector client* and a *connector server*.

A connector server is attached to an MBean server and listens for connection requests from clients.

A connector client takes care of finding the server and establishing a connection with it. A connector client will usually be in a different Java Virtual Machine¹ (JVM™) from the connector server, and will often be running on a different machine.

A given connector server can establish many concurrent connections with different clients.

A given connector client is connected to exactly one connector server. A client application can contain many connector clients connected to different connector servers. There can be more than one connection between a given client application and a given server.

Many different implementations of connectors are possible. In particular, there are many possibilities for the protocol used to communicate over a connection between client and server. This standard defines a standard protocol based on Remote Method Invocation (RMI) that must be supported by every conformant implementation. It also defines an optional protocol based directly on TCP sockets, called the JMX Messaging Protocol (JMXMP). An implementation of this standard can omit the JMXMP connector.

1. The terms "Java virtual machine" and "JVM" mean a virtual machine for the Java platform.

13.1 Sessions and Connections

A distinction is made between a *session* and a *connection*. A connector client sees a *session*. During the lifetime of that session, there can be many successive *connections* to the connector server. In the extreme case, there might be one connection per client request, for example if the connector uses a stateless transport such as the user datagram protocol (UDP) or the Java Message Service (JMS).

A session has state on the client, notably its listeners (see Section 13.4 “Adding Remote Listeners” on page 208). A session does not necessarily have state on the server, and for the two connectors defined by this specification, it does not.

A connection does not necessarily have state on the client or server, although for the two connectors defined here it does.

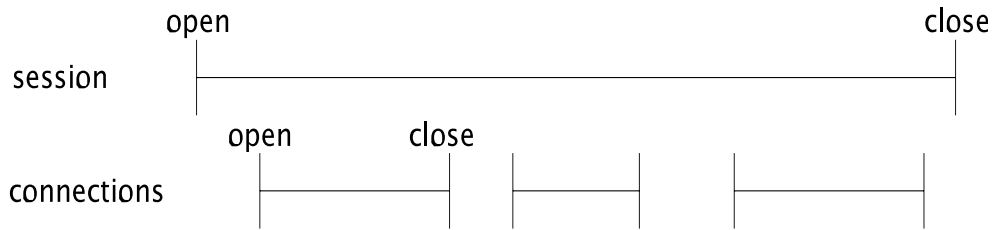


FIGURE 13-1 A Session Can Contain Many Successive Connections

In FIGURE 13-1 three connections are opened and closed over the lifetime of a single session.

13.2 Connection Establishment

In FIGURE 13-2, a connector client connects to a connector server with the address "service:jmx:jmxmp://host1:9876". A successful connection request returns the client end of the connection to the connector client.

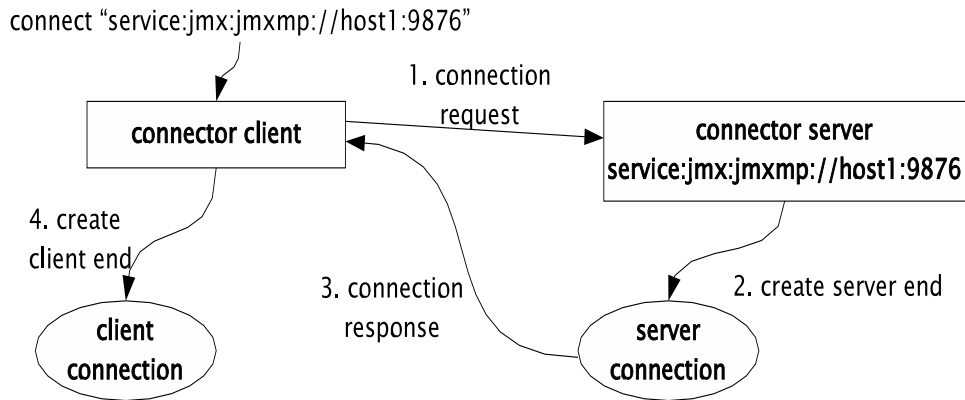


FIGURE 13-2 Connector Client and Server Communicate to Make a Connection

13.3 MBean Server Operations Through a Connection

From the client end of a connection, user code can obtain an object that implements the `MBeanServerConnection` interface. This interface is very similar to the `MBeanServer` interface that user code would use to interact with the MBean server if it were running in the same Java Virtual Machine.

`MBeanServerConnection` is the parent interface of `MBeanServer`. It contains all the same methods except for a small number of methods only appropriate for local access to the MBean server. All of the methods in `MBeanServerConnection` declare `IOException` in their "throws" clause in addition to the exceptions declared in `MBeanServer`.

Because `MBeanServer` extends `MBeanServerConnection`, client code can be written that works identically whether it is operating on a local MBean server or on a remote MBean server through a connector.

In FIGURE 13-3, the operation `getMBeanInfo("a:b=c")` on the `MBeanServerConnection` in a remote client is translated into a `getMBeanInfo` request that is sent to the server end of the connection via the connector protocol. The server reacts to this request by performing the corresponding operation on the local MBean server, and sends the results back to the client. If the operation succeeds, the client's `getMBeanInfo` call returns normally. If the operation produces an exception, the connector arranges for the client's `getMBeanInfo` call to receive the same exception. If there is a problem in the communication of the request, the client's `getMBeanInfo` call will get an `IOException`.

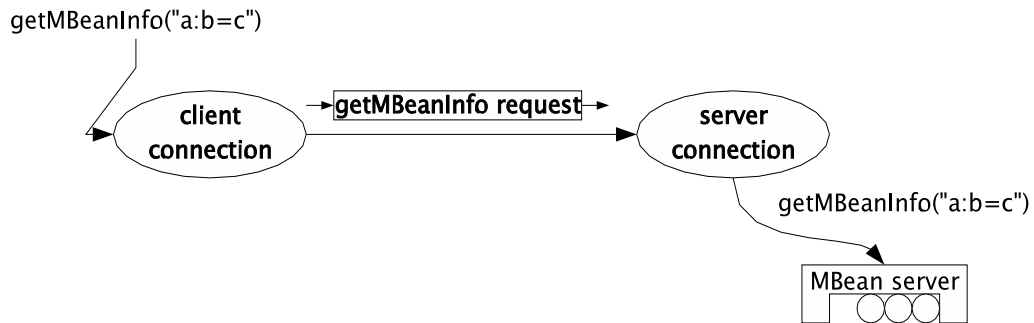


FIGURE 13-3 An Operation on the Client Results in the Same Operation on the MBean Server

13.4 Adding Remote Listeners

One of the operations in the `MBeanServerConnection` interface is the `addNotificationListener` operation. As in the local case, this operation registers a *listener* for the notifications emitted by a named MBean. A connector will arrange for the notifications to be sent from the server end of a connection to the client end, and from there to the listener.

The details of how notifications are sent depend on the connector protocol. The two connectors defined in this specification use a *stateless notification buffer*, as described in Section 13.4.3 “Notification Buffer” on page 210.

13.4.1 Filters and Handbacks

The `addNotificationListener` method in the `MBeanServerConnection` interface has four parameters: the *object name*, the *listener*, the *filter*, and the *handback*. The object name specifies which MBean to add the listener to. The listener is the object whose `handleNotification` method will be called when a notification is emitted by the MBean. As described in Section 13.4 “Adding Remote Listeners” on page 208, this listener object is local to the client.

The optional *filter* selects which notifications this listener is interested in. A given connector can execute the filter when the notification arrives at the client, or it can transmit the filter to the server to be executed there. Executing the filter on the server is much more efficient because it avoids sending a notification over the network only to have it discarded on arrival. Filters should be designed so that they

work whether they are run on the client or on the server. In particular, a filter should be an instance of a serializable class known to the server. Section 13.11 “Class Loading” on page 218, describes class loading in more detail.

The connectors defined by this standard execute filters on the server.

To force filtering to be done on the client, the filtering logic can be moved to the listener.

The optional *handback* parameter to `addNotificationListener` is an arbitrary object that will be given to the listener when the notification arrives. This allows the same listener object to be registered with several MBeans. The handback can be used to determine the appropriate context when a notification arrives. The handback object remains on the client - it is not transmitted to the server and does not have to be serializable.

The `MBeanServerConnection` interface also has an `addNotificationListener` variant that specifies the listener as an `ObjectName`, the name of another MBean that is to receive notifications. With this variant, both the filter and the handback are sent to the remote server.

13.4.2 Removing Listeners

In general, a listener that has been added with the following method is uniquely identified for a given *name* by the triple (*listener,filter,handback*):

```
addNotificationListener(ObjectName name,
                        NotificationListener listener,
                        NotificationFilter filter,
                        Object handback)
```

It can subsequently be removed either with the two-parameter `removeNotificationListener`, specifying just *listener*, or with the four-parameter `removeNotificationListener` that has the same parameters.

A problem arises with the four-parameter method in the remote case. The filter object that is deserialized in the `removeNotificationListener` method is not generally identical to the filter object that was deserialized for `addNotificationListener`. Since notification broadcaster MBeans usually check for equality in the (*listener,filter,handback*) triple using identity rather than the `equals` method, it would not in general be possible to remove just one (*listener,filter,handback*) triple remotely.

The standard connectors avoid this problem by using *listener identifiers*. When a connector client adds a (*listener,filter,handback*) triple to an MBean, the connector server returns a unique identifier for that triple on that MBean. When the connector client subsequently wants to remove the triple, it uses the identifier rather than passing the triple itself. To implement the two-parameter

`removeNotificationListener` form, the connector client looks up all the triples that had the same listener and sends a `removeNotificationListener` request with the listener identifier of each one.

This technique has the side-effect that a remote client can remove a triple even from an MBean that implements `NotificationBroadcaster` but not `NotificationEmitter`. A local client of the `MBeanServer` interface cannot do this.

13.4.3 Notification Buffer

The two connectors defined by this specification handle notifications and listeners as follows. Every connector server has a *notification buffer*. Conceptually, this is a list of every notification ever emitted by any MBean in the MBean server that the connector server is attached to. In practice, the list is of finite size, so when necessary the oldest notifications are discarded.

Entries in the notification buffer consist of a `Notification` object and an `ObjectName`. The `ObjectName` is the name of the MBean that emitted the notification.

For every MBean that can send notifications (implements the `NotificationBroadcaster` interface), the connector server registers a listener that adds each notification to the notification buffer. The connector server tracks the creation of MBeans, and when a new `NotificationBroadcaster` MBean is created, the listener is added to it.

Entries in the notification buffer have sequence numbers. Sequence numbers are positive. A later notification always has a greater sequence number than an earlier one. Sequence numbers are not necessarily contiguous, but the notification buffer always knows what the next sequence number will be.

FIGURE 13-4 shows a connector server with its notification buffer. The notification buffer has saved four notifications, with sequence numbers 40 to 43. The next notification will have sequence number 44.

The client state of a session includes the sequence number of the next notification that the client has not yet seen. In FIGURE 13-4, the client of session 1 has not yet seen the notifications starting with number 41. The client of session 2 has seen all notifications, so the next notification it will see will have the next available sequence number, 44.

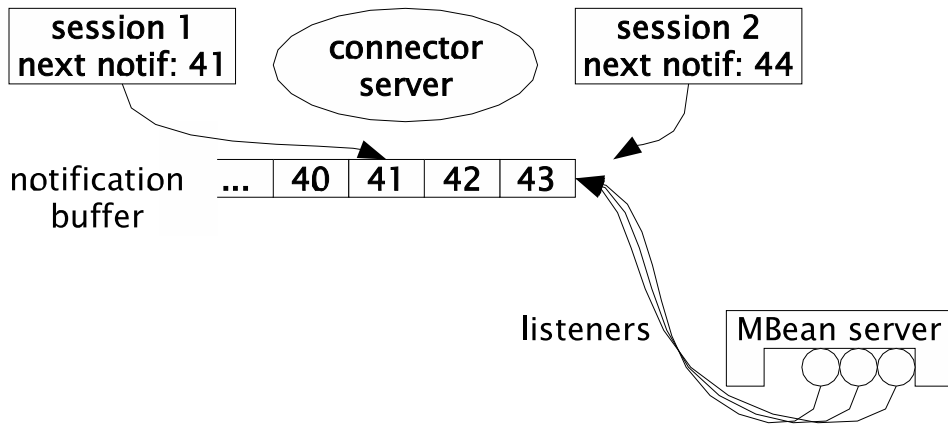


FIGURE 13-4 Notification Buffer Saves Notifications From All MBeans

When a new session is created, the client asks for the next sequence number that will be used. It is only interested in notifications with that number or greater, not the arbitrarily old notifications that are already present.

A notification buffer has no state related to the connector server. So an implementation can use the same notification buffer for more than one connector server.

13.4.4 Getting Notifications From the Notification Buffer

Conceptually, a connector client receives notifications by sending a *fetch-notifications* request to the connector server. The request looks like this:

“Give me the notifications starting with sequence number *s* that match my filters.”

Here, *s* is the next sequence number the client expects to see. In FIGURE 13-4, *s* is 41 for session 1 and 44 for session 2.

“My filters” means the `ObjectName` and `NotificationFilter` values for every `addNotificationListener` operation that has been done on the connector client. This filter list is either sent with every *fetch-notifications* request, or it is maintained as part of the state of a connection. The latter approach is followed in the two protocols defined by this specification, because the filter list is potentially very big.

The *fetch-notifications* request will wait until one of the following conditions is met:

- There is at least one notification in the buffer that matches the client's criteria, namely that has a sequence number at least s and matches the client's filters.
- A timeout specified by the client is reached.
- The connector server decides to terminate the operation, typically because of a timeout of its own.

The result of the *fetch-notifications* call includes the following information:

- Zero or more notifications that matched the client's criteria. The result does not have to include all available notifications. It may be limited to a maximum number, for example. But if there are notifications, they will be the earliest available ones.
- A sequence number n that is the number the client should use in its next *fetch-notifications* call. This is the sequence number of the first notification that matched the caller's criteria but was not included in the result, or it is the next available sequence number if all matched notifications were included.
- A sequence number f that is the smallest sequence number of a notification still in the buffer. If $f > s$, it is possible that notifications the client was interested in have been lost. It is not certain, however, because the notifications between s and f might not have matched the caller's filters.

This information is encapsulated in the `NotificationResult` class from the API.

As an example, suppose that in FIGURE 13-4 the notifications 41 and 43 match the filters for session 1. Its *fetch-notifications* call will have $s = 41$ and can return immediately with notifications 41 and 43, $n = 44$, and $f = 40$. No notifications have been lost ($f \leq s$) and the next *fetch-notifications* will have $s = 44$.

13.5 Concurrency

A JMX Remote API connector must support concurrent requests. If a thread calls a potentially slow operation like `invoke` on the client end of a connector, another thread should not be forced to wait for that operation to complete before performing an operation.

13.6 Normal Termination

Either end of a session can terminate the session at any time.

If the client terminates a session, the server will clean up any state relative to that client. If there are client operations in progress when the client terminates the session, then the threads that invoked them will receive an `IOException`.

If the server terminates a session, the client will get an `IOException` for any remote operations that were in progress and any remote operations subsequently attempted.

It is not specified what happens to MBean server operations that are running when the remote session that caused them is closed. Typically, they will run to completion, since in general there is no reliable way to stop them.

13.7 Abnormal Termination

The client end of a session can detect that the server end has terminated abnormally. This might happen for example because the JVM software that the server was running in exited, or because the machine it was running on crashed. The connector protocol (or its underlying transport) might also determine that the server is unreachable, because communication to it has not succeeded for a certain period of time. This can happen if there is a physical or configuration problem with the network.

In all of these cases, the client can terminate the session. The behavior seen by code using the client should be the same as if the server had terminated the session normally, except that the details of the exception seen by the client might differ.

Similarly, the server end of a session, or a connection within a session, can detect that the client end has terminated abnormally or become unreachable. It should behave as if the client had terminated the connection normally, except that the notification of connection termination indicates a failure.

13.7.1 Detecting Abnormal Termination

Transport protocols such as TCP usually have built-in detection of abnormal termination. When a Java Virtual Machine exits, any TCP connections it had are explicitly closed by the TCP protocol, meaning that the other end of the connection is informed promptly that the connection has been closed. But when a machine crashes or the network connection fails, this is detected less promptly. For example, TCP will only notice that a connection is broken if an attempt is made to write on it, and even then it will typically only signal the problem after a timeout on the order of minutes. Connectors should close connections that receive errors, but an additional mechanism is needed if connections are mostly idle or if the time to detect a failed connection is too long.

For the two connectors defined by this specification, an implementation is not required to detect failure promptly. However, the following approach is recommended:

1. A *fetch-notifications* call from the client should be terminated with zero notifications if none arrive within a certain period.

2. A connector server should close a connection that has not received any client requests (including *fetch-notifications*) for a certain time.
3. A client should specify a timeout in each *fetch-notifications* call. If the call does not return after the timeout (plus some margin for delays) then the client should close the connection.

This approach is based on the assumption that a client will always do a new *fetch-notifications* call shortly after the previous one returns. So case 2 never happens for a working connection.

If a session has no listeners, there is no need for it to do a *fetch-notifications* call. In this case, a server that follows the approach detailed here will close idle connections. The client will re-open the connection the next time it needs to do an operation on it.

13.8 Connector Server Addresses

A connector server usually has an address, which clients can use to establish connections to the connector server. Some connectors can provide alternative ways to establish connections, such as through connection *stubs* (see Section 13.9.2 “Connection Stubs” on page 215).

When a connector server has an address, this address is usually described by the class `JMXServiceURL`. The API documentation for that class and for the standard connectors explains the semantics of these addresses.

A user-defined connector can choose to use another address format, but it is recommended to use `JMXServiceURL` where possible.

An example of a connector server address is shown below:

```
service:jmx:jmxmp://host1:9876
```

All `JMXServiceURL` addresses begin with “`service:jmx:`”. The following `jmxmp` indicates the connector to use, in this case the JMXMP Connector (see Chapter 15 “Generic Connector”). `host1` and `9876` are respectively the host and the port on which the connector server is listening.

13.9 Creating a Connector Client

A connector client is represented by an object that implements the `JMXConnector` interface. There are two ways in which a connector client can be created:

- Using an address, as covered in Section 13.9.1 “`JMXConnectorFactory`” on page 215
- Using a connection stub, as covered in Section 13.9.2 “Connection Stubs” on page 215

Which way an application uses depends mainly on the infrastructure that is used to find the connector server to which the client wants to connect.

13.9.1 JMXConnectorFactory

If the client has the address (`JMXServiceURL`) of the connector server to which it wants to connect, it can use the `JMXConnectorFactory` to make the connection. This is the usual technique when the client has found the server through a text-based discovery or directory service such as SLP.

For example, an application *app1* that includes an MBean server might export that server to remote managers as follows:

1. Create a connector server `cServer`
2. Get `cServer`'s address `addr`, either by using the `JMXServiceURL` that was supplied to its constructor to tell it what address to use, or by calling `cServer.getAddress()`
3. Put the address somewhere the management applications can find it, for example in a directory or in an SLP service agent

A manager can start managing *app1* as follows:

1. Retrieve *addr* from where it was stored in step 3 above
2. Call `JMXConnectorFactory.connect(addr)`

13.9.2 Connection Stubs

An alternative way for a client to connect to a server is to obtain a *connector stub*. A connector stub is a `JMXConnector` object generated by a connector server. It is serializable so that it can be transmitted to a remote client. A client that retrieves a connector stub can then call the stub's `connect` method to connect to the connector server that generated it.

For example, an application *app1* that includes an MBean server might export that server to remote managers as follows:

1. Create a connector server `cServer`
2. Obtain a connector stub `cStub` by calling `cServer.toJMXConnector`
3. Put the stub somewhere the management applications can find it, for example in a directory, in the JiniTM lookup service, or in an HTTP server

A manager can start managing *app1* as follows:

1. Retrieve `cStub` from where it was stored in step 3 above
2. Call `cStub.connect` to connect to the remote MBean server through `cServer`

In some circumstances, a connector server might not have all the information needed to generate a connector stub that any client can use. The details of connection might depend on the client's environment. In such cases, the connector stub would need to be generated by a third party, for example by administrative tools that know the relevant details of the client and server environments.

13.9.3 Finding a Server

Chapter 17 “Bindings to Lookup Services”, defines how an agent based on JMX technology can register its connector servers with existing lookup and discovery infrastructures, so that a JMX Remote API client can create or obtain a `JMXConnector` object to connect to the advertised servers. In particular, that chapter provides the following information:

- Section 17.3 “Using the Service Location Protocol” on page 254, describes how a client can retrieve a JMX service URL from SLP, and use it to connect to the corresponding server
- Section 17.4 “Using the Jini Network Technology” on page 258, describes how a client can retrieve a connector stub from the Jini lookup service (LUS) and connect to the corresponding server
- Section 17.5 “Using the Java Naming and Directory Interface (LDAP Backend)” on page 264, describes how a client can retrieve a JMX service URL from the Lightweight Directory Access Protocol (LDAP) directory, and use it to connect to the corresponding server

13.10 Creating a Connector Server

A connector server is represented by an object of a subclass of `JMXConnectorServer`. The usual way to create a connector server is through the `JMXConnectorServerFactory`. Using a `JMXServiceURL` provided as a parameter, the factory determines what class to instantiate, in a way similar to the `JMXConnectorFactory` described in Section 13.9.1 “`JMXConnectorFactory`” on page 215.

A connector server can also be created by instantiating a subclass of `JMXConnectorServer` explicitly.

To be useful, a connector server must be attached to an MBean server, and it must be *active*.

A connector server can be attached to an MBean server in one of two ways. Either the MBean server to which it is attached is specified when the connector server is constructed, or the connector server is registered as an MBean in the MBean server to which it is attached.

A connector server does not have to be registered in an MBean server. It is even possible, though unusual, for a connector server to be registered in an MBean server different from the one to which it is attached.

CODE EXAMPLE 13-1 shows how to create a connector server that listens on an unspecified port on the local host. It is attached to the MBean server `mbs` but not registered in it:

CODE EXAMPLE 13-1 Creating a Connector Server attached to an MBean Server

```
MBeanServer mbs = MBeanServerFactory.createMBeanServer();
JMXServiceURL addr = new JMXServiceURL("jmxmp", null, 0);
JMXConnectorServer cs =
    JMXConnectorServerFactory.newJMXConnectorServer(addr, null, mbs);
cs.start();
```

The address that the connector server is actually listening on, including the port number that was allocated, can be obtained by calling `cs.getAddress()`.

CODE EXAMPLE 13-2 shows how to do the same thing but with a connector server that is registered as an MBean in the MBean server to which it is attached:

CODE EXAMPLE 13-2 Creating a Connector Server Registered in an MBean Server

```
MBeanServer mbs = MBeanServerFactory.createMBeanServer();
JMXServiceURL addr = new JMXServiceURL("jmxmp", null, 0);
JMXConnectorServer cs =
    JMXConnectorServerFactory.newJMXConnectorServer(addr, null, null);
ObjectName csName = new ObjectName(":type=cserver,name=mycserver");
mbs.registerMBean(cs, csName);
cs.start();
```

13.10.1 Publishing a Server

Chapter 17 “Bindings to Lookup Services” defines how an agent can publish its connector servers with existing lookup and discovery infrastructures, so that a JMX Remote API client that does not know about such a server can find it and connect to it. In particular, that section provides the following information:

- Section 17.3 “Using the Service Location Protocol” on page 254, describes how an agent registers the JMX service URL of a connector server with SLP, so that a JMX Remote API client can retrieve it and use it to connect to the server
- Section 17.4 “Using the Jini Network Technology” on page 258, describes how an agent registers the connector stub of a connector server with the Jini lookup service, so that a JMX Remote API client can retrieve this stub and connect to the server
- Section 17.5 “Using the Java Naming and Directory Interface (LDAP Backend)” on page 264, describes how an agent registers the JMX Service URL of a connector server in an LDAP directory, so that a JMX Remote API client can retrieve this URL and use it to connect to the server.

13.11 Class Loading

Every non-primitive Java object has a class, and every class has a class loader. A subtle pitfall of class loading is that the class `a.b.C` created by the class loader `cl1` is not the same as the class `a.b.C` created by the class loader `cl2`. Here, “created” refers to the class loader that actually creates the class with its `defineClass` method. If `cl1` and `cl2` both find `a.b.C` by delegating to another class loader `cl3`, it is the same class.

A value of type “`a.b.C` created by `cl1`” cannot be assigned to a variable or parameter of type “`a.b.C` created by `cl2`”. An attempt to do so will result in an exception such as `ClassCastException`.

When one end of a connection receives a serialized object from the other end, it is important that the object be deserialized with the right class loader. This section explains the rules for determining the class loader to use in every case.

These rules for class loading are needed when the types of attributes, or of operation parameters and return values, are application-specific Java types. To avoid having to deal with these rules, it is a good idea to use only standard types defined by the Java platform or by the JMX and JMX Remote APIs. The types defined for *Open MBeans* in the JMX API allow arbitrarily complex data structures to be described without requiring application-specific types. An important side-effect is that interoperation with non-Java clients is greatly simplified.

These rules are also needed when application-specific notification filters are applied. (See Section 13.4.1 “Filters and Handbacks” on page 208.) To avoid having to manage class-loading rules, consider using only the three standard notification filter types from the JMX API, `NotificationFilterSupport`, `MBeanServerNotificationFilter`, and `AttributeChangeNotificationFilter`. An alternative is to filter in the client’s listener, though this can increase network traffic with notifications that are discarded as soon as they are received.

13.11.1 Class Loading on the Client End

A connector client can specify a *default class loader* when making a connection to a server. This class loader is used when deserializing objects received from the server, whether they are returned values from `MBeanServerConnection` methods, exceptions thrown by those methods, or notifications emitted by MBeans to which the client is listening.

The default class loader is the value of the attribute `jmx.remote.default.class.loader` from the `JMXConnector` environment. The `JMXConnector` first looks for this attribute in the environment `Map` that was supplied when the `JMXConnector` was connected. If there was none, or the attribute is not found, it then looks in the environment `Map` that was supplied at creation time. If there was none, or the attribute is not found, then the default class loader is the context class loader (`Thread.currentThread().getContextClassLoader()`) that was in place when the `JMXConnector` was connected. It is not specified what happens if the default class loader determined by these rules is null.

If the value of the `jmx.remote.default.class.loader` attribute is not a class loader, then the attempt to connect the `JMXConnector` gets an `IllegalArgumentException`.

Note – serialization: When a `JMXConnector` is serialized, the environment `Map` that was supplied when the `JMXConnector` was created is lost: the `Map` is not serialized because it is expected to contain objects, like class loaders, which are not serializable. As a consequence, when a specific default class loader is required for a `JMXConnector`, it is recommended always to specify it in the `Map` supplied when connecting.

13.11.2 Class Loading on the Server End

The class loader to be used when deserializing parameters received from the client depends on the operation. Sometimes the appropriate class loader is the one that belongs to the target MBean, because that MBean might have parameter types that

are not defined by the JMX API or the JMX Remote API. Sometimes the appropriate class loader is one configured during the creation of the connector server, because the connector server is intended to be used with a particular management application. Such an application might define its own subclasses of `MBean` parameter types, or it might define its own `NotificationFilter` classes for listeners. An MBean being managed cannot be expected to anticipate every notification filter that a management application might want to use, so it does not make sense to use only the MBean's class loader to deserialize notification filters with listeners being added to the MBean.

Like a connector client, a connector server has a *default class loader* that is determined when the connector server is started. The default class loader is determined as follows:

- If the connector server's environment map contains the attribute `jmx.remote.default.class.loader`, the value of that attribute is the default class loader
- If the environment map contains the attribute `jmx.remote.default.class.loader.name`, the value of that attribute is the `ObjectName` of an MBean that is the default class loader. This allows a connector server to be created with a class loader that is a management applet (m-let) in the same MBean server
- If neither of the above attributes is defined, the default class loader is the thread's context class loader at the time when the `JMXConnectorServer` was started

If both `jmx.remote.default.class.loader` and `jmx.remote.default.class.loader.name` are defined, or if the value of `jmx.remote.default.class.loader` is not a `ClassLoader`, or if the value of `jmx.remote.default.class.loader.name` is not an `ObjectName` that names a `ClassLoader`, the attempt to start the connector server gets an `IllegalArgumentException`.

For certain operations that interact with a single "target" MBean, *M*, objects are deserialized using *M*'s *extended class loader*. This is a class loader that loads each class *X*, as follows:

1. The class loader that loaded or is loading *M* is asked to load *X*
2. If that fails with a `ClassNotFoundException`, the default class loader is asked to load *X*
3. If step 1 fails with an exception other than `ClassNotFoundException`, or if step 2 fails with any exception, that exception is the result of loading *X*

The rules for deserialization of `MBeanServerConnection` operations are as follows:

- The parameters to `setAttribute`, and `setAttributes` are deserialized using the target MBean's extended class loader

- The `Object` array in `invoke` is deserialized using the target MBean's extended class loader
- The `Object` array in the `createMBean` forms that have one is deserialized using the target MBean's extended class loader. Here, "the class loader that loaded or is loading *M*" is the class loader described in the API documentation for the particular `createMBean` form. In the case of the form that uses the Class Loader Repository, it is a class loader that always delegates to that repository
- The `QueryExp` in the `queryNames` and `queryMBeans` operations is deserialized using the default class loader
- The `NotificationFilter` and the `Object` handback in the `addNotificationListener` and `removeNotificationListener` operations (all forms) are deserialized using the target (notification broadcaster) MBean's extended class loader

Remaining parameters are of type `String` (which is a final class known to the bootstrap class loader), `String[]`, or `ObjectName`.

If a user-defined subclass of `ObjectName` is sent from client to server, it is not specified how it is deserialized, so this is not guaranteed to work in general.

13.12 Connector Server Security

Connector servers typically have some way of authenticating remote clients. For the RMI connector, this is done by supplying an object that implements the `JMXAuthenticator` interface when the connector server is created. For the JMXMP connector, this is done using SASL.

In both cases, the result of authentication is a JAAS `Subject` representing the authenticated identity. Requests received from the client are executed using this identity. With JAAS, you can define what permissions the identity has. In particular, you can control access to MBean server operations using the `MBeanPermission` class. For this to work, though, you must have a `SecurityManager`.

If a connector server does not support authentication or is not set up with authentication, then client requests are executed using the same identity that created the connector server.

As an alternative to JAAS, you can control access to MBean server operations by using an `MBeanServerForwarder`. This is an object that implements the `MBeanServer` interface by forwarding its methods to another `MBeanServer` object, possibly performing additional work before or after forwarding. In particular, the object can do arbitrary access checks. You can insert an `MBeanServerForwarder` between a connector server and its MBean server using the method `setMBeanServerForwarder`.

13.12.1 Subject Delegation

Any given connection to a connector server has at most one authenticated `Subject`. This means that if a client performs operations as or on behalf of several different identities, it must establish a separate connection for each one.

However, the two standard connectors also support the notion of *subject delegation*. A single connection is established between client and server using an authenticated identity, as usual. With each request, the client specifies a per-request `Subject`. The request is executed using this per-request identity, provided that the authenticated per-connection identity has permission to do so. That permission is specified with the permission `SubjectDelegationPermission`.

For each delegated `Subject`, the client obtains an `MBeanServerConnection` from the `JMXConnector` for the authenticated `Subject`. Requests using this `MBeanServerConnection` are sent with the delegated `Subject`. `MBeanServerConnection` objects for any number of delegated identities can be obtained from the same `JMXConnector` and used simultaneously.

13.12.2 Access Control Context

`MBean Server` operations on behalf of a remote client are executed in an access control context (see `java.security.AccessControlContext`) where checked permissions must be held both by the authenticated `Subject` (or delegated `Subject`) *and* by the `Subject` that created the connector server. Without the latter check, an entity that had permissions to create a connector server but not some other permissions might be able to obtain those other permissions by creating a connector server and sending requests to it.

If the `Subject` that created the connector server has a `SubjectDelegationPermission` for every `Principal` in the authenticated (or delegated) `Subject`, then its permissions are not checked for `MBean Server` operations. This means that there are two ways to configure the permissions of the connector server creator. Either it must have all the permissions that any remote client will need for its operations; or it must have a `SubjectDelegationPermission` for every `Principal` that a remote client will authenticate or delegate.

Suppose a security context (subject and/or codebase and/or code signers), say *creator*, makes a `JMXConnectorServer`. Later, a connection arrives and is authenticated with the `Principal` *remote*. An `MBeanServer.getAttribute` operation is performed over the connection, and needs to access a file. This means that the permissions being checked are `MBeanPermission` and `FilePermission`. The operation will succeed if either of the following conditions is true:

- both *remote* and *creator* have the `MBeanPermission` and the `FilePermission`, or
- *remote* has the `MBeanPermission` and the `FilePermission`, and *creator* has `SubjectDelegationPermission(remote)`.

A policy file for the second case might look like this:

```
grant codebase "file:/agent.jar" {
    permission javax.management.remote.SubjectDelegationPermission
        "javax.management.remote.JMXPrincipal.remote";
}

grant principal javax.management.remote.JMXPrincipal "remote" {
    permission javax.management.MBeanPermission "Stats", "getAttribute";
    permission java.io.FilePermission "stats.txt", "read";
}
```


RMI Connector

The RMI connector is the only connector that must be present in all implementations of this specification. It uses the RMI infrastructure to communicate between client and server.

14.1 RMI Transports

RMI defines two standard transports, the Java Remote Method Protocol (JRMP) and the Internet Inter-ORB Protocol (IIOP).

JRMP is the default transport. This is the transport you get if you use only the `java.rmi.*` classes from the Java 2 Platform Standard Edition (the J2SE™ platform).

IIOP is a protocol defined by CORBA. Using RMI over IIOP allows for interoperability with other programming languages. It is covered by the `javax.rmi.*` and `org.omg.*` classes from the J2SE platform.

RMI over these two transports is referred to as RMI/JRMP and RMI/IIOP.

The RMI connector supports both transports. Refer to the API documentation (in particular the description of the `javax.management.remote.rmi` package) for details.

14.2 Mechanics of the RMI Connector

For every RMI connector server, there is a remotely-exported object that implements the remote interface `RMIServer`. A client that wants to communicate with the connector server needs to obtain a remote reference, or *stub*, that is connected to this remote object (how the stub can be obtained is described in Section 14.3 “How to Connect to an RMI Connector Server” on page 229). RMI arranges that any method

called on the stub is forwarded to the remote object. So, a client that has a stub for the `RMIServer` object can call a method on it, resulting in the same method being called in the server's object.

FIGURE 14-1 shows two clients that both have stubs for the same server object. The server object is labeled *impl* because it is the object that implements the functionality of the `RMIServer` interface.

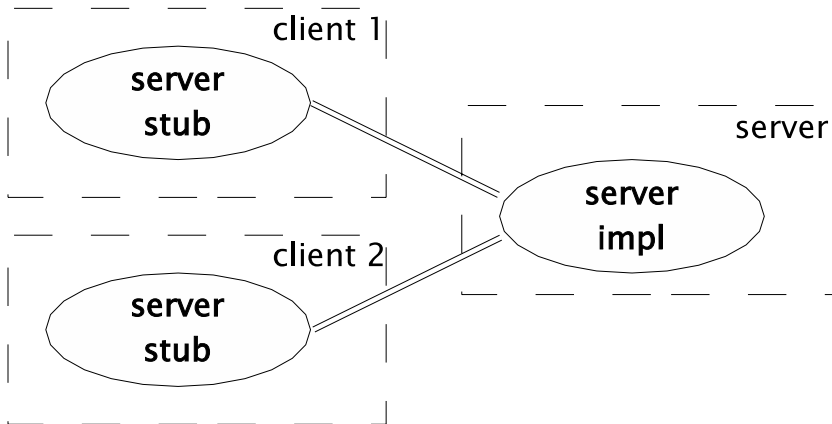
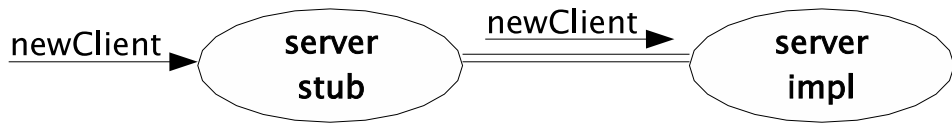
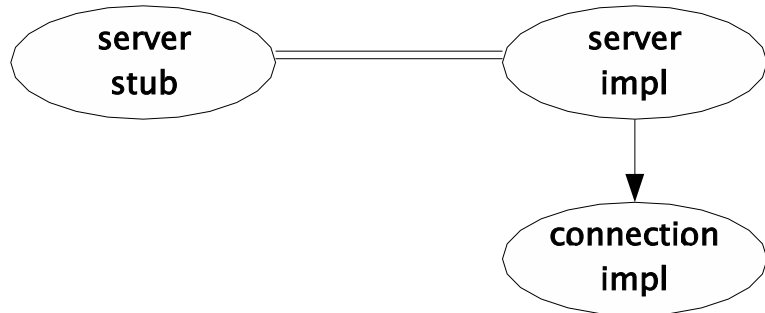


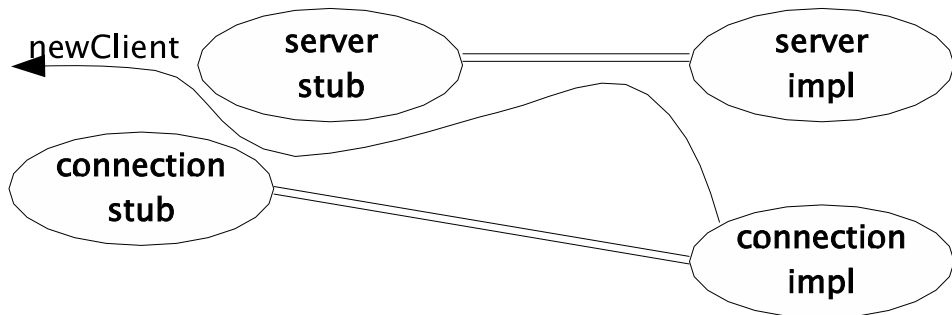
FIGURE 14-1 Several Clients can Have Stubs Connected to the Same Server Object



1. client calls newClient method on server stub



2. server creates new RMI connection object



3. stub for new object is result of newClient method

FIGURE 14-2 A New Client Connection Is a New Remote Object on the Server

In addition to the remote object representing the connector server, there is one remote object for every client connection made through the connector to the MBean server. When a client wants to invoke methods on the remote MBean server, it invokes the `newClient` method in its server stub. This causes the `newClient` method in the remote server object to be invoked. This method creates a new remote object that implements the remote interface `RMIClientConnection`, as shown in FIGURE 14-2. This interface contains all the remotely-accessible methods of the MBean

server. The value returned from the client's `newClient` method is a stub that is connected to this new object. When the client calls an MBean server method such as `getAttribute`, this produces a call to the corresponding method in the `RMIConnection` stub, and hence a remote call to the corresponding implementation object in the server.

14.2.1 Wrapping the RMI Objects

User code does not usually interact directly with the `RMIserver` and `RMIConnection` objects.

On the server side, the `RMIserver` object is created and exported by an `RMIConnectorServer`. `RMIConnectorServer` is a subclass of `JMXConnectorServer`, and as such is a connector server for the purposes of this standard. `RMIConnection` objects are created internally by the `RMIserver` implementation, but user code in the server never sees them.

On the client side, an `RMIserver` stub can be obtained explicitly, as described in Section 14.3 “How to Connect to an RMI Connector Server” on page 229. More usually, it is obtained as part of the process of looking up a URL for the RMI connector, but is wrapped in an `RMIConnector` object. User code usually only deals with this `RMIConnector` object. `RMIConnector` implements the `JMXConnector` interface and it is through this interface that it is usually accessed.

In normal use, user code never invokes any methods from `RMIserver`, and never sees any objects of type `RMIConnection`. These objects are hidden by the `RMIConnector` class.

14.2.2 RMIConnection

The `RMIConnection` interface is similar to the `MBeanServerConnection` interface defined by the JMX specification, but has some important differences:

- Parameters that are subject to the class loading rules detailed in Section 13.11 “Class Loading” on page 218 are wrapped inside a `MarshaledObject` so that they can be unwrapped by the server after it has determined the appropriate class loader to use
- The `addNotificationListeners` and `removeNotificationListener` methods use listener IDs instead of listeners, as detailed in Section 13.4 “Adding Remote Listeners” on page 208
- There are additional methods to get the connection ID and to close the connection
- There is an additional method to obtain outstanding notifications

The `RMICConnection` object represents a *connection*, not a *session*, in the terminology of Section 13.1 “Sessions and Connections” on page 206. Either end of the connection can close it at any time without affecting the session. The server closes the connection by unexporting the `RMICConnection` object. Ongoing RMI calls on the object run to completion and return normally, but new calls will fail. When the client sees such a failure, it will obtain a new `RMICConnection` object as described in Section 14.2 “Mechanics of the RMI Connector” on page 225.

14.2.3 Notifications

The RMI connector uses the techniques described in Section 13.4 “Adding Remote Listeners” on page 208. The connector server has a stateless notification buffer (Section 13.4.3 on page 210). If the connector client has listeners, it uses the `fetchNotifications` call on the `RMICConnection` object to receive notifications for them.

The list of `(ObjectName,NotificationFilter)` pairs corresponding to the client’s listeners is not passed in every call to `fetchNotifications`. Rather, it is established with a single `addNotificationListeners` call when the `RMICConnection` object is created. Changes to the notification list while the connection is open are made with further calls to `addNotificationListeners` and to `removeNotificationListener`.

14.3 How to Connect to an RMI Connector Server

Broadly, there are three ways to connect to an RMI connector server:

1. Supply a `JMXServiceURL` to the `JMXConnectorFactory` that specifies the `rmi` or `iiop` protocol. This is the most usual way to connect. The `JMXServiceURL` either contains the stub in an encoded form, or indicates a directory entry in which an `RMIServer` stub can be found. This is further described in the API specification of the `javax.management.remote.rmi` package. The details of looking up this directory entry and creating a `JMXConnector` from it are hidden from the caller
2. Obtain a `JMXConnector` stub from somewhere, for example a directory such as LDAP, the Jini Lookup Service, or as the returned value of an RMI method call. This stub is an object generated by `RMICConnectorServer.toJMXConnector`. It is an object of type `JMXConnector`. It is not an RMI stub and should not be confused with the RMI stubs of type `RMIServer` or `RMICConnection`. However, it references an `RMIServer` stub which it uses when its `connect` method is called

3. Obtain an `RMIserver` stub from somewhere and use it as a parameter to the constructor of `RMIConnector`

14.4 Basic Security With the RMI Connector

The RMI connector provides a simple mechanism for securing and authenticating the connection between a client and a server. This mechanism is not intended to address every possible security configuration, but provides a basic level of security for environments using the RMI connector. More advanced security requirements are better addressed by the JMXMP connector (see Section 15.3.3 “Security Features in the JMXMP Connector” on page 241).

To make an RMI connector server secure, the environment supplied at its creation must contain the property `jmx.remote.authenticator`, whose associated value is an object that implements the interface `JMXAuthenticator`. This object is responsible for examining the authentication information supplied by the client and either deriving a JAAS Subject representing the client, or rejecting the connection request with a `SecurityException`.

A client connecting to a server that has an `JMXAuthenticator` must supply the authentication information that the `JMXAuthenticator` will examine. The environment supplied to the connect operation must include the property `jmx.remote.credentials`, whose associated value is the authentication information. This object must be serializable.

This specification does not include any predefined authentication system. The simplest example of such a system is a secret string shared between client and server. The client supplies this string as its `jmx.remote.credentials`, and the server’s `JMXAuthenticator` checks that it has the correct value.

As a slightly more complicated example, the authentication information could be a `String[2]` that includes a username and a password. The `JMXAuthenticator` verifies these, for example by consulting a password file or by logging in through some system-dependent mechanism, and if successful derives a `Subject` based on the given username.

14.4.1 How Security Affects the RMI Connector Protocol

The authentication information supplied by the client is passed as an argument to the `newClient` call (see FIGURE 14-2). The connector server gives it to the `JMXAuthenticator`. If the `JMXAuthenticator` throws an exception, that exception is propagated to the client. If the `JMXAuthenticator` succeeds, it returns a `Subject`, and that `Subject` is passed as a parameter to the constructor of the new

`RMICConnection` object. All of the MBean server methods in `RMICConnection` perform privileged work as this particular `Subject`, so that they have the permissions appropriate to the authenticated client.

14.4.2 Achieving Real Security

The solution outlined above is enough to provide a basic level of security. A number of problems have to be addressed to achieve a real level of security, however:

1. If the authentication information includes a password, and if the network is not secure, then attackers might be able to see the password sent from client to server
2. Attackers might be able to substitute their own server for the server that the client thinks it is talking to, and retrieve the password that the client sends to authenticate itself
3. Attackers might be able to see the RMI object ID of a legitimately-created `RMICConnection` object as it is accessed remotely. They could then use RMI to call that object, executing MBean server methods using the `Subject` that was authenticated when the object was created
4. Attackers might be able to guess this RMI object ID, for instance if object IDs are allocated as consecutive small integers

The first three problems can be solved by using an RMI socket factory so that the connection between client and server uses the Secure Socket Layer (SSL). This is covered in more detail elsewhere (see for example "Using RMI with SSL" [RMI/SSL]).

A special case of problem 2 is that attackers might be able to modify the contents of a directory or lookup service that is used during connection establishment. This might be either the directory that is used to find the `RMIServer` stub, or the directory that is used to find the URL. If an RMI Registry is used for the `RMIServer` stub, it should be secured with SSL.

The fourth problem can be solved by setting the standard RMI system property `java.rmi.server.randomIDs` to "true". This causes the 64-bit object ID of every export RMI object to be generated using a cryptographically strong random number generator. (See the documentation for the class `java.rmi.server.ObjID`.)

14.5 Protocol Versioning

The remote `RMIServer` interface includes a method `getVersion` that returns a string including a protocol version number. This standard specifies version 1.0 of the RMI connector protocol, which is currently the only version. Any given future version of this standard might or might not include an updated version of the protocol.

Each protocol version will have a version number which is the same as the version of this standard that first defines it. For example, if version 1.1 of this standard does not change the protocol but version 1.2 does, then the next RMI connector protocol version number will be 1.2.

All future versions of the RMI connector will include a remote `RMIServer` object that has at least the same methods as the current version, 1.0, and in particular the `getVersion` method. A future version might add further methods too.

If a future version adds methods to the `RMIServer` interface, it must ensure that the methods that a 1.0 client calls work as expected.

If the client side of the RMI connector defined in a future version uses methods added to the server in that version, it must check, using `getVersion`, that the server it is communicating with supports that version. Otherwise, it must limit itself to the methods that the server does support, perhaps losing some functionality as a consequence.

Generic Connector

The JMX Remote API includes a *generic connector* as an optional part of the API. This connector is designed to be configurable by plugging in modules to define the following:

- The *transport protocol* used to send requests from the client to the server and to send responses and notifications from the server to the clients
- The *object wrapping* for objects sent from the client to the server whose class loader can depend on the target MBean

The JMXMP Connector is a configuration of the generic connector where the transport protocol is based on TCP and the object wrapping is native Java serialization (as defined by `java.io.ObjectOutputStream` etc.). Security is based on JSSE [JSSE], JAAS [JAAS], and SASL [JSR28][RFC2222].

The generic connector and its JMXMP configuration are optional, which means that an implementation can choose not to include them. An implementation that does include them must conform to their specification here and in the API documentation.

15.1 Pluggable Transport Protocol

Each configuration of the generic connector includes a *transport protocol*, which is an implementation of the interface `MessageConnection`. Each end of a connection has an instance of this interface. The interface defines three main methods:

- The `writeMessage` method writes a Java object to the other end of the connection. The Java object is of the type `Message` defined by the connector. It can reference other Java objects of arbitrary Java types. For the JMXMP Connector, the possible types of messages are contained in the package `javax.management.remote.message`.
- The `readMessage` method reads a Java object from the other end of the connection. The Java object is of type `Message` and again can refer to objects of arbitrary other types.

- The `close` method closes the connection

The connection is a full-duplex connection between the client and the server. A stream of requests is sent from client to server, and a stream of responses and notifications is sent from server to client. See FIGURE 15-1.

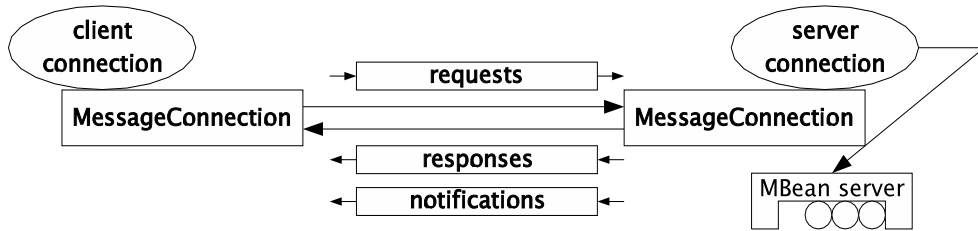


FIGURE 15-1 `MessageConnection` Defines a Full-Duplex Transport Between Client and Server

When client code issues an `MBeanServerConnection` request such as `getMBeanInfo`, the request is wrapped inside an `MBeanServerRequestMessage` object and written to the server using `MessageConnection.writeMessage`. The client code then waits for the corresponding response. Meanwhile, another thread in the client can write another request. When a response arrives, its message ID is used to match it to the request it belongs to, and the thread that issued that request is woken up with the response.

15.2 Pluggable Object Wrapping

The arguments to an MBean method called through `MBeanServer.invoke`, and the attribute values supplied to `setAttribute` or `setAttributes`, can be of Java classes that are known to the target MBean but not to the connector server. If these objects were treated like any other, the connector server would get a `ClassNotFoundException` when it tried to deserialize a request containing them.

To avoid this problem, deserialization at the server end of a connection proceeds in two stages. First, the objects that are necessarily of classes known to the connector server are deserialized. This is enough to determine what kind of request has been received, which MBean it is destined for (if any), and therefore what class loader is appropriate for use. Then the remaining objects (arguments to `invoke` or attribute values for `setAttribute(s)`) can be deserialized using this class loader.

The `ObjectWrapping` interface allows object wrapping to be customized. By default, it constructs a byte array containing the output of `ObjectOutputStream.writeObject` on the object or objects to be wrapped. But this would be inappropriate if, for example, the `MessageConnection` is using the

Extensible Markup Language (XML). So, in such a case an `ObjectWrapping` object could be plugged into the connector that wraps the objects in XML. This XML can then be included in the larger XML text constructed by the `MessageConnection`.

15.3 Generic Connector Protocol

The generic connector protocol defines a set of protocol messages that are exchanged between the client and the server ends of the connection, and the sequence these message exchanges must follow. Implementations of this specification must exchange these messages in the defined sequence so that they can interoperate with other implementations. FIGURE 15-2 depicts the UML diagram of all the messages defined by the generic connector protocol.

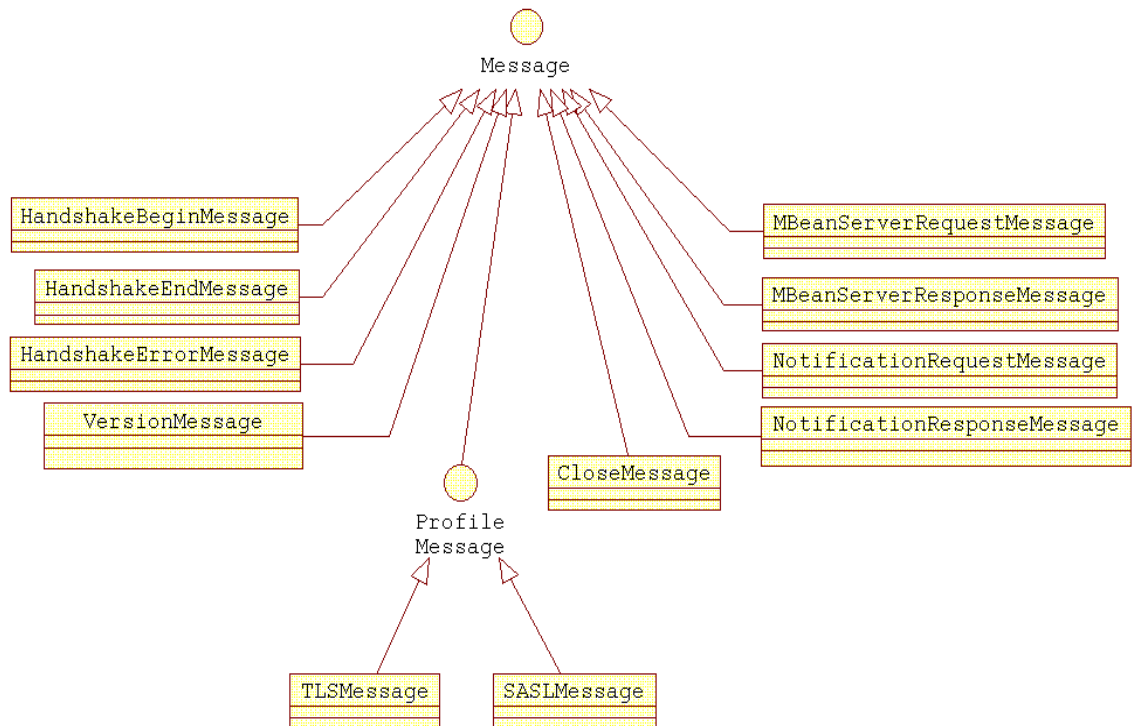


FIGURE 15-2 Generic Connector Protocol Messages

The generic connector protocol messages can be divided into four categories:

- Handshake messages:

- `HandshakeBeginMessage`
 - `HandshakeEndMessage`

HandshakeErrorMessage
VersionMessage

- Profile messages:

TLSSMessage (JMXMP Connector only)
SASLMessage (JMXMP Connector only)

- MBean server operation messages:

MBeanServerRequestMessage
MBeanServerResponseMessage
NotificationRequestMessage
NotificationResponseMessage

- Connection messages

CloseMessage

15.3.1 Handshake and Profile Message Exchanges

The handshake message exchanges are started by the server end of the connection as soon as the `connect` method on the `JMXConnector` class is called by the client and the connection between the client and the server is established.

The server end of the connection sends a `HandshakeBeginMessage` to the client with the profiles supported by the server. These profiles are retrieved from the environment map through the `jmx.remote.profiles` property. The client then starts the profile message exchanges for the profiles chosen from the server's supported profiles.

The JMXMP profile is used to negotiate the version of JMXMP to use. This profile is always implicitly enabled, but is only negotiated if the client and server differ in their default versions. See Section 15.3.5 "Protocol Versioning" on page 243.

For the other profiles, the client will first check that all the profiles requested in its environment map are supported by the server. If not, it will send a `HandshakeErrorMessage` to the server and close the connection. (This is the behavior of the standard JMX Remote API. Other APIs for JMXMP can provide ways to pick which of the proposed profiles to use.)

Then, for each profile asked for in the client's environment map, the client will negotiate that profile. The order in which profiles are negotiated is the order they appear in the client's environment map. This order can be important. For example, if the client negotiates the SASL/PLAIN profile before the TLS profile, it will send a password in clear text over the connection. If it negotiates TLS first, the connection will become encrypted before the password is sent.

It is not specified how the server accepts or denies the sequence of profiles run by the client. However, it is recommended that if the profiles in the server's environment map imply a certain level of security, the server should reject a

connection whose negotiated profiles do not ensure that level of security. For example, if the server is configured with only the TLS profile, then it should reject connections that do not negotiate TLS. If the server is configured with the TLS profile and with the SASL/DIGEST-MD5 profile specifying the same level of security as regards authentication and encryption, then it should reject connections that negotiate neither profile.

The profile exchanges are performed one at a time and always started by the client. Once the profile exchanges are completed the client sends a `HandshakeEndMessage` to the server. No further profile exchanges are then possible. The server replies either with the same `HandshakeEndMessage` if it accepts the profiles that have been negotiated, or with a `HandshakeErrorMessage` if it does not. In the latter case, the connection is closed.

After the handshake phase has been completed the client can get a reference to the remote MBean server, send MBean server requests, and register listeners for receiving notifications. The server will send responses to the client MBean server requests and will forward notifications to the interested clients. FIGURE 15-3 depicts the initial handshake and profile message exchanges.

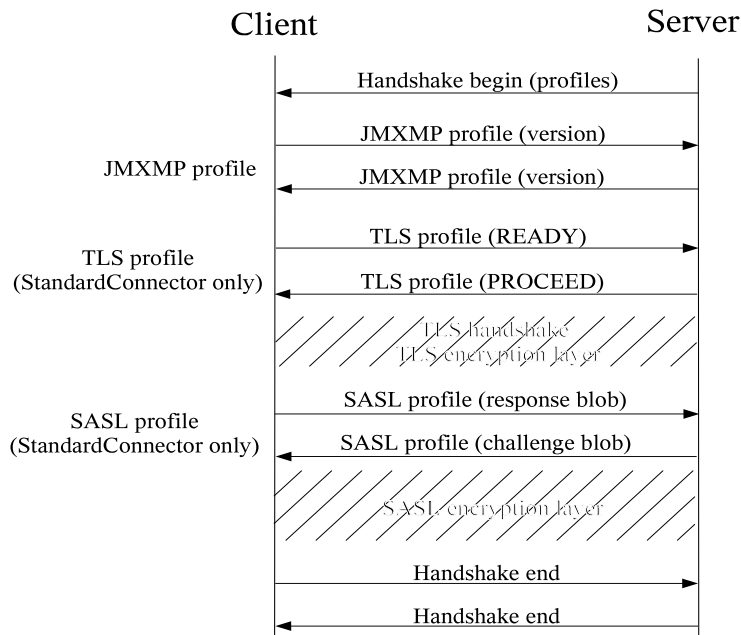


FIGURE 15-3 Handshake and Profile Message Exchanges

Notice that only the handshake begin and handshake end messages are mandatory. The profile message exchanges depend on the configuration of the server and the client by means of the `jmx.remote.profiles` property in the environment map passed in at the creation of the `JMXConnector` and `JMXConnectorServer`.

At any time during the handshake phase, if an error is encountered by either peer (client or server), it must send an indication (`HandshakeErrorMessage`) as to why the operation failed. The peer that encountered the problem will send the error message to the other peer and immediately close the connection. The peer that receives the message on the other end of the connection will also close the connection immediately on reception of a handshake error message. FIGURE 15-4 depicts how an error is indicated by either a client or a server to the other peer during the initial handshake message exchanges.

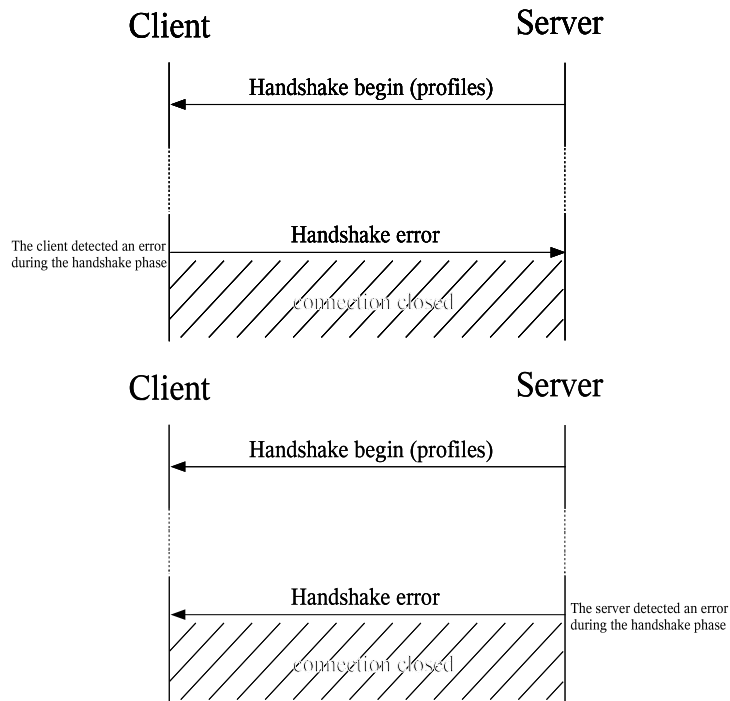


FIGURE 15-4 Handshake Error Message Exchanges

15.3.2 MBean Server Operation and Connection Message Exchanges

Once the initial handshake phase has been terminated, and all profiles negotiated, the client can retrieve a reference to the remote MBean server by calling the `getMBeanServerConnection` method on the `JMXConnector` instance. Through the `MBeanServerConnection` interface the client can perform operations on the registered MBeans, including registration for receiving notifications. These MBean server operations will be mapped by the protocol to `MBeanServerRequestMessage` messages. For each such message the server will receive it, decode it, perform the operation on the MBean server, and return the result of the operation in an `MBeanServerResponseMessage` message.

If several client threads are performing MBean server operations at the same time, there can be several `MBeanServerRequestMessages` that have been sent without yet having received the corresponding `MBeanServerResponseMessages`. There is no requirement that a client receive a response for each request before sending the next request.

Each `MBeanServerRequestMessage` contains an identifier that the matching `MBeanServerResponseMessage` must also contain. At any time, the client has a set of identifiers `{id1, id2, ...}` for requests it has sent that have not yet received a response. Each new request must have an identifier that is not in the set, and that is added to the set when the request is sent. Each response must have an identifier that is in the set, and that is removed from the set when the response is received. It is a protocol error for these conditions to be violated. The peer that detects the error must close the connection, optionally after sending a `CloseMessage` to the other peer.

Notifications are handled using the techniques described in Section 13.4 “Adding Remote Listeners” on page 208. The connector server has a stateless notification buffer (Section 13.4.3 on page 210). If the connector client has listeners, it uses the `NotificationRequestMessage` to receive notifications for them. Each such message solicits a `NotificationReplyMessage`.

The list of `(ObjectName, NotificationFilter)` pairs corresponding to the client’s listeners is not passed in every `NotificationRequestMessage`. Rather, it is established with a single `addNotificationListeners` in an `MBeanServerRequestMessage` when the connection is established. Changes to the notification list while the connection is open are made with further `MBeanServerRequestMessages` containing `addNotificationListeners` or `removeNotificationListener`.

FIGURE 15-5 depicts the MBean server operation message exchanges.

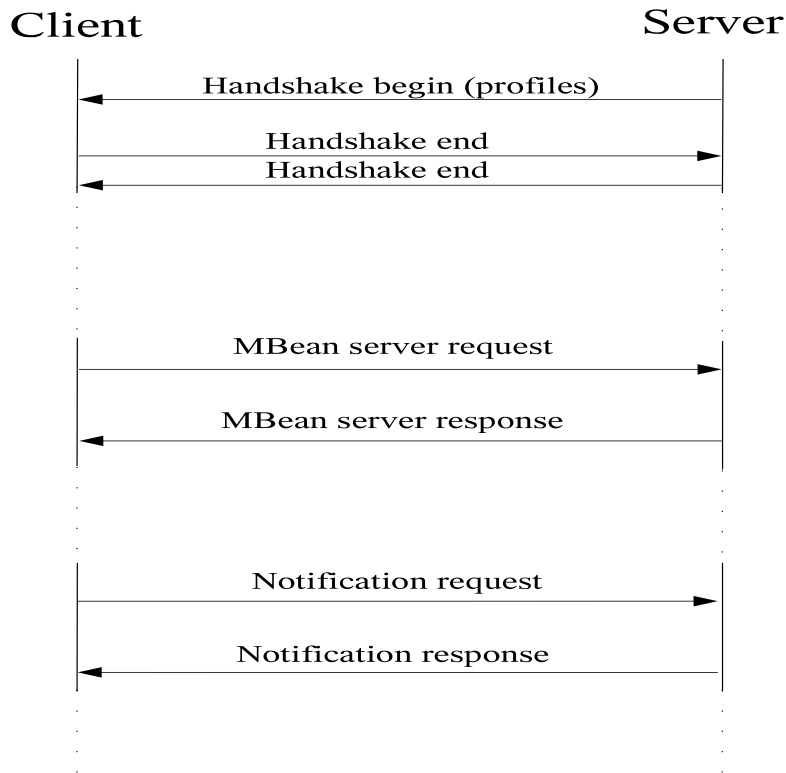


FIGURE 15-5 MBean Server Operations Message Exchanges

At any time after the handshake phase and during the MBean server operation message exchanges, either the client or the server can want to close the connection. On the one hand, the client can achieve that by calling the `close` method on the `JMXConnector` instance. On the other hand, the server can achieve that by calling the `stop` method on the `JMXConnectorServer` instance. Additionally, the client or server can close the connection at any time, for example as detailed in Section 13.7.1 “Detecting Abnormal Termination” on page 213. The peer initiating the connection close action will send a message of type `CloseMessage` to inform the other peer that the connection must be closed and that the necessary clean-up should be carried out.

When a client sends or receives a `CloseMessage` it must not send any further requests to the server over that connection. The server will continue to process existing requests and send the corresponding replies before closing the connection.

FIGURE 15-6 depicts the close-connection message exchanges.

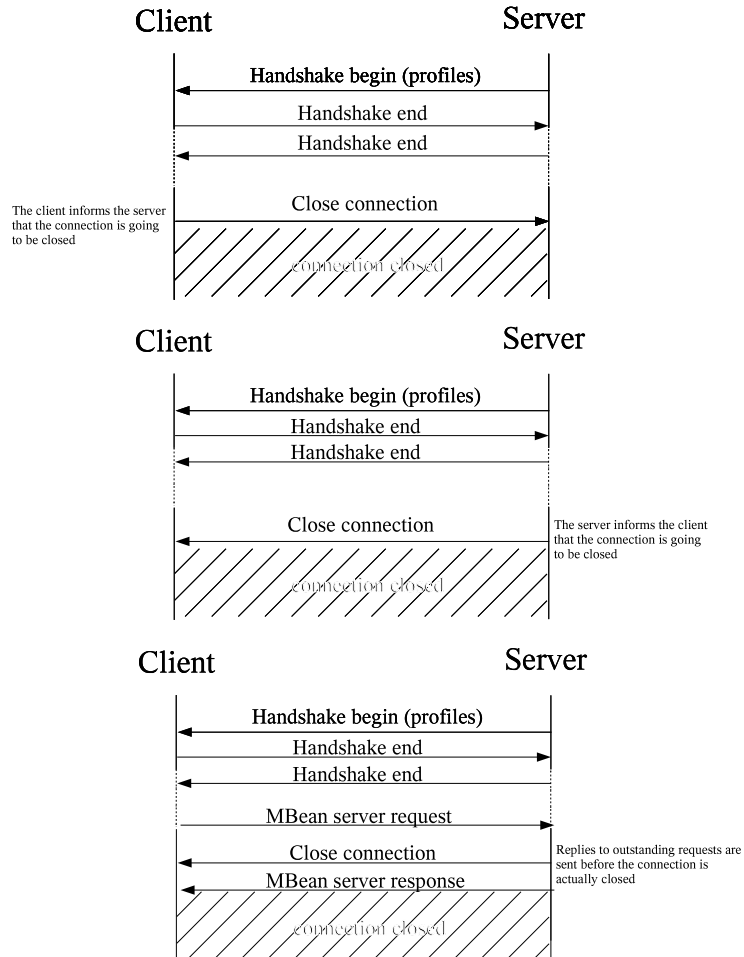


FIGURE 15-6 Close-Connection Message Exchanges

15.3.3 Security Features in the JMXMP Connector

The JMXMP Connector provides support for authentication and authorization through the TLS and SASL profiles. The JMX Remote API does not mandate the implementation and support of any specific SASL mechanism. It simply relies on third-party implementations that can be plugged in using the standard SASL interface [JSR28].

15.3.3.1 TLS Profile

The TLS profile allows the client and server ends of a connection to negotiate a TLS encryption layer. Certificate-based authentication and mutual client/server authentication are optional features configurable through properties in the environment map (see Section 15.3.6 “Properties Controlling Client and Server” on page 244).

15.3.3.2 SASL Profile

When using a SASL profile the way authentication is carried out is defined by the selected SASL mechanism and can vary from one mechanism to another.

However, at the end of the SASL handshake exchanges an authorization identity has been negotiated between the SASL client and the SASL server. Thus, the SASL profile has to make this identity available to allow the MBean server and the underlying MBeans to perform access control checks based on this identity.

The SASL profile implementation uses the JAAS framework to construct a `JMXPrincipal` based on this authorization identity, and stores this `JMXPrincipal` in a `Subject`. Then, when the `JMXMPCConnectorServer` performs any of the subsequent MBean server operations, it must do so with the given subject for the required privileged action using an appropriate access control context.

An MBean interested in retrieving the authorization information can do so (if it has the appropriate permissions) by calling:

```
AccessControlContext acc = AccessController.getContext();
Subject subject = Subject.getSubject(acc);
Set principals = subject.getPrincipals();
```

15.3.4 Protocol Violations

If a peer receives a message from the other peer that does not respect the protocol described here, its behavior is unspecified. The recommended behavior is to send a `CloseMessage` indicating the detected violation and to close the connection immediately afterwards.

15.3.5 Protocol Versioning

This standard specifies version 1.0 of the JMXMP protocol, which is currently the only version. Any given future version of this standard might or might not include an updated version of the protocol.

Each protocol version will have a version number which is the same as the version of this standard that first defines it. For example, if version 1.1 of this standard does not change the protocol but version 1.2 does, then the next JMXMP protocol version number will be 1.2.

The first message sent over a newly-opened connection is a handshake begin message from the server to the client. This message includes the latest JMXMP version that the server understands. If the client also understands that version, then the subsequent communication will take place using that version. If the client only understands an earlier version, then it will send a `VersionMessage` requesting that the earlier version be used. If the server understands this earlier version, then it will reply with the same `VersionMessage`, and the subsequent communication will take place using that version. Otherwise, the server will send a `HandshakeErrorMessage` and the communication will be aborted.

In other words, suppose the server version is S and the client version is C . Then the version V to be used for communication is determined as follows:

- Server to client: "Version S "
- If client understands S , $V = S$
- Otherwise:
 - Client to server: "Version C "
 - If server understands C :
 - Server to client: "Version C "
 - $V = C$
 - Otherwise (server does not understand C):
 - Server to client: "Handshake error."
 - Connection aborted

A consequence of this negotiation is that every version of the protocol must understand every other version's `HandshakeBeginMessage` and `VersionMessage`. This will be true provided that Java serial compatibility is respected. See the section *Type Changes Affecting Serialization* in [Serial].

It is expected but not required that every implementation of any version of this standard understand all protocol versions from previous versions of the standard.

15.3.6 Properties Controlling Client and Server

When creating a `JMXConnector` or a `JMXConnectorServer`, an environment map can be supplied. One of the functions of this environment is to provide configuration parameters for the underlying profiles. The following subsections describe these parameters.

15.3.6.1 Global Properties of the Generic Connector

These properties control global aspects of the connection, that is they are valid regardless of the profiles that are selected.

- `jmx.remote.profiles`

A string that is a space-separated list of profile names to be supported by the client and/or the server. Examples of profile names are: `JMXMP`, `TLS`, `SASL/EXTERNAL`, `SASL/OTP`. If this property is unspecified, no profiles will be used.

- `jmx.remote.context`

An arbitrary `Object` to be conveyed by the handshake messages from one peer to the other. The `Object` should be serializable and of a class that is known to the other peer. If this property is unspecified, a null context will be conveyed.

The `JMXMP Connector` currently makes no use of this object and does not expose it to user code on the client or server.

- `jmx.remote.authenticator`

A `JMXAuthenticator` that is used at the end of the handshake phase to validate the new connection. The `authenticate` method of this object is called with a two-element `Object[]` as a parameter. The first element is the connection ID of the new connection. The second element is the authenticated `Subject`, if any. The method returns the authenticated `Subject` to use for the connection, or null if there is no authenticated ID. The returned `Subject` is usually the same as the `Subject` passed as a parameter, but it can have different `Principals`. If the authenticator does not accept the connection id or `Subject`, it can throw a `SecurityException`.

15.3.6.2 TLS Properties

The following properties control the TLS profile:

- `jmx.remote.tls.socket.factory`

An object of type `javax.net.ssl.SSLSocketFactory` that is an already initialized TLS socket factory. The `SSLSocketFactory` can be created and initialized through the `SSLContext` factory. If the value of this property is not specified, the TLS socket factory defaults to `SSLSocketFactory.getDefault()`.

- `jmx.remote.tls.enabled.protocols`

A string that is a space-separated list of TLS protocols to enable. If the value of this property is not specified, the TLS enabled protocols default to `SSLSocket.getEnabledProtocols()`.

- `jmx.remote.tls.enabled.cipher.suites`

A string that is a space-separated list of TLS cipher suites to enable. If the value of this property is not specified the TLS enabled cipher suites default to `SSLSocket.getEnabledCipherSuites()`.

- `jmx.remote.tls.need.client.authentication`

A string that is "true" or "false" according to whether the connector server requires client authentication. If true, a client that does not authenticate during the handshake sequence will be refused.

- `jmx.remote.tls.want.client.authentication`

A string that is "true" or "false" according to whether the connector server requires client authentication if appropriate to the cipher suite negotiated. If true, then if a client negotiates a cipher suite that supports authentication but that client does not authenticate itself, the connection will be refused.

15.3.6.3 SASL Properties

The following properties control the SASL profile:

- `jmx.remote.sasl.authorization.id`

A string that is the connector client's identity for authorization when it is different from the authentication identity. If this property is unspecified, the provider derives an authorization identity from the authentication identity.

- `jmx.remote.sasl.callback.handler`

An object of type `javax.security.auth.callback.CallbackHandler` that is the callback handler to be invoked by the SASL mechanism to retrieve user information. If this property is unspecified, no callback handler will be used.

Defining a New Transport

The standard protocols defined by this specification might not correspond to all possible environments. Examples of other protocols that might be of interest are:

- A protocol that runs over a serial line to manage a JMX API agent in a device that is not networked
- A protocol that uses HTTP/S because it is a familiar protocol that system administrators might be more willing to let through firewalls than RMI or JMXMP
- A protocol that formats messages in XML (perhaps in an XML-based RPC protocol such as SOAP) to build on an existing XML-based infrastructure. Such a transport could potentially be used by non-Java clients

There are two ways to implement a user-defined protocol. One is to define a transport for the generic connector using the `MessageConnection` and `MessageConnectionServer` classes as described in Chapter 15 “Generic Connector”. The other is to define a new provider for the `JMXConnectorFactory`.

Defining a transport for the generic connector has the advantage that many of the trickier implementation details, in particular concerning listeners, are already handled. The transport has to take care of establishing the connection and serializing and deserializing the various `Message` classes. Potentially, the transport can include other exchanges, for example to set up a secure connection, that are not the result of a `MessageConnection.writeMessage` and are never seen by a `MessageConnection.readMessage`. For example, this is the case for the TLS and SASL exchanges in the JMXMP Connector.

Defining a provider for the `JMXConnectorFactory` is explained in the API documentation for that class. A provider can be based on the generic connector, or it can implement a protocol completely from scratch.

Bindings to Lookup Services

This standard specifies connectors that make it possible for a JMX Remote API client to access and manage MBeans exposed through a JMX API agent (an MBean server) running in a remote JVM. It also defines a `JMXServiceURL` class, which represents the address of a JMX Remote API connector server, and makes it possible for a client to obtain a JMX Remote API connector connected to that server. However, this standard does not provide any specific API that would make it possible for a client to find the address of a connector server attached to an agent it knows about, or to discover which agents are running, and what the addresses of the connector servers are that make it possible to connect to them. Rather than reinventing the wheel, this standard instead details how to advertise and find agents using existing discovery and lookup infrastructures.

This specification discusses three such infrastructures:

- The Service Location Protocol [SLP], as defined by [RFC 2608] and [RFC 2609]
- The Jini Network Technology [Jini]
- The Java Naming and Directory Interface™ ("J.N.D.I.") API [JNDI] with an LDAP backend

The goal of this chapter is to specify how a JMX API agent can register its connector servers with these infrastructures, and how a JMX Remote API client can query these infrastructures in order to find and connect to the advertised servers.

This chapter imposes no requirements on implementations of the JMX Remote API. It details the conventions to be followed so that a server can be registered and found by clients, without having to share special knowledge between client and server.

17.1 Terminology

The term *JMX Remote API Agent* (or agent) is used throughout this section to identify a logical server application composed of:

- One MBean server

- One or more JMX Remote API connector servers allowing remote clients to access the MBeans contained in that MBean server

The term *JMX Remote API client* (or client) is used to identify a logical client application which opens a client connection with a JMX Remote API agent.

Note that a single JVM machine can contain many agents and/or clients.

17.2 General Principles

Although the APIs with which to register and query a server access point using a lookup service vary from one infrastructure to another, the general principles remain the same:

- The agent creates one or more JMX Remote API connector servers
- Then for each connector to expose, the `JMXServiceURL` (SLP, JNDI/LDAP) or the `JMXConnector` stub (Jini networking technology, JNDI/LDAP) is registered with the lookup service, possibly giving additional attributes which qualify the agent and/or connector
- The client queries the lookup service, and retrieves one or more `JMXServiceURL` addresses (or `JMXConnector` stubs) that match the query
- Then, it either uses the `JMXConnectorFactory` to obtain a `JMXConnector` connected with the server identified by a retrieved `JMXServiceURL` (SLP, JNDI/LDAP), or it directly connects to the server using the provided `JMXConnector` stub (Jini, JNDI/LDAP)

17.2.1 JMXServiceURL Versus JMXConnector Stubs

When using SLP, it is natural to register and retrieve a service URL from the lookup service. However, it is not as natural when using networking technologies like Jini. In the Jini networking technology, the Service object you register and get from the lookup service is usually a stub that directly implements the interface of the underlying service, and not an object that gives you back some information on how to connect to the service. Therefore this standard specifies different ways of advertising a connector server, depending on the underlying lookup service used:

- **SLP:** register the URL string representation of the JMX Service URL (`JMXServiceURL.toString()`). This is natural as SLP is a URL-based protocol. See Section 17.3 “Using the Service Location Protocol” on page 254.
- **Jini networking technology:** register a `JMXConnector` stub. The `JMXConnector` interface is directly the interface of the JMX Connector Service. See Section 17.4 “Using the Jini Network Technology” on page 258

- **JNDI API/LDAP:** register the URL string representation of the JMX Service URL (`JMXServiceURL.toString()`). The JNDI API can be configured on the client side (via `StateFactories` and `ObjectFactories` - see [JNDI - Java Objects]) to create and return a new `JMXConnector` automatically from the `DirContext` containing the JMX Service URL, or simply return the `DirContext` from which that JMX Service URL can be extracted. See Section 17.5 “Using the Java Naming and Directory Interface (LDAP Backend)” on page 264.
An alternative way to use JNDI/LDAP is to store a `JMXConnector` stub directly, as described for Jini. This specification does not define a standard way to do that.

17.2.2 Lookup Attributes

All three infrastructures considered in this specification have the notion of lookup attributes. These attributes are properties that qualify the registered services. They are passed to the infrastructure when the service is registered, and can be used as filters when performing a lookup.

A client can then query the lookup service to find all the connectors that match one or more attributes. A client that obtains several services as a result of a lookup query can also further inquire about the lookup attributes registered for those services to determine which of the returned matching services it wants to use.

For a client to be able to format a query to the lookup service independently of the JMX Remote API implementation used on the agent side, and to understand the meaning of the retrieved attributes, this standard specifies a common set of JMX Remote API lookup attributes whose semantics will be known by all agents and clients. In the remainder of this specification we will use the term *Lookup Attributes* for these.

When registering a connector server with a lookup service, an agent will:

1. Build the `JMXServiceURL` describing its connector server (SLP, JNDI/LDAP), or obtain a `JMXConnector` stub from that server (using Jini networking technology)
2. Register that URL (SLP, JNDI/LDAP), or `JMXConnector` stub (using Jini networking technology) with the lookup service
3. Provide any additional lookup attributes that might help a client to locate the server

TABLE 17-1 defines the set of common lookup attributes that can be provided at connector registration and that can be used to filter the lookup. Most of these attributes are optional: an agent can choose whether it wants to specify them when it registers a `JMXServiceURL` with the lookup service.

Note – The name format of the lookup attributes is different depending on the back-end lookup service (see Section 17.4 “Using the Jini Network Technology” on page 258)

TABLE 17-1 Lookup Attributes for Connectors

Name / ID	Type	Multi-valued	Optional	Description
AgentName	String	No	Mandatory	A simple name used to identify the agent in a common way. Can also be viewed as a logical name for the service implemented by the agent. Makes it possible to search for all connectors registered by a given agent. This specification does not define the format of an agent name. However, the characters colon (:) and slash (/) are reserved for future use.

TABLE 17-1 Lookup Attributes for Connectors

Name / ID	Type	Multi-valued	Optional	Description
ProtocolType	String	No	Optional	The protocol type of the registered connector, as returned by <code>JMXServiceURL.getProtocol()</code> . Makes it possible to retrieve only the connectors using a given protocol that the client supports.
AgentHost	String	Yes	Optional	The name(s) or IP address(es) of the host on which the agent is running. This attribute is multivalued in order to allow aliasing - namely, if one single host is known under several names. This attribute is multivalued only if the underlying lookup protocol supports multivalued attributes.
Property	String	Yes	Optional	A string containing a Java-like property, in the form " <code><property-name>=<value></code> " - for example, " <code>com.sun.jmx.remote.tcp.connect.timeout=200</code> ". This attribute is multivalued so that it can be used to map several properties. It might be used by agents as a means to provide additional information to client applications. For instance, this attribute could be used to hold some of the attributes that were passed to a connector server within the environment map at construction time. However, an agent must not rely on the fact that a Client will read these attributes, and a client must not rely on the fact that an agent will provide them. All the information that any client will need to connect to a specific server must be contained in the server's JMX Service URL, or in its JMX API connector stub.

17.3 Using the Service Location Protocol

The Service Location Protocol [SLP] is an IETF standards track protocol [RFC 2608], [RFC 2609] that provides a framework to allow networking applications to discover the existence, location, and configuration of networked services in enterprise networks. You may wish to read the [SLP White Paper] for a concise description of SLP, and its positioning with respect to other technologies, like DNSSRV and LDAP.

17.3.1 SLP Implementation

The Java SLP API is the object of [JSR 140]. At the time of writing, this JSR is not yet finalized. The code extracts in this section are based on Sun's proprietary Java implementation of SLP, which closely follows [RFC 2614]. Code based on other implementations of that RFC will work similarly.

17.3.2 SLP Service URL

The `JMXServiceURL` defined by this standard is directly compliant with [RFC 2609]. Therefore there is a direct mapping between JMX Service URLs and SLP Service URLs, since their String representation is identical.

17.3.3 SLP Lookup Attributes

SLP supports multivalued attribute registrations; these attributes are provided at registration time, when registering the Service URL of the connector server. The filtering method used for lookup is an LDAPv3 filter string. The attributes that must or may be provided by an agent when registering a connector server URL are those defined in Section 17.2.2 "Lookup Attributes" on page 251.

17.3.4 Code Templates

The following sections provide some code templates for SLP.

17.3.4.1 Discovering the SLP Service

With SLP, discovering the lookup service is transparent to the user; the running SLP daemon is responsible for finding the Service Agent or Directory Agent (depending on the configuration of the daemon).

In fact, one line is enough to locate the lookup service, as shown in CODE EXAMPLE 17-1:

CODE EXAMPLE 17-1 Discovering the SLP Service

```
import com.sun.slp.ServiceLocationManager;
import com.sun.slp.ServiceLocationException;
import com.sun.slp.Advertiser;
import com.sun.slp.Locator;
...
try {

    // Getting the Advertiser (for registration purposes)
    Advertiser slpAdvertiser = ServiceLocationManager.getAdvertiser(Locale.US);

    // Getting the Locator (for lookup purposes)
    Locator slpLocator = ServiceLocationManager.getLocator(Locale.US);

} catch(ServiceLocationException e) {...}
```

17.3.4.2 Registering a JMX Service URL With SLP

The class `Advertiser` is used to perform the SLP registrations, as shown in CODE EXAMPLE 17-2:

CODE EXAMPLE 17-2 Registering a Service URL With SLP

```
import com.sun.slp.ServiceURL;
import com.sun.slp.ServiceLocationAttribute;
...
try {

    // Create a new JMXMPCConnectorServer, let the system allocate a
    // a port number.
    //
    JMXServiceURL jmxUrl = new JMXServiceURL("service:jmx:jmxmp://myhost:0");
    final JMXConnectorServer cserver = new JMXMPCConnectorServer(jmxUrl,null);

    // Get the Connector Server address
    final JMXServiceURL srvAddr = cserver.getAddress();

    // Note: It is recommended that the JMX Agents make use of the leasing
    //       feature of SLP, and periodically renew their lease.
    final ServiceURL serviceURL =
        new ServiceURL(srvAddr.toString(), ServiceURL.LIFETIME_DEFAULT);

    final Vector attributes = new Vector();
    final Vector attrValues = new Vector();

    // Using the default SLP scope
    attrValues.add("DEFAULT");
    final ServiceLocationAttribute attr1 =
        new ServiceLocationAttribute("SCOPE", attrValues);
    attributes.add(attr1);

    // AgentName attribute
    attrValues.removeAllElements();
    attrValues.add(new String("my-jmx-agent"));
    final ServiceLocationAttribute attr2 =
        new ServiceLocationAttribute("AgentName", attrValues);
    attributes.add(attr2);

    ...
    // Registration
    slpAdvertiser.register(serviceURL, attributes);

} catch(ServiceLocationException e) {...}
```


17.3.4.3 Looking up a JMX Service URL With SLP

The class `Locator` is used to perform the SLP lookup, as shown in CODE EXAMPLE 17-3:

CODE EXAMPLE 17-3 Looking up a JMX Service URL With SLP

```
import com.sun.slp.ServiceType;
import com.sun.slp.ServiceLocationEnumeration;
...
try {
    // lookup in default SCOPE.
    final Vector scopes = new Vector();
    scopes.add("DEFAULT");

    // Set the LDAPv3 query string
    //     Here we look for a specific agent called "my-jmx-agent",
    //     but we could have asked for any agent by using a wildcard:
    //     final String query = "&(AgentName=*)";
    //
    final String query = "&(AgentName=my-jmx-agent)";

    // lookup
    final ServiceLocationEnumeration result =
        slpLocator.findServices(new ServiceType("service:jmx"), scopes, query);

    // Extract the list of returned ServiceURL
    while(result.hasMoreElements()) {
        final ServiceURL surl = (ServiceURL) result.next();

        // Get the attributes
        final ServiceLocationEnumeration slpAttributes =
            slpLocator.findAttributes(surl, scopes, new Vector());

        while(slpAttributes.hasMoreElements()) {
            final ServiceLocationAttribute slpAttribute =
                (ServiceLocationAttribute) slpAttributes.nextElement();
            ...
        }

        // Open a connection
        final JMXServiceURL jmxUrl = new JMXServiceURL(surl.toString());
        final JMXConnector client = JMXConnectorFactory.connect(jmxUrl);
        ...
    }
} catch(ServiceLocationException e) {...}
```

17.4 Using the Jini Network Technology

The *Jini Network Technology* [Jini] is an open software architecture that enables developers to create network-centric services that are highly adaptive to change.

The Jini specification offers a standard lookup service. A running Jini lookup service can be discovered with a simple API call. A remote service (device, software, application, etc.) that wants to be registered in the Jini lookup service provides a serializable Java object. When looked up by a remote client, a copy of this Java object is returned. Usually, this object acts as a proxy to the remote service.

In addition, Jini networking technology offers various APIs and mechanisms to download code from a remote HTTP server (necessary to get the classes required for instantiating the proxy objects), and the Jini specification supports security for code download based on the RMI security manager.

17.4.1 Jini Networking Technology Implementation

The Jini networking technology is Java-based software the implementation of which is available for download under the Sun Community Source Licence v3.0 (with Jini Technology Specific Attachment v1.0). See <http://www.sun.com/software/communitysource/jini/download.html>

17.4.2 Service Registration

The Jini specification is based on service registration. A service is registered through a serializable Java object, which can be a stub, a proxy or a simple class providing information about the service. Usually, the registered service is a stub which provides a direct link to the underlying service. Thus, although it would be possible to use the `JMXServiceURL` as the service, this standard specifies the use of a JMX Remote API connector stub, implementing the `JMXConnector` interface, as the service. This is consistent with the Jini specification's philosophy, where objects retrieved from the Jini lookup service are usually proxies implementing the interface of the service looked up.

The Jini lookup service, which uses Java RMI marshalling and dynamic class loading semantics, will make use of RMI annotations to download automatically from the server side all the classes needed to deserialize the service object on the client side. This makes it possible for a server to register any private implementation class, and for a client to use that class (through its generic `JMXConnector` interface) without any a-priori knowledge of the server implementation. However, this requires a certain amount of configuration from the server-side. This standard completely specifies the JMX Remote API connector stubs for the protocols it describes, so that

an instance of such a class serialized from the JMX Remote API implementation on the server side can be deserialized in an instance of the same class using the implementation on the client side, without having to download any new classes. Thus, no special configuration is needed on the server side when using standard connectors. Providers and users of non-standard connectors should however perform the required configuration steps if they want to make their non-standard connectors available to generic JMX API clients.

17.4.3 Using JMX Remote API Connector Stubs

When registering a JMX Remote API connector stub, the server application will either call the `JMXConnectorFactory.newConnector` method to obtain an unconnected stub, or call the `toJMXConnector` method on the `JMXConnectorServer` it wants to register. The `toJMXConnector` method returns a serializable connector stub that can be directly registered as the service provided by that connector.

When the client looks up the registered connector from the Jini lookup service, the returned connector stub is not yet connected to its corresponding server. The client application needs to call the `JMXConnector.connect()` method on that object before using it.

Calling `JMXConnector.connect()` on the server side is shown in CODE EXAMPLE 17-4:

CODE EXAMPLE 17-4 Calling `JMXConnector.connect()` on the Server Side

```
// get the connector stub:
JMXConnector c = server.toJMXConnector(null);

// register c as the Jini Service.
...
```

Calling `JMXConnector.connect()` on the client side, as shown in CODE EXAMPLE 17-5:

CODE EXAMPLE 17-5 Calling `JMXConnector.connect()` on the Client Side

```
// Obtain the service from Jini
Object service = ...
JMXConnector c = (JMXConnector) service;

// Build the env Map, add security parameters,
Map env = new HashMap();
env.put(...)

// Connect with the server
c.connect(env);
```

17.4.4 Jini Lookup Service Attributes

Like SLP, the Jini lookup service supports the specification of additional lookup attributes, called *entries*. The Java class of these attributes must implement the `net.jini.core.entry.Entry` interface. The `Name` entry defined by the Jini specification is interpreted as meaning the `AgentName` as defined in Section 17.2.2 “Lookup Attributes” on page 251. As this specification was being completed, the other entries were being standardized through the Jini Community Decision Process (JDP). Refer to the JMX technology home page for current information:

<http://java.sun.com/products/JavaManagement/>

17.4.5 Code Templates

The following sections provide some code templates for the Jini lookup service:

17.4.5.1 Discovering the Jini Lookup Service

The Jini lookup service is represented by the `net.jini.core.lookup.ServiceRegistrar` class. There are two ways to discover the Jini lookup service. The first and most simple way assumes that you know the address of the lookup service, as shown in CODE EXAMPLE 17-6:

CODE EXAMPLE 17-6 Discovering the Jini Lookup Service Using an Address

```
import net.jini.core.lookup.ServiceRegistrar;
import net.jini.core.discovery.LookupLocator;
...
LookupLocator lookup = new LookupLocator("jini://my_host");
ServiceRegistrar registrar = lookup.getRegistrar();
```

The second solution uses a broadcast mechanism to retrieve the lookup services running on the accessible network, as shown in CODE EXAMPLE 17-7:

CODE EXAMPLE 17-7 Discovering the Jini Lookup Service Using a Broadcast Mechanism

```
import net.jini.discovery.LookupDiscovery;
import net.jini.discovery.DiscoveryListener;
import net.jini.discovery.DiscoveryEvent;
import net.jini.core.lookup.ServiceRegistrar;
...
LookupDiscovery lookupDiscovery = null;
try {
    lookupDiscovery = new LookupDiscovery(null);
} catch (IOException e) {...}

lookupDiscovery.addDiscoveryListener(new LookupDiscoveryListener());

private class LookupDiscoveryListener implements DiscoveryListener {

    public LookupDiscoveryListener() {
    }

    public void discovered(DiscoveryEvent evnt) {
        ServiceRegistrar[] regs = evnt.getRegistrars();
        for(int i = 0; i < regs.length; i++) {
```

CODE EXAMPLE 17-7 Discovering the Jini Lookup Service Using a Broadcast Mechanism

```
String[] regGroups = regs[i].getGroups();
// Must verify here that the ServiceRegistrar
// contains the groups I want to register in...
}

// It is generally better here to launch another Thread to use
// the discovered ServiceRegistrar; this avoids blocking the
// discovery process.
}

public void discarded(DiscoveryEvent evnt) {}
}
```

17.4.5.2 Registering a JMX Remote API Connector Stub With the Jini Lookup Service

Registering a JMX Remote API Connector Stub with the Jini Lookup Service is shown in CODE EXAMPLE 17-8:

CODE EXAMPLE 17-8 Registering a JMX Remote API Connector Stub With the Jini Lookup Service

```
import net.jini.core.lookup.ServiceRegistrar;
import net.jini.core.lookup.ServiceItem;
import net.jini.core.lookup.ServiceRegistration;
import net.jini.core.entry.Entry;
import net.jini.core.lease.Lease;
import java.rmi.RemoteException;
...
// Get the Jini ServiceRegistrar with one of the above methods
ServiceRegistrar registrar = ...;

// Get a connector stub for the server you want to export
//
JMXConnector proxy = jmxConnectorServer.toJMXConnector(null);

// Prepare Service's attributes entry
Entry[] serviceAttrs = new Entry[] {
    new net.jini.lookup.entry.Name("MyAgentName");
    // Add here the lookup attributes you want to specify.
};
```

CODE EXAMPLE 17-8 Registering a JMX Remote API Connector Stub With the Jini Lookup Service

```
// Create a ServiceItem from the service instance
ServiceItem srvcItem = new ServiceItem(null, proxy, serviceAttrs);

// Register the Service with the Lookup Service
try {
    ServiceRegistration srvcRegistration =
        registrar.register(srvcItem, Lease.ANY);
    System.out.println("Registered ServiceID: " +
        srvcRegistration.getServiceID().toString());
} catch(RemoteException e) {...}
```

17.4.5.3 Looking up a JMX Connector Stub From the Jini Lookup Service

Looking up a JMX Connector stub from the Jini lookup service is shown in CODE EXAMPLE 17-9:

CODE EXAMPLE 17-9 Looking up a JMX Connector Stub From the Jini Lookup Service

```
import net.jini.core.lookup.ServiceTemplate;
import net.jini.core.lookup.ServiceMatches;
import net.jini.core.lookup.ServiceRegistrar;
import net.jini.core.entry.Entry;
...
// Get the Jini ServiceRegistrar with one of the above methods
ServiceRegistrar registrar = ...;

// Prepare Service's attributes entry to be matched
Entry[] serviceAttrs = new Entry[] {
    // Retrieve all services for which a Name entry was registered,
    // whatever the name is (null = wildcard).
    new net.jini.lookup.entry.Name(null)

    // Add here any other matching attribute.
};

// Look for a specific JMXMP Connector (you may also pass
// JMXConnector.class if you wish to get all types of JMXConnector)
//
ServiceTemplate template = new ServiceTemplate(null,
```

CODE EXAMPLE 17-9 Looking up a JMX Connector Stub From the Jini Lookup Service

```
        new Class[] {JMXMPCConnector.class}, serviceAttrs);

ServiceMatches matches = null;
try {
    matches = registrar.lookup(template, Integer.MAX_VALUE);
} catch (RemoteException e) {...}

// Retrieve the JMX Connector and initiate a connection
for(int i = 0; i < matches.totalMatches; i++) {
    if(matches.items[i].service != null) {

        // Get the JMXConnector
        JMXConnector c = (JMXConnector)(matches.items[i].service);

        // Prepare env (security parameters etc...)
        Map env = new HashMap();
        env.put(...);

        // Initiate the connection
        c.connect(env);

        // Get the remote MBeanServer handle
        MBeanServerConnection server = c.getMBeanServerConnection();
        ...
    }
}
```

17.5 Using the Java Naming and Directory Interface (LDAP Backend)

The *Java Naming and Directory Interface* [JNDI] is a standard extension to the Java platform, providing Java technology-enabled applications with a unified interface to multiple naming and directory services in the enterprise. In particular, it provides a means to access X.500 directory services through the Lightweight Directory Access Protocol (LDAP). This standard defines how an LDAP server can be used to store information about JMX API agents, and how JMX Remote API clients can look up this information to connect to the agents.

A good understanding of using JNDI API with an LDAP backend can be obtained by following the [LDAP Thread in the JNDI Tutorial].

17.5.1 LDAP Schema for Registration of JMX Connectors

Nodes in the LDAP directory tree are typed. A node can have several object classes. JMX Connectors should be registered in nodes of class *jmxConnector*. The *jmxConnector* class contains two attributes, which are the JMX Service URL of the corresponding connector (*jmxServiceURL*), and the name of the JMX API agent exporting this connector (*jmxAgentName*). The JMX Service URL can be absent if the agent is not accepting connections. The *jmxConnector* class also includes optional attributes, like *jmxAgentHost* and *jmxProtocolType*. The agent name makes it possible for a client application to get a connection to an agent it knows by name. Together with the *jmxAgentHost* and *jmxProtocolType* it also makes it possible to perform filtered queries, for instance, "find all the JMXMP connectors of <this> JMX API agent" or "find all connectors of all agents running on <that> node". CODE EXAMPLE 17-10 is the schema definition (as specified in [RFC 2252]) that should be used to register JMX Remote API connectors:

CODE EXAMPLE 17-10 LDAP Schema for Registration of JMX Remote API Connectors

```
-- jmxServiceURL attribute is an IA5 String
( 1.3.6.1.4.1.42.2.27.11.1.1 NAME 'jmxServiceURL'
  DESC 'String representation of a JMX Service URL'
  SYNTAX 1.3.6.1.4.1.1466.115.121.1.26 SINGLE-VALUE )

-- jmxAgentName attribute is an IA5 String
( 1.3.6.1.4.1.42.2.27.11.1.2 NAME 'jmxAgentName'
  DESC 'Name of the JMX Agent'
  SYNTAX 1.3.6.1.4.1.1466.115.121.1.26 SINGLE-VALUE )

-- jmxProtocolType attribute is an IA5 String
( 1.3.6.1.4.1.42.2.27.11.1.3 NAME 'jmxProtocolType'
  DESC 'Protocol used by the registered connector'
  SYNTAX 1.3.6.1.4.1.1466.115.121.1.26 SINGLE-VALUE )

-- jmxAgentHost attribute is an IA5 String
( 1.3.6.1.4.1.42.2.27.11.1.4 NAME 'jmxAgentHost'
  DESC 'Names or IP Addresses of the host on which the
  agent is running. When multiple values are
  given, they should be aliases to the same host.'
  SYNTAX 1.3.6.1.4.1.1466.115.121.1.26 )

-- jmxProperty attribute is an IA5 String
( 1.3.6.1.4.1.42.2.27.11.1.5 NAME 'jmxProperty'
  DESC 'Java-like property characterizing the registered object.
  The form of each value should be: "<property-name>=<value>".
  For instance: "com.sun.jmx.remote.tcp.timeout=200" '
  SYNTAX 1.3.6.1.4.1.1466.115.121.1.26 )
```

CODE EXAMPLE 17-10 LDAP Schema for Registration of JMX Remote API Connectors

```
-- jmxExpirationDate attribute is a Generalized Time
-- see [RFC 2252] - or X.208 for a description of
--           Generalized Time
( 1.3.6.1.4.1.42.2.27.11.1.6 NAME 'jmxExpirationDate'
  DESC 'Date at which the JMX Service URL will
        be considered obsolete and can be removed
        from the directory tree'
  SYNTAX 1.3.6.1.4.1.1466.115.121.1.24 SINGLE-VALUE )

-- from RFC-2256 --
( 2.5.4.13 NAME 'description'
  EQUALITY caseIgnoreMatch
  SUBSTR caseIgnoreSubstringsMatch
  SYNTAX 1.3.6.1.4.1.1466.115.121.1.15{1024} )

-- jmxConnector class - represents a JMX Connector.
--                       must contain the JMX Service URL
--                       and the JMX Agent Name
( 1.3.6.1.4.1.42.2.27.11.2.1 NAME 'jmxConnector'
  DESC 'A class representing a JMX Connector, and
        containing a JMX Service URL.
        The jmxServiceURL is not present if the server
        is not accepting connections'
  AUXILIARY
  MUST ( jmxAgentName )
  MAY ( jmxServiceURL $ jmxAgentHost $ jmxProtocolType $
        jmxProperty $ jmxExpirationDate $ description ) )
```

The *jmxConnector* class is an AUXILIARY class, which means that its properties can be added to any node in the directory tree - namely, it does not impose any restriction on the structure of the directory tree.

To create a node in the directory tree, you also need a STRUCTURAL class. This specification does not impose any restriction on the structural classes that can contain JMX Remote API connectors. You can, for instance, reuse the *javaContainer* class from the *Java Schema* [JNDI - Java Schema] as defined in [RFC 2713], namely, create a node whose object classes would be *javaContainer* (STRUCTURAL) and *jmxConnector* (AUXILIARY). The node containing the *jmxConnector* can also have any additional auxiliary classes.

17.5.2 Mapping to Java Objects

This specification only requires that the JMX Service URL is stored in LDAP. JMX API agents can additionally store a serialized JMX Remote API connector stub, but this is not required by this specification. Clients should only rely on the JMX Service URL. The JNDI API makes it possible for a client to use `StateFactories` and `ObjectFactories` [JNDI - Java Objects] to recreate a `JMXConnector` from the URL when performing a `lookup()`, even if there is no Java Object bound to the containing `DirContext`. Alternatively, a client can directly retrieve the `jmxServiceURL` attribute to obtain a `JMXConnector` from the `JMXConnectorFactory`. Whether the JNDI API `lookup()` returns a `JMXConnector` or a `DirContext` depends on the configuration settings on the client side (`InitialContext`), and remains local to that client.

17.5.3 Structure of the JMX Remote API Registration Tree

The actual structure of a directory varies from one organization to another. Each organization, or enterprise, has its own directory tree structure, with guidelines, policies, etc. In order for JMX API agents to be able to integrate with any pre-existing directory structure, this specification does not impose a fixed directory tree structure for registering agents and JMX Remote API connector servers. Connectors must simply be located in nodes of the class `jmxConnector`. This makes it possible for an organization to set up its own structure for registering agents in an LDAP server. For instance, if an organization has an existing directory containing a node for each host in its network, it could decide to register each agent below the node of the host it is running on.

17.5.4 Leasing

JNDI/LDAP does not provide any built-in lease service. If an agent goes down, its service URLs might remain in the directory server forever. The *jmxExpirationDate* attribute in the *jmxConnector* auxiliary class can be used to avoid that happening, as shown in CODE EXAMPLE 17-11:

CODE EXAMPLE 17-11 Leasing using the *jmxExpirationDate* Attribute

```
-- jmxExpirationDate attribute is a Generalized Time
-- see [RFC 2252] - or X.208 for a description of
--           Generalized Time
( 1.3.6.1.4.1.42.2.27.11.1.6 NAME 'jmxExpirationDate'
  DESC 'Date at which the JMX Service URL will
        be considered obsolete and may be removed
        from the directory tree'
  SYNTAX 1.3.6.1.4.1.1466.115.121.1.24 SINGLE-VALUE )
```

A JMX API agent would have to update the *jmxExpirationDate* attribute periodically. A Directory administrator might then write a daemon that would remove the *jmxConnector* nodes (or more generically the *jmxServiceURL* attributes) for which the *jmxExpirationDate* is obsolete.

17.5.5 Code Templates

The following sections provide some code templates for the JNDI API lookup service

17.5.5.1 Discovering the LDAP Server

JNDI/LDAP does not provide any standard means for discovering the LDAP server. Assuming the standard port (389) on the local host is the entry point is usually not an option, since the LDAP server is usually centralized, rather than having one server per host. The JNDI API specifies a means to discover the LDAP server(s) through DNS [JNDI - LDAP Servers Discovery], but this is operating system dependent, and not always feasible either since the LDAP servers cannot always be registered in DNS. This specification thus does not address the issue of discovering the LDAP server.

The JNDI API tutorial gives an example of how to configure an `InitialContext` with a list of LDAP URLs [JNDI - Multi URL].

17.5.5.2 Registering a JMXServiceURL in the LDAP server

This specification does not impose any structure on the directory tree for registering JMX Service URLs. It is assumed that the JMX API agent knows where to register its connectors, either from configuration, or from some built-in logic adapted to the environment in which it is running. This specification defines the form of the data that is registered in the directory (the *how* rather than the *where*), so that any JMX Remote API client can look it up in a generic way. See CODE EXAMPLE 17-12.

CODE EXAMPLE 17-12 Registering a JMXServiceURL in the LDAP server

```
import javax.naming.InitialContext;
import javax.naming.directory.DirContext;
import javax.naming.directory.Attribute;
import javax.naming.directory.BasicAttribute;
import javax.naming.directory.Attributes;
import javax.naming.directory.BasicAttributes;
...

// Create initial context
Hashtable env = new Hashtable(11);
env.put(InitialContext.PROVIDER_URL, ldapServerUrls);
env.put(...);
InitialContext root = new InitialContext(env);

// Assuming that the Directory Administrator has created a
// context for this agent, get the DN of that context
// from configuration (e.g. Java property)
// String myOwnLdapDN =
//     System.getProperty("com.sun.jmx.myapplication.dn");
String myOwnLdapDN = ....
DirContext myContext = (DirContext)root.lookup(myOwnLdapDN);

// Create connector server
JMXServiceURL jmxUrl = new
    JMXServiceURL("service:jmx:jmxmp://localhost:9999");
JMXConnectorServer connectorServer =
    JMXConnectorServerFactory.newJMXConnectorServer(jmxUrl, null, null);

// Prepare attributes for register connector server
Attributes attrs = new BasicAttributes();

// Prepare objectClass attribute: we're going to create
// a javaContainer (STRUCTURAL) containing a
// jmxConnector (AUXILIARY).
```

CODE EXAMPLE 17-12 Registering a JMXServiceURL in the LDAP server

```
Attribute objclass = new BasicAttribute("objectClass");
objclass.add("top");
objclass.add("javaContainer");
objclass.add("jmxConnector");
attrs.put(objclass);

// Add jmxServiceURL of the connector.
attrs.put("jmxServiceURL", jmxUrl.toString());

// Add jmxAgentName
attrs.put("jmxAgentName", "MyAgentName");

// Add optional attributes, if needed
attrs.put("jmxProtocolType", "jmxmp");
attrs.put("jmxAgentHost", InetAddress.getLocalHost().getHostName());

// Now create the sub context in which to register the URL
// of the JMXMP connector.
// (we assume that the subcontext does not exist yet -
// ideally the agent should contain some more complex logic:
// if the context already exists, simply modify its attributes,
// otherwise, create it with its attributes).
myContext.createSubcontext("cn=service:jmx:rmi", attrs);
```

17.5.5.3 Looking up a JMX Service URL From the LDAP Server

CODE EXAMPLE 17-13 shows how to look up a JMX service URL from the LDAP server.

CODE EXAMPLE 17-13 Looking up a JMX Service URL From the LDAP Server

```
import javax.naming.InitialContext;
import javax.naming.NamingEnumeration;
import javax.naming.directory.DirContext;
import javax.naming.directory.Attribute;
import javax.naming.directory.Attributes;
import javax.naming.directory.SearchResult;
import javax.naming.directory.SearchControls;
...

// Create initial context
Hashtable env = new Hashtable();
env.put(InitialContext.PROVIDER_URL, ldapServerUrls);
env.put(...);
InitialContext root = new InitialContext(env);

// Prepare search filter
String filter = "&(objectClass=jmxConnector) (jmxServiceURL=*)";

// Prepare the search controls
SearchControls ctrls = new SearchControls();

// Want to get all jmxConnector objects, wherever they've been
// registered.
ctrls.setSearchScope(SearchControls.SUBTREE_SCOPE);

// Want to get only the jmxServiceURL (comment this line and
// all attributes will be returned).
ctrls.setReturningAttributes(new String[] { "jmxServiceURL" });

// Search...
final NamingEnumeration results = root.search("", filter, ctrls);

// Get the URL...
for (;results.hasMore()); {
    final SearchResult res = (SearchResult) results.nextElement();
```

CODE EXAMPLE 17-13 Looking up a JMX Service URL From the LDAP Server

```
final Attributes  attrs = res.getAttributes();
final Attribute  attr  = attrs.get("jmxServiceURL");
final String     urlStr = (String)attr.get();

// Make a connector...
final JMXServiceURL url = new JMXServiceURL(urlStr);
final JMXConnector conn =
    JMXConnectorFactory.newConnector(url,null);

// Start using the connector...
conn.connect(null);
...
}
```

17.6 Registration With Standards Bodies

In parallel with the completion of this specification, the following registrations are being made with standards bodies:

- For SLP, the `jmx` service type and associated service template are being registered with IANA
- For LDAP, the OIDs for the lookup attributes defined in Section 17.5.1 “LDAP Schema for Registration of JMX Connectors” on page 265 are defined in Sun’s OID namespace
- For the Jini networking technology, the entries for the lookup attributes are being defined through the Jini Community Decision Process (JDP)

Summary of Environment Parameters

The environment parameters defined by this standard all begin with the string "jmx.remote.". Implementations that define further parameters can use one of the following conventions:

- The reverse domain name convention used by Java platform packages, for example "com.sun.jmx.remote.something"
- A name beginning with the string "jmx.remote.x." (including the final period)

An implementation must not define non-standard parameters that begin with "jmx.remote." unless they begin with "jmx.remote.x."

Names beginning with "jmx.remote.x." can be shared between different implementations. They are useful for agreed-on experimental extensions, but they run the risk of collision, where two implementations use the same name to mean two different things.

In TABLE 18-1, each parameter is defined by the following characteristics:

- The *name* after the initial "jmx.remote." string
- The *type* that the associated value must have
- Whether the parameter applies to connector clients, to connector servers, or both
- For server parameters, whether the parameter is visible, that is whether it appears in the Map returned by `JMXConnectorServerMBean.getAttributes()`

TABLE 18-1 Environment Parameters

Name <code>jmx.remote.+</code>	Type	Client/ Server	Visible	Meaning
<code>authenticator</code>	JMXAuthen- ticator	Server	No	Object to authenticate incoming connections to the connector. See Section 14.4 “Basic Security With the RMI Connector” on page 230, and Section 15.3.6.1 “Global Properties of the Generic Connector” on page 244.
<code>context</code>	Object	Both	No	Context transmitted during handshake. See Section 15.3.6 “Properties Controlling Client and Server” on page 244
<code>credentials</code>	Object	Client	N/A	Client credentials to authenticate to the RMI connector server. See Section 14.4 “Basic Security With the RMI Connector” on page 230
<code>default.class. loader</code>	Class Loader	Both	No	Default class loader to deserialize objects received from the other end of a connection. See Section 13.11 “Class Loading” on page 218
<code>default.class. loader.name</code>	Object Name	Server	Yes	Name of class loader MBean that will be used to deserialize objects received from the client. See Section 13.11 “Class Loading” on page 218
<code>jndi.rebind</code>	String	Server	Yes	“true” or “false” according as an RMI stub object can overwrite an existing object at the JNDI address specified in a JMXServiceURL
<code>message.connection</code>	MessageCo nnection	Client	N/A	Object describing the transport used by the Generic Connector. See Section 15.1 “Pluggable Transport Protocol” on page 233

TABLE 18-1 Environment Parameters

Name <code>jmx.remote.+</code>	Type	Client/Server	Visible	Meaning
<code>message.connection.server</code>	<code>MessageConnectorServer</code>	Server	No	Object describing the transport used by the <code>GenericConnectorServer</code> . See Section 15.1 “Pluggable Transport Protocol” on page 233
<code>object.wrapping</code>	<code>ObjectWrapping</code>	Both	No	Object describing how parameters with non-default serialization are handled. See Section 15.2 “Pluggable Object Wrapping” on page 234
<code>profiles</code>	<code>String</code>	Both	Yes	List of profiles proposed (server) or required (client) by the connector. See Section 15.3.6 “Properties Controlling Client and Server” on page 244
<code>protocol.provider.class.loader</code>	<code>ClassLoader</code>	Client	N/A	See <code>JMXConnectorFactory</code> documentation.
<code>protocol.provider.pkgs</code>	<code>String</code>	Client	N/A	See <code>JMXConnectorFactory</code> documentation.
<code>rmi.client.socket.factory</code>	<code>RMIClientSocketFactory</code>	Server	No	Client socket factory for connections to the RMI connector. See Section 14.4 “Basic Security With the RMI Connector” on page 230
<code>rmi.server.socket.factory</code>	<code>RMI ServerSocketFactory</code>	Server	No	Server socket factory for connections to the RMI connector. See Section 14.4 “Basic Security With the RMI Connector” on page 230
<code>sasl.authorization.id</code>	<code>String</code>	Client	N/A	Authorization ID when this is different from the authentication ID. See Section 15.3.6 “Properties Controlling Client and Server” on page 244
<code>sasl.callback.handler</code>	<code>CallbackHandler</code>	Both	No	Callback handler for SASL mechanism. See Section 15.3.6 “Properties Controlling Client and Server” on page 244

TABLE 18-1 Environment Parameters

Name <code>javax.remote.*</code>	Type	Client/ Server	Visible	Meaning
<code>server.address.wildcard</code>	String	Server	Yes	"true" or "false" according to whether connector server should listen on all local network interfaces or just one. See <code>JMXMPCConnectorServer</code> documentation.
<code>tls.enabled.cipher.suites</code>	String	Both	Yes	TLS cipher suites to enable. See Section 15.3.6 "Properties Controlling Client and Server" on page 244
<code>tls.enabled.protocols</code>	String	Both	Yes	TLS protocols to enable. See Section 15.3.6 "Properties Controlling Client and Server" on page 244
<code>tls.need.client.authentication</code>	String	Server	Yes	"true" or "false" according to whether connector server requires client authentication. See Section 15.3.6 "Properties Controlling Client and Server" on page 244
<code>tls.socket.factory</code>	SSLSocket Factory	Both	No	TLS socket factory for this connector. See Section 15.3.6 "Properties Controlling Client and Server" on page 244
<code>tls.want.client.authentication</code>	String	Server	Yes	"true" or "false" according to whether connector server requires client authentication if supported by the negotiated cipher suite. See Section 15.3.6 "Properties Controlling Client and Server" on page 244

A

Service Templates

This appendix defines the service templates that describe the `service:jmx` services in conformance to [RFC 2609]. These service template are a formal description of the bindings between the Service Location Protocol and JSR 160 connectors.

Note – The following templates are a copy of the submissions that have been made to `svrloc-list@iana.org`.

A.1 Service Template for the `service:jmx` Abstract Service Type

- **Template Filename:** `jmx.1.0.en`
- **Name of submitter:** JSR-160 Expert Group <`jsr-160-comments@jcp.org`>
- **Language of service template:** `en`
- **Security considerations:**
 - Security is defined by each of the concrete service types.
 - See those templates for further details.
- **TemplateText:**

CODE EXAMPLE A-1 Service template for the `service:jmx` Abstract Service Type

```
Name of submitter: JSR-160 Expert Group <jsr-160-comments@jcp.org>
Language of service template: en
Security considerations:
    Security is defined by each of the concrete service types.
    See those templates for further details.

TemplateText:
-----template begins here-----
template-type=jmx
```

CODE EXAMPLE A-1 Service template for the service:jmx Abstract Service Type

```
template-version=1.0
template-description=
    This is an abstract service type. The purpose of the jmx service
    type is to organize in a single category all JMX Connectors that
    make it possible to access JMX Agents remotely.
    JMX Connectors are defined by the Java Specification Request 160
    (JSR 160). More information on JSR 160 can be obtained from the
    Java Community Process Home Page at:
        http://www.jcp.org/en/jsr/detail?id=160

template-url-syntax=
    url-path= ; Depends on the concrete service type.

AgentName= string L
# The name of the JMX Agent - see JSR 160 specification.

ProtocolType= string O L
# The type of the protocol supported by the JMX Connector.
# Currently only two protocols are mandatory in the specification: "rmi" and
# "iiop". A third optional protocol is also standardized: "jmxmp".
# However this could be extended in the future to support other types
# of protocols, e.g. "http", "https", "soap", "beep", etc...
# Thus, the allowed values of this attribute are at least "rmi" and "iiop"
# for every implementation; additionally "jmxmp" for implementations that
# support it; and other protocol names that are understood by client and
# server.
# The value of this attribute is the same as the protocol name that appears
# after "service:jmx:" in the Service URL. Registering the ProtocolType
# attribute means clients can search for connectors of a particular type.

AgentHost= string O M L
# The host name or IP address of the host on which the JMX Agent is running.
# If multiple values are given they must be aliases to the same host.

Property= string O M L
# Additional properties qualifying the agent, in the form of Java-like
# properties, e.g. "com.sun.jmx.remote.connect.timeout=200"
# Note that in order to include '=' in an attribute value, it must be
# escaped. Thus the example would be encoded as
```

```
# "com.sun.jmx.remote.connect.timeout\3D200"  
-----template ends here-----
```

A.2 Service Template for the service:jmx:jmxmp Concrete Service Type

- **Template Filename:** jmx:jmxmp.1.0.en
- **Name of submitter:** JSR-160 Expert Group <jsr-160-comments@jcp.org>
- **Language of service template:** en
- **Security considerations:**
 - Security for the JMXMP connector is defined by JSR 160 specification and is based on SASL mechanisms.
 - For further details please refer to JSR 160 specification available at <http://www.jcp.org/en/jsr/detail?id=160>
- **TemplateText:**

CODE EXAMPLE A-2 Service Template for the service:jmx:jmxmp Concrete Service Type

```
Name of submitter: JSR-160 Expert Group <jsr-160-comments@jcp.org>  
Language of service template: en  
Security considerations:  
    Security for the JMXMP connector is defined by JSR 160  
    specification and is based on SASL mechanisms.  
    For further details please refer to JSR 160 specification  
    available at http://www.jcp.org/en/jsr/detail?id=160  
  
TemplateText:  
-----template begins here-----  
  
template-type=jmx:jmxmp  
  
template-version=1.0  
  
template-description=  
    This template describes the JMXMP Connector defined by JSR 160.
```

CODE EXAMPLE A-2 Service Template for the `service:jmx:jmxmp` Concrete Service Type

```
More information on this connector can be obtained from the
JSR 160 specification available from the JCP Home Page at:
http://www.jcp.org/en/jsr/detail?id=160
```

```
template-url-syntax=
  url-path= ; There is no URL path defined for a jmx:jmxmp URL.
```

```
# Example of a valid Service URL:
# service:jmx:jmxmp://myhost:9876
# There are no default values for the host or port number, so in
# general these must be supplied when registering the URL.
-----template ends here-----
```

A.3 Service Template for the `service:jmx:rmi` Concrete Service Type

- **Template Filename:** `jmx:rmi.1.0.en`
- **Name of submitter:** JSR-160 Expert Group <`jsr-160-comments@jcp.org`>
- **Language of service template:** `en`
- **Security considerations:**

Java Specification Request (JSR) 160 defines a secure configuration of the `jmx:rmi` connector, based on SSL socket factories.

For further details please refer to JSR 160 specification available at <http://www.jcp.org/en/jsr/detail?id=160>
- **TemplateText:**

CODE EXAMPLE A-3 Service Template for the `service:jmx:rmi` Concrete Service Type

```
Name of submitter: JSR-160 Expert Group <jsr-160-comments@jcp.org>
Language of service template: en
Security considerations:
  Java Specification Request (JSR) 160 defines a secure
  configuration of the jmx:rmi connector, based on SSL socket
  factories.
  For further details please refer to JSR 160 specification
  available at http://www.jcp.org/en/jsr/detail?id=160
```


CODE EXAMPLE A-3 Service Template for the service:jmx:rmi Concrete Service Type

```
TemplateText:
-----template begins here-----
template-type=jmx:rmi

template-version=1.0
template-description=
    This template describes the RMI Connector defined by JSR 160.
    More information on this connector can be obtained from the
    JSR 160 specification available from the JCP Home Page at:
        http://www.jcp.org/en/jsr/detail?id=160

template-url-syntax=
    url-path          =   jndi-path / stub-path
    stub-path         =   "/stub/" *xchar
        ; serialized RMI stub encoded as BASE64 without newlines
    jndi-path         =   "/jndi/" *xchar
        ; name understood by JNDI API, shows where RMI stub is stored
    ; The following rules are extracted from RFC 2609
    safe              =   "$" / "-" / "_" / "." / "~"
    extra            =   "!" / "*" / "'" / "(" / ")" / "," / "+"
    uchar            =   unreserved / escaped
    xchar            =   unreserved / reserved / escaped
    escaped           =   1*(`\' HEXDIG HEXDIG)
    reserved         =   ";" / "/" / "?" / ":" / "@" / "&" / "=" / "+"
    unreserved       =   ALPHA / DIGIT / safe / extra

# Examples of the stub form:
# service:jmx:rmi://myhost:9999/stub/r00ABX<270 chars deleted>gAAAEa==
# service:jmx:rmi:///stub/r00ABX<270 chars deleted>gAAAEa==
# This form contains the serialized form of the Java object representing
# the RMI stub, encoded in BASE64 without newlines. It is generated by
# the connector server, and is not intended to be human-readable.
#
# Examples of the JNDI form:
# service:jmx:rmi://myhost:9999/jndi/ldap://namehost:389/a=b,c=d
# service:jmx:rmi:///jndi/ldap://namehost:389/a=b,c=d
# If the client has an appropriate JNDI configuration, it can use
# a URL such as this:
# service:jmx:rmi:///jndi/a=b,c=d
#
# In both the /stub/ and /jndi/ forms, the hostname and port number
# (myhost:9999 in the examples) are not used by the client and, if
```

CODE EXAMPLE A-3 Service Template for the `service:jmx:rmi` Concrete Service Type

```
# present, are essentially comments. The connector server address
# is actually stored in the serialized stub (/stub/ form) or in the
# directory entry (/jndi/ form).
#
# For more information, see the JSR 160 specification, notably the
# package javax.management.remote.rmi.
-----template ends here-----
```

A.4 Service Template for the `service:jmx:iiop` Concrete Service Type

- **Template Filename:** `jmx:iiop.1.0.en`
- **Name of submitter:** JSR-160 Expert Group <jsr-160-comments@jcp.org>
- **Language of service template:** `en`
- **Security considerations:**

There is no special security defined for the `jmx:iiop` connector, besides the mechanisms provided by RMI over IIOP itself. In its default configuration, the `jmx:iiop` connector is not secure. Applications that are concerned with security should therefore not advertise their `jmx:iiop` connectors through this template, unless they have taken the appropriate steps to make it secure.

For further details please refer to JSR 160 specification available at <http://www.jcp.org/en/jsr/detail?id=160>

- **TemplateText:**

CODE EXAMPLE A-4

```
Name of submitter: JSR-160 Expert Group <jsr-160-comments@jcp.org>
Language of service template: en
Security considerations:
There is no special security defined for the jmx:iiop connector,
besides the mechanisms provided by RMI over IIOP itself. In its
default configuration, the jmx:iiop connector is not
secure. Applications that are concerned with security should therefore
not advertise their jmx:iiop connectors through this template, unless
they have taken the appropriate steps to make it secure.

For further details please refer to JSR 160 specification available at
```

CODE EXAMPLE A-4

```
http://www.jcp.org/en/jsr/detail?id=160

TemplateText:
-----template begins here-----

template-type=jmx:rmi-iiop
template-version=1.0

template-description=
    This template describes the RMI/IIOP Connector defined by JSR 160.
    More information on this connector can be obtained from the
    JSR 160 specification available from the JCP Home Page at:
    http://www.jcp.org/en/jsr/detail?id=160
template-url-syntax=
    url-path          =   jndi-path / ior-path
    ior-path          =   "/ior/IOR:" *HEXDIG
                       ; CORBA IOR
    jndi-path         =   "/jndi/" *xchar
                       ; name understood by JNDI API, shows where RMI/IIOP stub is stored
    ; The following rules are extracted from RFC 2609
    safe              =   "$" / "-" / "_" / "." / "~"
    extra             =   "!" / "*" / "'" / "(" / ")" / "," / "+"
    uchar             =   unreserved / escaped
    xchar             =   unreserved / reserved / escaped
    escaped            =   1*(`\' HEXDIG HEXDIG)
    reserved          =   ";" / "/" / "?" / ":" / "@" / "&" / "=" / "+"
    unreserved        =   ALPHA / DIGIT / safe / extra

# Examples of the IOR form:
# service:jmx:iiop://myhost:9999/ior/IOR:000000000000003b<350 chars deleted>00
# service:jmx:iiop:///ior/IOR:000000000000003b<350 chars deleted>00
# This form contains the CORBA IOR for the remote object representing
# the connector server. It is generated by the connector server, and
# is not intended to be human-readable.
#
# Examples of the JNDI form:
# service:jmx:iiop://myhost:9999/jndi/ldap://namehost:389/a=b,c=d
# service:jmx:iiop:///jndi/ldap://namehost:389/a=b,c=d
# If the client has an appropriate JNDI configuration, it can use
# a URL such as this:
# service:jmx:iiop:///jndi/a=b,c=d
#
# In both the /ior/ and /jndi/ forms, the hostname and port number
```

CODE EXAMPLE A-4

```
# (myhost:9999 in the examples) are not used by the client and, if
# present, are essentially comments. The connector server address is
# actually stored in the IOR (/ior/ form) or in the directory entry
# (/jndi/ form).
#
# For more information, see the JSR 160 specification, notably the
# package javax.management.remote.rmi.
-----template ends here-----
```

CODE EXAMPLE A-5 Service Template for the service:jmx:iiop Concrete Service Type

```
-----template begins here-----

template-type=jmx:rmi-iiop
template-version=1.0

template-description=
  This template describes the RMI/IIOP Connector defined by JSR 160.
  More information on this connector can be obtained from the
  JSR 160 specification available from the JCP Home Page at:
  http://www.jcp.org/en/jsr/detail?id=160
template-url-syntax=
  url-path      =  jndi-path / ior-path
  jndi-path     =  "/jndi/" *xchar
                ; name understood by JNDI API, shows where RMI/IIOP stub is stored
  ior-path      =  "/ior/IOR:" *HEXDIG
                ; CORBA IOR
  ; The following rules are extracted from RFC 2609
  safe          =  "$" / "-" / "_" / "." / "~"
  extra        =  "!" / "*" / "'" / "(" / ")" / "," / "+"
  uchar        =  unreserved / escaped
  xchar        =  unreserved / reserved / escaped
  escaped       =  1*(\'" HEXDIG HEXDIG)
  reserved     =  ";" / "/" / "?" / ":" / "@" / "&" / "=" / "+"
  unreserved   =  ALPHA / DIGIT / safe / extra

-----template ends here-----
```

B

Non-standard environment parameters

This appendix lists non-standard environment parameters that are understood by the Reference Implementation of this specification. These attributes are defined in the `jmx.remote.x` namespace. As described in Chapter 18 “Summary of Environment Parameters”, this namespace is reserved for non-standard extensions to the parameters defined in this specification.

Implementations are not required to support the parameters defined here. However, implementors are encouraged to use the same name and semantics where applicable.

The format of this table is the same as for the table in TABLE 18-1 on page 274.

Where the type of an attribute is “integer”, the value can be of any subclass of `java.lang.Number`, typically `Integer` or `Long`. It can also be a string, which is parsed as a decimal integer.

When the type of an attribute is “boolean”, the value must be one of the strings “true” or “false”, ignoring case.

TABLE B-1 Environment Parameters

Name	Type	Client/ Server	Visible	Meaning
<code>jmx.remote.x.+</code>				
<code>access.file</code>	String	Server	No	Name of a file containing access levels for simple RMI and JMXMP connector access control. Uses Properties file format: property name is user name, property value is "readonly" or "readwrite".
<code>check.notification.emission</code>	boolean	Server	Yes	If true, a client will only receive a given notification if it has permission to call <code>addNotificationListener</code> on the MBean that sent the notification. It must have had that permission to register its listener, but may have lost it since.
<code>check.stub</code>	boolean	Client	N/A	If true, the RMI connector client will require the RMI stubs it is given to contain the standard SSL/TLS-based <code>RMIClientSocketFactory</code> .
<code>client.connection.check.period</code>	integer	Client	N/A	Time in milliseconds between client probes of an open connection. The client will do a harmless operation on the connection with this period in order to detect communication problems on otherwise-idle connections. The value can be negative or zero to disable this probing.
<code>fetch.notifications.executor</code>	Executor	Client	N/A	<code>java.util.concurrent.Executor</code> to be used for the remote <code>fetchNotifications</code> operation.
<code>login.config</code>	String	Server	Yes	JAAS <code>LoginContext</code> configuration entry name for authentication. The <code>CallbackHandler</code> will make the username and password (supplied as an array of two Strings via <code>jmx.remote.credentials</code>) available to the <code>LoginModule</code> through the <code>NameCallback</code> and <code>PasswordCallback</code> .
<code>notification.buffer.size</code>	integer	Server	Yes	Minimum size of the buffer that stores notifications for one or more connector servers. A connector server will remember a notification if there have not been this many others since it was sent.
<code>notification.fetch.max</code>	integer	Client	N/A	Maximum number of notifications that a client (RMI or JMXMP) will request in a single <code>fetchNotifications</code> request.
<code>notification.fetch.timeout</code>	integer	Client	N/A	Timeout in milliseconds that a client (RMI or JMXMP) will specify in each <code>fetchNotifications</code> request.

TABLE B-1 Environment Parameters

Name	Type	Client/ Server	Visible	Meaning
<code>jmx.remote.x.+</code>	String	Server	No	Name of a file containing username and password entries for RMI authentication. Uses Properties file format: property name is user name, property value is password.
<code>request.waiting.timeout</code>	integer	Client	N/A	Timeout in milliseconds for the response to each JMXMP client request. If a response does not arrive within this time, the connection is assumed to be broken and is terminated. Specifying too short a value will cause this to happen for requests whose treatment happens to be slow. Default value is infinite.
<code>server.connection.timeout</code>	integer	Server	Yes	Time in milliseconds that the server will keep a connection open after answering the most recent client request.
<code>server.max.threads</code>	integer	Server	Yes	Maximum number of server threads for each JMXMP connection. If more than this many requests arrive simultaneously, the surplus ones will be blocked until others complete.
<code>server.min.threads</code>	integer	Server	Yes	Minimum number of server threads for each JMXMP connection. The server will keep at least this many threads alive, even if the current number of requests is less than this.

References

J

JAAS

Sun Microsystems, Java Authentication and Authorization Service (JAAS), [http
//java.sun.com/products/jaas/](http://java.sun.com/products/jaas/)

Jini

Sun Microsystems, Jini Network Technology, [,http
//www.sun.com/software/jini/](http://www.sun.com/software/jini/)

JNDI ,

Sun Microsystems, Java Naming and Directory Interface,[http
//java.sun.com/products/jndi/](http://java.sun.com/products/jndi/)

JNDI - Java Objects

JNDI Tutorial, Java Objects and the Directory, [http
//java.sun.com/products/jndi/tutorial/objects/index.html](http://java.sun.com/products/jndi/tutorial/objects/index.html)

JNDI - Java Schema

JNDI Tutorial, Java Schema for the Directory,[http
//java.sun.com/products/jndi/tutorial/config/LDAP/java.schema](http://java.sun.com/products/jndi/tutorial/config/LDAP/java.schema)

JNDI - LDAP Servers Discovery

JNDI Tutorial, Automatic Discovery of LDAP Servers, [,http
//java.sun.com/products/jndi/tutorial/ldap/connect/create.html#AUTO](http://java.sun.com/products/jndi/tutorial/ldap/connect/create.html#AUTO)

JNDI - Multi URL

JNDI Tutorial, How to specify more than one URL when creating initial context., [,http
//java.sun.com/products/jndi/tutorial/ldap/misc/src/MultiUrls.java](http://java.sun.com/products/jndi/tutorial/ldap/misc/src/MultiUrls.java)

JSR 140

Nick Briers, et al, Service Location Protocol (SLP) API for Java, 2001,[http
//www.jcp.org/en/jsr/detail?id=140](http://www.jcp.org/en/jsr/detail?id=140)

JSR28

Lee, Rosanna, et al, Java SASL Specification, [http
//jcp.org/en/jsr/detail?id=28](http://jcp.org/en/jsr/detail?id=28)

JSSE

Sun Microsystems, Java Secure Socket Extension (JSSE), [,http
//java.sun.com/products/jsse/](http://java.sun.com/products/jsse/)

L

LDAP Thread in the JNDI Tutorial

Tips for LDAP Users, [http
//java.sun.com/products/jndi/tutorial/ldap/index.html](http://java.sun.com/products/jndi/tutorial/ldap/index.html)

R

RFC , , ,

RFC 2608

E. Guttman, et al, Service Location Protocol, Version 2, 1999,[http
//www.ietf.org/rfc/rfc2608.txt](http://www.ietf.org/rfc/rfc2608.txt)

RFC 2609

E. Guttman, C. Perkins, J. Kempf, 1999, <http://www.ietf.org/rfc/rfc2609.txt>
RFC 2614

J. Kempf, E. Guttman., An API for Service Location, 1999, <http://www.ietf.org/rfc/rfc2614.txt>
RFC 2713

V. Ryan, et al., Schema for Representing Java Objects in an LDAP Directory, 1999, <http://www.ietf.org/rfc/rfc2713.txt>
RFC2222

Myers, J, Simple Authentication and Security Layer (SASL), 1997, <ftp://ftp.rfc-editor.org/in-notes/rfc2222.txt>

RMI/SSL
Sun Microsystems, Using RMI with SSL, 2001

S
Serial
Sun Microsystems, Inc, Java Object Serialization Specification

SLP
IETF SVRLOC working group, Service Location Protocol, <http://www.srvloc.org/>

SLP White Paper
C. Perkins, http://playground.sun.com/srvloc/slp_white_paper.html