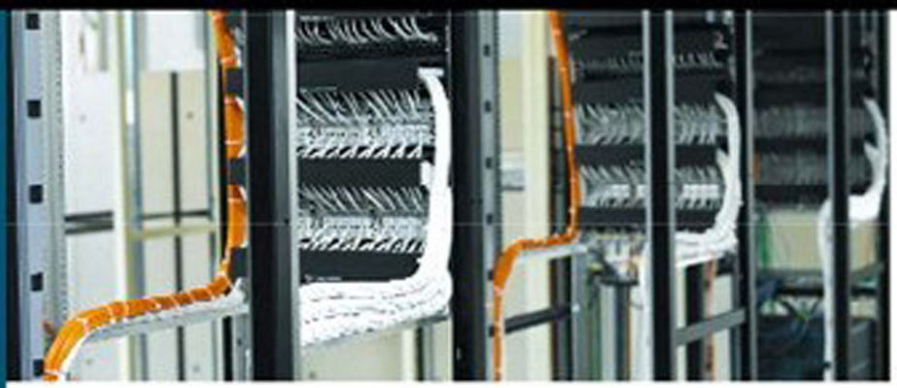

QoS for IP/MPLS Networks

A comprehensive guide to implementing QoS in IP/MPLS networks using Cisco IOS and Cisco IOS XR Software

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Published by:
Cisco Press
800 East 96th Street
Indianapolis, IN 46240 USA

Printed in the United States of America 1 2 3 4 5 6 7 8 9 0

First Printing June 2006

Library of Congress Cataloging-in-Publication Number is on file.

ISBN: 1-58714-391-7

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Dedications

Thanks for withstanding long, long working hours.

Acknowledgments

I would like to give special thanks to Bob Olsen and Sandeep Bajaj for sharing their technical expertise through so many years. They have patiently tolerated my constant interruptions and have provided useful insight on different topics included in the book.

Special thanks to the reviewers, Mark Gallo and Raymond Zhang. I appreciate your detailed comments. I am to blame for any remaining inaccuracies or omissions.

Big thanks to Bruce Davie, whose responsiveness at key points encouraged me to persist in my goal. I highly regard his unusual ability to abstract complexity and clearly illustrate the essence of intricate technology concepts. Much of his work has directly and indirectly influenced the content of this book. Similarly, I extend my gratitude to François Le Faucheur and Jean Philippe Vasseur. They have had the patience to discuss with me many aspects of these technologies in numerous occasions. *Merci!*

Thanks to Ramesh Uppili for contributing to the presentation of key topics in multiple ways.

I also want to thank Rakesh Gandi, Prashanth Yelandur, Ashish Savla, Bobby Kaligotla, Lawrence Wobker, Ashok Ganesan, Jay Thontakudi, and Scott Yow for facilitating the discussion of Cisco IOS XR in this book.

Special thanks to the Cisco Press team: John Kane, Chris Cleveland, Jill Batistick, San Dee Phillips, and Elizabeth Peterson. I really appreciate your attention to detail and extraordinary patience with me. I wish John the best in his new endeavors.

Finally, if you have read this far in search of your name, this paragraph is for you. I have to acknowledge that numerous individuals contributed through insightful discussions. They unhappily or maybe happily remain anonymous. Thanks!

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Contents at a Glance

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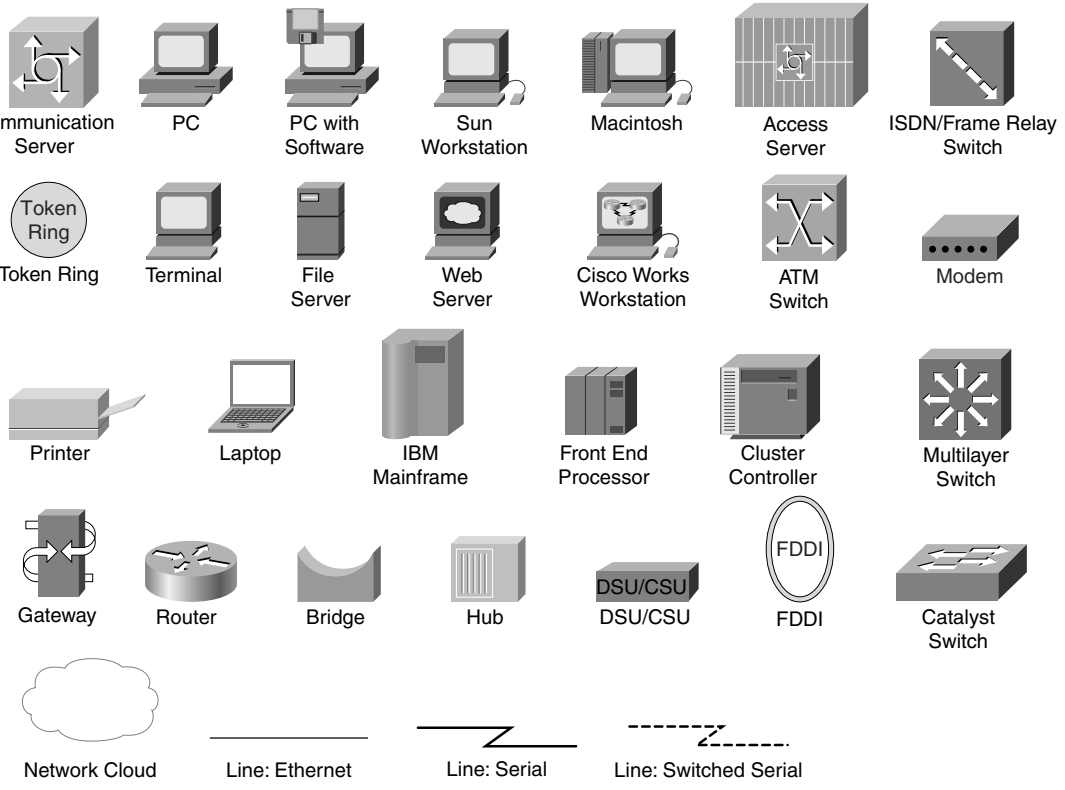

Command Syntax Conventions

The conventions used to present command syntax in this book are the same conventions used in the IOS Command Reference. The Command Reference describes these conventions as follows:

- **Boldface** indicates commands and keywords that are entered literally as shown. In actual configuration examples and output (not general command syntax), boldface indicates commands that are manually input by the user (such as a **show** command).
- *Italics* indicate arguments for which you supply actual values.
- Vertical bars (|) separate alternative, mutually exclusive elements. Note, however, that the vertical bar (pipe operand) is also used to filter command-line interface command output; in that scenario, the operand (|) precedes the **begin**, **exclude**, or **include** keywords, which are then followed by a regular expression.
- Square brackets [ ] indicate optional elements.
- Braces { } indicate a required choice.
- Braces within brackets [{ }] indicate a required choice within an optional element.

Foreword

The phrase “IP QoS” was for many years considered an oxymoron. Indeed, much of the success of the IP architecture could be traced to its adoption of a "best effort" service model, enabling IP to run over just about any underlying network technology. Best effort service, however, is defined by a lack of assurance that packets will be delivered in a timely manner, or even delivered at all. Such a service model limits the potential of IP networks to support applications that demand timely packet delivery, such as interactive telephony and multimedia applications.

As far back as 1979, there were proposals to extend the IP service model to support applications with stronger QoS requirements. However, this remained a research topic until the early 1990s. By that point, the idea of convergence—carrying many applications with diverse QoS needs on a single network—was gaining currency, although the word “convergence” would not become a buzzword for several years. ATM was widely expected to be the packet switching technology that would enable this convergence, but a concerted effort to add QoS to IP was also getting underway. The seminal 1992 paper by Clark, Shenker, and Zhang on support of real-time applications in the Internet put a serious stake in the ground for IP QoS, and work at the IETF to standardize a set of IP QoS mechanisms began shortly thereafter. The Integrated Services architecture and Resource Reservation Protocol resulted, and the Differentiated Services architecture followed.

Another technical development with big implications for IP QoS was Multiprotocol Label Switching, which grew out of work on Tag Switching at Cisco begun in 1996. There was considerable confusion about exactly what impact MPLS would have on IP QoS, in part because of the resemblances between MPLS and ATM, which had its own QoS model. In reality, the biggest single effect MPLS had on QoS was to add another tool to the QoS toolbox, in the form of traffic engineering with constraint-based routing. It is for this reason more than any other that MPLS and QoS deserve to be covered in a single book.

Which brings us to the current volume. IP QoS can now be considered a mature technology, not just something for the bleeding edge. It is also notoriously complex to understand and to configure correctly. Some of this complexity is intrinsic; some is an accident of history. On the intrinsic side, understanding QoS is hard because it requires the ability to operate at many different levels of abstraction. One needs to understand the high level QoS architectures, to have a behavioral model of QoS features inside a router, to know how those features map onto a particular piece of hardware, and to understand the CLI that is used to control those features. This is where this book sets itself apart from the pack of QoS books. Some cover QoS architecture and IETF standards. Some provide information on CLI commands. But this is the only book I've found that walks the reader through the levels of abstraction from high level architecture to low level CLI, with a clear explanation of the abstract QoS behavior model that all routers support providing the bridge between the levels. By reading this book, you will understand both the big picture of QoS and the details necessary to deploy it in a real network.

Another factor that made QoS difficult to manage in the past was a somewhat ad hoc approach to its implementation. Combinations of features were sometimes implemented in a monolithic way, and inconsistency across platforms was the norm. This situation has improved massively in recent years, notably with the adoption of the Modular QoS CLI across most of the Cisco product line. Thus, QoS deployment is much more straightfoward than it once was, and this book's timely coverage of the MQC and its underlying behavioral model will make it even easier.

Many readers may be tempted to jump straight to the last chapter's guidance on how to design and deploy a QoS strategy in a backbone network. Santiago's extensive real-world deployment experience certainly makes this chapter especially valuable. However, the preceding four chapters are the ones that will provide you with a fundamental understanding of QoS. Thus, rather than blindly following a QoS "recipe," you'll be able to make the right design decisions to meet the needs of your own applications and customers. If you really want to understand QoS fully, this is the book to read, from start to finish.

Bruce Davie
Cisco Fellow

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Introduction

The motivation behind this book is the continued interest in the implementation of *quality of service* (QoS) in IP/MPLS networks. QoS arises as a key requirement for these networks, which have become the preferred technology platform for building converged networks that support multiple services. The topic can be one of the most complex aspects of the network design, implementation, and operation. Despite the importance of and interest in this topic, no other Cisco Press title provides a detailed discussion of this subject. A significant amount of the content of this book also applies to pure IP networks that do not have immediate plans to migrate to a full IP/MPLS network.

This material covers both QoS and *Multiprotocol Label Switching Traffic Engineering* (MPLS TE). In particular, it covers MPLS TE as a technology that complements traditional QoS technologies. MPLS TE can be an instrumental tool to improve the QoS guarantees that an IP/MPLS network offers. As such, it can contribute to improving both network performance and availability. However, this book provides a concise discussion of MPLS TE. Those readers interested in further information should consult the Cisco Press title *Traffic Engineering with MPLS*.

The book takes the point of view of those individuals responsible for the IP/MPLS network. Other Cisco Press titles describe the details of the QoS implementation for those devices receiving the services that the network offers.

You should have a basic understanding of both IP and MPLS to obtain the most benefit from this book. That understanding should include basic IP addressing and routing, along with the basics of MPLS forwarding. However, the book provides a technology overview of QoS and MPLS TE to help those with less exposure to these technologies or to serve as a review/reference to those more familiar with those topics.

This book touches a broad topic and does not pretend to address all QoS aspects of interest. You can expect future Cisco Press books to cover important areas, including the following:

- Implementation of QoS for specific services (for instance, IP, Ethernet, ATM)
- QoS management (including monitoring and provisioning)
- Interprovider QoS

Visit this book's website, http://www.ciscopress.com/title/1587052334, for further information.

Who Should Read This Book?

This book's primary audience is the technical staff of those organizations building IP/MPLS networks as an infrastructure to provide multiple services. The material includes technology, configuration, and operational details to help in the design, implementation, and operation of QoS in IP/MPLS networks. Service providers are a prime example of the organizations that this book targets. However, government agencies, educational institutions, and large enterprises pursuing IP/MPLS will find the material equally useful.

A secondary audience for this book is those individuals in charge of service definition or those individuals subscribing to network services. Both types can benefit from a better understanding of the differentiation capabilities that IP/MPLS networks can offer.

How This Book Is Organized

Although this book could be read cover to cover, it is designed to be flexible and allow you to easily move between chapters and sections of chapters to cover just the material that you need more work with. The content is roughly divided into three parts:

- Chapters 1 and 2 provide a technology overview.
- Chapters 3 and 4 discuss Cisco implemenation.
- Chapter 5 covers different backbone design options.

Here is a brief synopsis of each chapter:

Chapter 1, "QoS Technology Overview"—This chapter provides a review of QoS technology for IP and IP/MPLS networks. The chapter initially discusses the IP QoS architectures and how they apply to MPLS. Multiple sections elaborate on MPLS support for *Differentiated Services* (DiffServ), including a detailed discussion on *EXP-inferred-class link switched path* (E-LSP), *Label-inferred-class LSP* (L-LSP), and DiffServ tunneling models (pipe, short pipe, and uniform). This dicussion leads into a summary of traffic-management mechanisms with a detailed look at traffic policing, traffic shaping, traffic scheduling, active queue manangemt, and so on. The chapter also discusses QoS signaling with a focus on the *Resource Reservation Protocol* (RSVP).

Chapter 2, "MPLS TE Technology Overview"—This chapter reviews the basic operation of this technology with its DiffServ extensions and applicability as a traffic-protection alternative. This review elaborates on the concepts of contraint-based routing, *DiffServ-aware Traffic Engineering* (DS-TE) and *fast reroute* (FRR) (including link, shared-risk link group, and node protection).

Chapter 3, "Cisco QoS"—This chapter covers the Cisco QoS behavioral model and the *modular QoS command-line interface* (MCQ). The chapter abstracts the platform specifics to facilitate the understanding of Cisco QoS and provides a complete reference of the configuration commands. In addition, the chapter includes numerous examples to illustrate the configuration and verification of different traffic-management mechanisms in Cisco IOS and Cisco IOS XR. This material is equially relevant to IP and IP/MPLS networks.

Chapter 4, "Cisco MPLS Traffic Engineering"—This chapter presents Cisco implementation of MPLS Traffic Engineering in both Cisco IOS and Cisco IOS XR. It includes multiple configuration and verification examples illustrating the implementation of basic MPLS TE, DS-TE, and FRR.

Chapter 5, "Backbone Infrastructure"—This chapter discusses the backbone performance requirements and the different design options. The chapter reviews different designs, ranging from a best-effort backbone to the most elaborate scenarios combining DiffServ, DS-TE, and FRR. Numerous configuration examples illustrate their implementation using Cisco IOS and Cisco IOS XR.

In this chapter, you learn the following topics:

- Cisco QoS Behavioral Model
- The Modular QoS Command-Line Interface

CHAPTER 3

Cisco QoS

This chapter provides an overview of the *quality of service* (QoS) implementation and configuration in Cisco products. This overview includes details about algorithms and configuration commands. The material includes simple examples to illustrate the use of the commands. Chapter 5, "Backbone Infrastrusture," provides more elaborate examples. You will find details about both Cisco IOS and Cisco IOS XR implementations. This chapter does not include platform or hardware details because of their constant evolution. The material assumes that you are already familiar with the technology aspects of QoS. Chapter 1, "QoS Technology Overview," includes a technology overview that you can use as a reference.

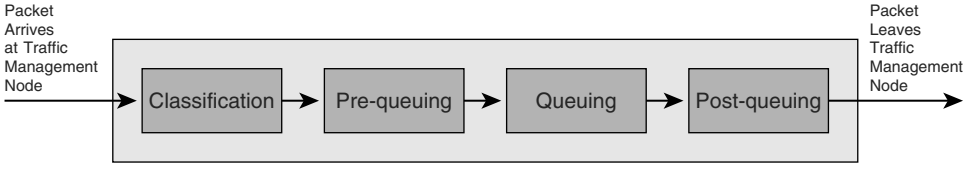
Cisco QoS Behavioral Model

Cisco uses an abstract QoS behavioral model that provides consistency across devices. Cisco platforms may ultimately use different internal QoS implementations. However, the Cisco QoS behavioral model provides a common abstraction that hides the implementation details and facilitates the implementation of QoS across different product families. The model is flexible enough to provide a wide range of possible QoS behaviors despite its simplicity. A good understanding of this model will help you comprehend QoS configuration on Cisco devices. Later sections in this chapter present an overview of QoS configuration commands and their relationship with this model.

The QoS behavioral model relies on the concept of a *traffic-management node* (TMN). This concept represents an abstraction of a collection of QoS actions that a device applies to traffic at a particular point during packet forwarding. The TMN identifies one or more traffic streams and defines the actions performed on each stream. The underlying implementation infers what structures and mechanisms (including possible queues) will provide the behavior that the TMN actions define.

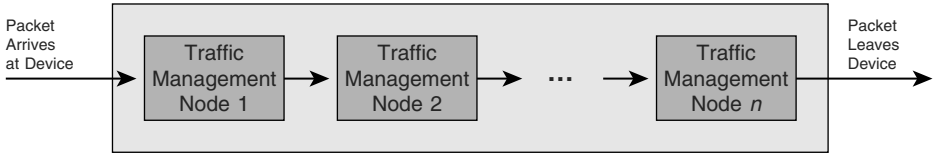
The TMN has four components, in the following order: classification, pre-queuing, queuing, and post-queuing. All components are optional and user configurable. Figure 3-1 provides a functional view of a packet traversing a TMN. The next sections provide more details on these components.

Figure 3-1 *Components in a TMN*



A packet might encounter zero or more TMNs while traversing a device. A TMN typically exists at points where congestion can happen. A device can have several congestion points in its forwarding path depending on its architecture. However, a TMN can also exist at other points where congestion does not occur. The input and output interfaces are the most common points where a packet might encounter a TMN. Some distributed platforms may support a TMN for traffic entering their switching fabric. A TMN can also exist at the interface to the route processor. This TMN manages the traffic that the route processor sends and receives. Figure 3-2 shows a packet passing through multiple TMNs.

Figure 3-2 *Packet Traversing Multiple TMNs*



Classification Component

The classification component identifies traffic streams using packet contents or context information. The TMN associates each traffic stream with a class name. The TMN typically uses packet headers to classify traffic. These headers include Layer 2, Layer 3, and Layer 4 headers.

The classification component can also inspect (statefully or not) the packet payload or use packet context information such as input interface. All traffic that does not match any explicitly configured classification criteria becomes part of a default class that uses the **class-default** keyword. If the classification component does not exist, all traffic becomes part of this default class. In summary, the classification component receives a traffic aggregate and identifies one or more streams that it associates with class names.

Pre-Queuing Component

The pre-queuing component groups a set of QoS actions that must precede queuing in the TMN. This is the second entry in the list of TMN components. The pre-queuing component

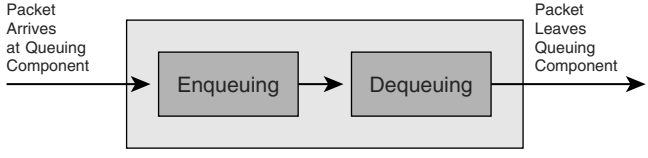
always follows the classification component. It includes actions such as policing, marking, dropping, and header compression. Despite its name, this component does not imply that a queuing component must exist in every TMN. However, the prequeuing component must precede a queuing component if one exists.

The pre-queuing component can affect the operation of subsequent components. For instance, a policing action may re-mark packets. The new packet marking would affect any active queue management in the queuing component. The pre-queuing component does not affect the result of the classification component. That is, the TMN does not reclassify packets.

Queuing Component

The queuing component provides bandwidth management during periods of congestion. Queuing is the third entry in the list of possible TMN components. It always precedes the post-queuing component and always follows the classification and pre-queuing components. The queuing component includes two subcomponents: enqueuing and dequeuing. These subcomponents use a set of parameters to control how traffic enters and leaves that queue. A TMN may process traffic at a point where congestion does not occur, and therefore, the queuing component will not exist. Figure 3-3 illustrates the structure of the queuing component.

Figure 3-3 *Queuing Component in the TMN*



Enqueuing Subcomponent

Enqueuing controls the size of a queue by deciding which packets enter a queue. A maximum queue depth represents the simple form of control that implements a tail drop policy. That is, enqueuing of packets stops when the queue reaches the maximum queue size (that is, the tail of the queue).

Enqueuing can also use the queue management mechanism that section "Active Queue Management" in Chapter 1 described. In such a case, the enqueuing subcomponent is responsible for computing the packet-drop probability based on the average queue size and the minimum and maximum thresholds. It would make a dropping decision using the computed drop probability.

Dequeuing Subcomponent

The dequeuing subcomponent controls packet departure from queues. It represents an abstraction of the scheduling and shaping mechanisms that sections "Traffic Shaping" and "Congestion Management" presented in Chapter 1. Four attributes can influence traffic dequeuing:

- The minimum-bandwidth guarantee represents the worst-case bandwidth allocation that the queue will receive.
- The maximum bandwidth defines the best-case bandwidth allocation for the queue. In some cases, it corresponds to a shaper rate.
- The excess bandwidth defines the distribution of excess bandwidth beyond the minimum-bandwidth guarantee.
- The priority attribute defines whether the scheduler must service a queue ahead of all other queues of lower priority.

The configuration flexibility of the queue attributes defines two-parameter versus three-parameter schedulers. A TMN uses a two-parameter scheduler if the minimum and maximum bandwidth guarantees are independent, whereas the excess bandwidth depends on one of the other two guarantees (typically, the minimum guarantee). Therefore, the configuration of the minimum and excess bandwidths is mutually exclusive. One parameter implies the other. A TMN with a three-parameter scheduler supports the independent configuration of minimum, maximum, and excess bandwidth amounts for each queue. This configuration flexibility allows a TMN to offer more varied behaviors. In particular, a queue can provide better latency and jitter characteristics if it receives more excess bandwidth.

The TMN has implicit default values for the minimum, maximum, and excess-bandwidth attributes. If a queue does not have a configuration for a minimum-bandwidth guarantee, the scheduler will not guarantee any bandwidth to the queue. If the queue does not have a maximum bandwidth attribute, the queue can receive as much bandwidth as possible.

Two-parameter and three-parameter schedulers have a different default behavior for the excess-bandwidth attribute. Three-parameter schedulers share excess bandwidth equally among queues without an explicit excess-bandwidth configuration. Two-parameter schedulers share excess bandwidth proportionally to the minimum-bandwidth guarantee. If a minimum-bandwidth configuration does not exist, the scheduler shares the excess bandwidth equally.

Figure 3-4 shows a sample TMN with four queues. The first queue is a priority queue with a maximum-bandwidth guarantee. The second and third queues have explicit minimum- and maximum-bandwidth guarantees. The last queue has only a maximum-bandwidth guarantee. All nonpriority queues rely on the default excess-bandwidth configuration. The exact amount of bandwidth that each queue receives depends on the traffic patterns and the type of scheduler. Either a two-parameter or three-parameter scheduler could support this configuration given that none of the queues have an explicit minimum and excess-

bandwidth configuration. Table 3-1 summarizes the four dequeuing attributes and their defaults.

Figure 3-4 *Sample Bandwidth Configuration for a TMN with Four Queues*

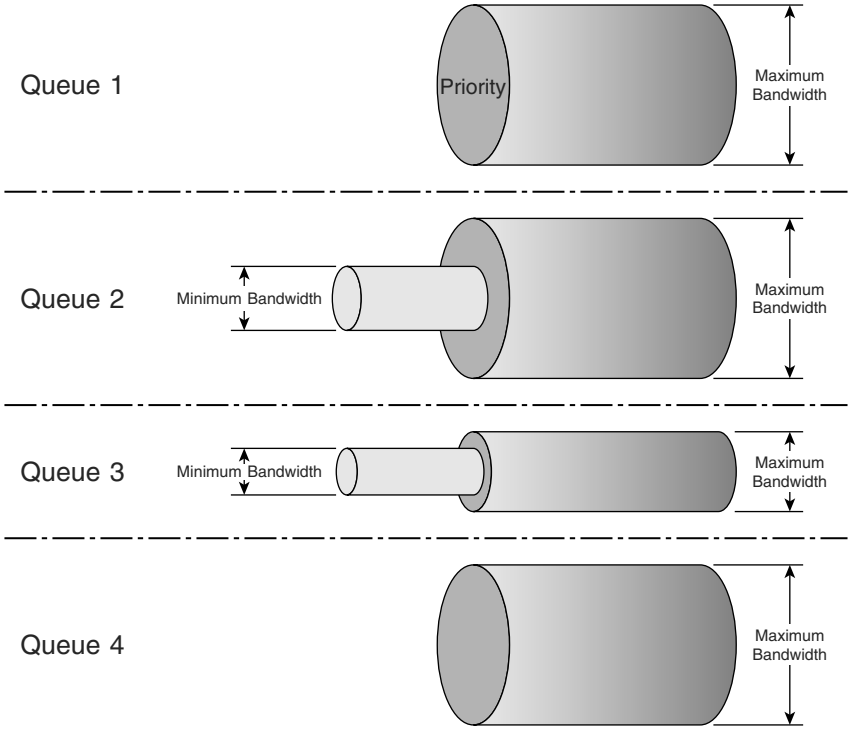


Table 3-1 *Dequeuing Attributes in the TMN*

Dequeuing Attribute	Description	Default
Minimum bandwidth	Worst-case bandwidth allocation.	No bandwidth is guaranteed.
Maximum bandwidth	Best-case bandwidth allocation.	As much bandwidth as possible is allocated.
Excess bandwidth	Distribution of excess bandwidth beyond the minimum-bandwidth guarantee.	Equal excess-bandwidth sharing for three-parameter schedulers. Proportional excess-bandwidth sharing for two-parameter schedulers.
Priority	Strict priority relative to other queues. Scheduler serves queues according to their priority.	No strict priority.

Post-Queuing Component

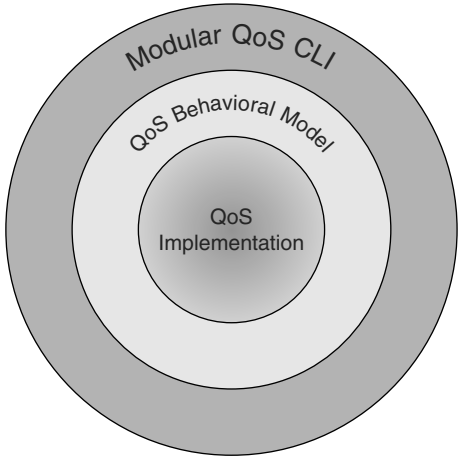
The post-queuing component defines the QoS actions that must follow queuing in the TMN. This is the fourth and last component of the TMN. It defines the last group of actions before the packet leaves the TMN.

This component is useful for actions where packet sequencing is important given that the queuing component generally reorders packets across queues. As an example, some compression mechanisms use sequence numbers and packets should receive their respective sequence number when the queuing component schedules the packet for transmission. As with the pre-queuing component, this component does not imply that a queuing component must exist. However, it must follow it if present.

Modular QoS Command-Line Interface

Cisco IOS and IOS XR use the *modular QoS command-line interface* (MQC) as the configuration framework for the Cisco QoS behavioral model. The MQC acts as a template-based configuration interface to the underlying TMN. The MQC and the QoS behavioral model hide the details of the QoS implementation from the user. The MQC facilitates QoS deployment by providing a common set of commands with the same syntax and semantics. At the same time, it provides platforms greater flexibility in the selection of their QoS implementation. Figure 3-5 illustrates the relationship between MQC, the QoS behavioral model, and the QoS implementation.

Figure 3-5 *Relationship Between the MQC, the QoS Behavioral Model, and the QoS Implementation*



The MQC has three configuration components:

- **Class map**—Defines a class of traffic via matching rules. It corresponds to the classification component of the TMN.
- **Policy map**—Defines a policy that contains QoS actions to be applied to some classes of traffic. It typically references the classes that **class-map** commands defined. It provides the configuration for the pre-queuing, queuing, and post-queuing components of the TMN.
- **Service policy**—Associates a policy with a particular target and direction within a device. A **policy-map** command must have defined the policy previously. The separation of the policy definition from the policy invocation reduces the complexity of the QoS configuration.

NOTE Class names and policy names are case-sensitive.

The configuration of the **service-policy** command determines both the direction and attachment point of the QoS policy. You can attach a policy to an interface (physical or logical), a *permanent virtual circuit* (PVC), or special points to control route processor traffic. Examples of logical interfaces include the following:

- **MFR** (*Multilink Frame Relay*)
- **Multilink** (*Multilink PPP*)
- **Port-channel** (Ethernet channel of interfaces)
- **POS-channel** (*Packet-over-SONET/SDH* channel of interfaces)
- **Virtual Template**

Two directions are possible for a policy: input and output. The policy direction is relative to the attachment point. The attachment point and direction influence the type of actions that a policy supports (for example, some interfaces may not support input queuing policies). This chapter and Chapter 5, "Backbone Infrastructure," provide numerous policy examples.

Example 3-1 shows an example of a QoS policy using the MQC. This example includes two explicit class definitions: CLASS1 and CLASS2. The policy with name POLICY1 references those two classes in addition to the default class (class-default). As mentioned previously, this class does not require configuration and represents all traffic that does not match the explicitly configured classes. The policy is attached to the interface GigabitEthernet3/0 in the input direction. Therefore, the policy will process packets entering the device through that interface. This particular example shows only placeholders for the **class-map** statements and the class actions in the policy map. The following section provides more details about the configuration syntax and options.

Example 3-1 *QoS Policy Configuration Using the MQC*

```
class-map match-all CLASS1
  match <statement-1>
class-map match-any CLASS2
  match <statement-2>
  match <statement-3>
  match <statement-4>
!
policy-map POLICY1
  class CLASS1
   police <action-1>
  class CLASS2
   <action-2>
   <action-3>
  class class-default
   <action-4>
!
interface GigabitEthernet3/0
 ip address 192.168.0.1 255.255.255.254
 service-policy input POLICY1
!
```

The **show policy-map** command is the primary command for verifying the operation and configuration of a QoS policy. The output from this command displays the counters relative to all the actions configured on the policy. Those counters are a vital tool to troubleshoot QoS problems. The **clear counters** command resets all interface counters, including MQC counters, in Cisco IOS. The **clear qos counters** command clears the MQC counters in Cisco IOS XR. You will not find **debug** commands to monitor the operation of traffic-management mechanisms in the forwarding place because of the per-packet processing impact. Cisco IOS XR includes some debug options (using the debug qos command prefix), but those are useful to troubleshoot the internal details of the QoS implementation on a platform. They are not generally practical as an operational tool. In addition, the show qos interface command displays the hardware-programmed values for an interface with an attached policy, but does not display any counter information.

Table 3-2 summarizes the three most common forms of the **show policy-map** command. The following sections include specific examples of the output of this command. Formatting differences apply between Cisco IOS and Cisco IOS XR.

Table 3-2 *Policy Verification Using the **show policy-map** Command*

Syntax	Description
show policy-map *name*	Displays policy configuration
show policy-map interface [*name* [**dlci**|**vc**|**vp**]][{**input**|**output**} **class** *name*]	Displays counters for a policy attached to an interface, Frame Relay DLCI,* ATM PVC, or ATM PVP*

Table 3-2 *Policy Verification Using the **show policy-map** Command (Continued)*

Syntax	Description
show policy-map control-plane [**all**|**slot** *value*][{**input**|**output**} **class** *name*]	Displays counters for a policy controlling control-plane traffic
show policy-map switch-fabric { **unicast** | **multicast**}	Displays counters for a policy controlling traffic sent to the switch fabric

* DLCI = data-link connection identifier
PVC = permanent virtual path

NOTE Platforms with a distributed architecture might exhibit a delay in updating counters when compared with platforms with a centralized architecture.

Hardware Support for the MQC

MQC support has wide support in all products running Cisco IOS and Cisco IOS XR. New software releases have constantly enhanced this framework since it was first introduced in 1999. Before that time, Cisco switches and routers already offered a good amount of QoS functionality. MQC has gradually incorporated more features and today offers greater functionality than earlier, sometimes platform-specific, features. In some cases, you might still have to rely on non-MQC features. However, those cases should be the exception and not the rule. You should expect that most, if not all, future QoS enhancements will involve MQC.

This book does not include a detailed description of QoS support on specific Cisco equipment. Different devices play different roles in a network, and those roles define the functionality, performance, and scale those devices should provide. You will find differences depending on the device series, software release, hardware modules, and, sometimes, configured services. You should rely on the software and hardware documentation to understand what commands are available on a particular device and any deviations from the Cisco behavioral model.

Traffic-Management Mechanisms

This section covers the details of the configuration options in the MQC. It presents the commands that enable you to configure the components of the TMN (classification, prequeuing, queuing, and post-queuing). You will find an explanation of each function with a brief syntax overview, configuration examples, and sample outputs of the **show policy-map interface** command. The information focuses on the most commonly used commands and gives you a good understanding about how to use the command and verify its operation. Do *not* consider it a complete command reference guide. For a complete description of all command options and a complete syntax, consult the Cisco IOS and Cisco IOS XR documentation.

Traffic Classification

You configure packet classification using **class-map** commands. Class maps define the classification component of the TMN. They can include one or more **match** commands. These commands provide a wide range of criteria for packet classification. They vary from Layer 2 (for example, MAC address, ATM *Cell Loss Priority* [CLP]) to application level criteria (for example, an URL). Within a policy the classification process for a packet ends when the packet matches a class. Therefore, the classification can associate only each packet with a single class.

Packets that do not satisfy the matching criteria of any class map become part of the implicit default class that you reference with the **class-default** command keyword. Tables 3-3 through 3-7 provide a summary of most of the matching criteria that the MQC supports.

Table 3-3 *Matching Criteria Using IP and MPLS* Headers*

Syntax	Matching Criteria
match access-group {*value*|**name** *value*}	Numbered or named access list (Cisco IOS only)
match access-group [**ipv4**|**ipv6**] *value*	Access list (Cisco IOS XR only)
match precedence *list*	List of precedence values (IPv4 and IPv6)
match dscp *list*	List of DSCP* values (IPv4 and IPv6)
match mpls experimental topmost *list*	List of EXP* values for MPLS
match packet length {**min** *value*[**max** *value*]|[**min** *value*] **max** *value*}	IP packet size (including IP header)

* MPLS = Multiprotocol Label Switching

DSCP = Differentiated Services Code Point

EXP = Experimental bit

NOTE Earlier implementations of the **match mpls experimental topmost** command did not use the **topmost** keyword.

NOTE Earlier implementations of the **match precedence** command used the **match ip precedence** syntax. Similarly, earlier implementations of the **match dscp** command used the **match ip dscp** syntax.

Table 3-4 *Matching Criteria on External Packet Characteristics*

Syntax	Matching Criteria
match input-interface *value*	Interface packet arrived at
match qos-group *list*	List of internal packet class marking
match discard-class *list*	List of nternal packet marking identifying drop profile

Table 3-5 *Matching Criteria for Ethernet, ATM, and Frame Relay*

Syntax	Matching Criteria
match cos *list*	List of Ethernet 802.1Q user priority values
match cos inner *list*	List of inner Ethernet 802.1Q user priority values for packets with double VLAN encapsulation
match source-address mac *value*	Ethernet source MAC address
match destination-address mac *value*	Ethernet destination MAC address
match spantree bpdu	Ethernet spanning-tree BPDU*
match vlan *range*	Range of Ethernet VLAN IDs
match vlan inner *range*	Range of inner VLAN IDs for packets with double VLAN encapsulation
match atm ilmi	ATM ILMI* packets
match atm oam	ATM OAM* cells
match atm clp	ATM CLP bit
match frame-relay dlci *range*	Frame Relay DLCI
match frame-relay de	Frame Relay DE* bit
match frame-relay lmi	Frame Relay LMI* packets

* BPDU = bridge protocol data unit

ILMI = interim local management interface

OAM = operation, administration, and maintenance

DE = Discard Eligibility bit

LMI = local management interface

NOTE Earlier implementations of the **match frame-relay dlci**, **match frame-relay de**, and **match frame-relay lmi** commands used the **match fr-dlci** syntax, **match fr-de** syntax, and **match fr-lmi** syntax respectively.

Table 3-6 *Matching Criteria for Protocols and Packet Payload*

Syntax	Matching Criteria
match ip rtp *start offset*	RTP* packets with UDP ports between *start* and *start+offset*
match protocol arp	ARP* packets
match protocol cdp	CDP* packets
match protocol clns	ISO CLNS* packets
match protocol clns_es	ISO CLNS ES* packets
match protocol clns_is	ISO CLNS IS* packets
match protocol cmns	ISO CMNS* packets
match protocol compressedtcp	Compressed TCP
match protocol ip	IPv4 packets
match protocol ipv6	IPv6 packets

* RTP = Real-Time mTransport Protocol

ARP = Address Resolution Protocol

CDP = Cisco Discovery Protocol

CLNS = Connectionless Network Service

ES = End System

IS = Intermediate System

CMNS = Connection-Mode Network Service

NOTE Table 3-6 includes only a small fraction of the protocols that the **match protocol** command supports. Depending on the platform and software, this command can match more than 80 different protocols and applications. Some of them provide stateful inspection of the packet payload to identify traffic that is not easily classified (for example, peer-to-peer applications). See the Cisco *network-based application recognition* (NBAR) documentation for more details.

Table 3-7 *Matching Criteria for Hierarchical Class Definitions*

Syntax	Matching Criteria
match class-map *name*	Class map name

A class map supports logical operations of **match** commands. You can define a logical OR, a logical AND, or a negation of match commands. The **match-any** keyword defines a logical OR of all the **match** statements in a class map. Similarly, the **match-all** keyword defines a logical AND. In addition, the **match not** command negates individual matching criteria. More-complex operations combining these operations require hierarchical configurations that the section "Hierarchical Classification" covers. Some **match** commands (for example, **match dscp** and **match mpls experimental topmost**) accept list of values. In those cases, a packet satisfies the statement if it matches any of the values in the list.

Example 3-2 shows four different class configurations. The first class, CLASS1, includes packets that match access list 99 or have a DSCP value of EF. CLASS2 matches packets with a DSCP of AF11, AF12, or AF13. MPLS packets with EXP values of 3 or 4 will match CLASS3. Notice that the **match-all** keyword in CLASS2 and CLASS3 does not change the logical OR operation that the multiple values in the **match** statements imply. CLASS4 matches ATM OAM cells and CLASS5 matches IPv6 packets with a DSCP of default. Multiple policies could reference these classes.

Example 3-2 *Traffic-Classification Configuration*

```
class-map match-any CLASS1
  match access-group 99
  match  dscp ef
class-map match-all CLASS2
  match  dscp af11  af12  af13
class-map match-all CLASS3
  match mpls experimental topmost 3  4
class-map match-all CLASS4
  match atm oam
class-map match-all CLASS5
  match protocol ipv6
  match  dscp default
!
```

Example 3-3 and 3-4 highlight the classification counters that a policy maintains. Example 3-3 illustrates the **show policy-map** output in Cisco IOS for a policy that references the CLASS1 and CLASS2 definitions in Example 3-2. There are three main classification counters:

- Classified packets
- Classified bytes
- Offered (average) rate (5 minutes by default)

You can see that the policy has classified 28,000 packets as CLASS1. Those packets amount to 41,608,000 bytes. The average arrival rate was 188,000 bps for CLASS1 in the past 5 minutes. Similarly, the policy has classified 14,000 packets (or 20,804,000 bytes) as CLASS2, which has an average arrival rate of 95,000 bps. The default class (class-default) received 42,000 packets representing 62,412,000 bytes. The average rate of packets arriving at this class is 282,000 bps. In this example, the same set of counters is available per **match** statement for those class maps using the **match-any** keyword.

NOTE A number of platforms do not support separate classification counters for each **match** statement. Consult the platform documentation for details.

TIP You can control the averaging interval for an interface using the load-interval command. This command impacts the calculation of average rates for the policies you apply to the interface and other average rates associated with the interface counters.

Example 3-3 *Classification Counters in Cisco IOS*

```
Router#show policy-map interface pos0/0/0

 POS0/0/0

  Service-policy output: POLICY1

    Class-map: CLASS1 (match-any)
      28000 packets, 41608000 bytes
      5 minute offered rate 188000 bps, drop rate 0 bps
      Match: access-group 99
        0 packets, 0 bytes
        5 minute rate 0 bps
      Match: dscp ef (46)
        28000 packets, 41608000 bytes
        5 minute rate 188000 bps
      QoS Set
        dscp cs5
          Packets marked 28000

    Class-map: CLASS2 (match-all)
      14000 packets, 20804000 bytes
      5 minute offered rate 95000 bps, drop rate 0 bps
      Match: dscp af11 (10) af12 (12) af13 (14)
      QoS Set
        dscp cs1
          Packets marked 14000
```

Example 3-3 *Classification Counters in Cisco IOS (Continued)*

```
    Class-map: class-default (match-any)
      42000 packets, 62412000 bytes
      5 minute offered rate 282000 bps, drop rate 0 bps
      Match: any
        42000 packets, 62412000 bytes
        5 minute rate 282000 bps
      QoS Set
        dscp default
          Packets marked 42000
Router#
```

Example 3-4 shows the **show policy-map** output for an equivalent policy using Cisco IOS XR. The same counters are present, but the output format differs. POLICY1 has classified 40,000 packets as CLASS1, 20,000 packets as CLASS2, and 60,000 packets in the default class (class-default). Those packets amount to 59,280,000, 29,640,000 and 88,920,000 bytes, respectively. The average arrival rates for these three classes are 758, 379, and 1136 kbps respectively.

Example 3-4 *Classification Counters in Cisco IOS XR*

```
RP/0/4/CPU0:Router#show policy-map interface pos0/3/0/3
POS0/3/0/3 input: POLICY1

Class CLASS1
  Classification statistics          (packets/bytes)     (rate - kbps)
    Matched              :               40000/59280000              758
    Transmitted          :               40000/59280000              758
    Total Dropped        :                   0/0                     0
  Marking statistics (S/W only)      (packets/bytes)
    Marked               :                   0/0
  Queueing statistics
    Vital           (packets)            : 0
    Queue ID                             : None (Bundle)
    Taildropped(packets/bytes)           : 0/0

Class CLASS2
  Classification statistics          (packets/bytes)     (rate - kbps)
    Matched              :               20000/29640000              379
    Transmitted          :               20000/29640000              379
    Total Dropped        :                   0/0                     0
  Marking statistics (S/W only)      (packets/bytes)
    Marked               :                   0/0
  Queueing statistics
    Vital           (packets)            : 0
    Queue ID                             : None (Bundle)
    Taildropped(packets/bytes)           : 0/0

Class class-default
  Classification statistics          (packets/bytes)     (rate - kbps)
    Matched              :               60000/88920000             1136
    Transmitted          :               60000/88920000             1136
    Total Dropped        :                   0/0                     0
```

continues

Example 3-4 *Classification Counters in Cisco IOS XR (Continued)*

```
  Marking statistics (S/W only)      (packets/bytes)
    Marked              :                  0/0
  Queueing statistics
    Vital           (packets)           : 0
    Queue ID                            : None (Bundle)
    Taildropped(packets/bytes)          : 0/0
RP/0/4/CPU0:Router#
```

Traffic Marking

Marking is one of the actions of the pre-queuing component in the TMN. The **set** command is the major method to mark a field associated with a packet. The **set** command supports a wide range of marking criteria, including Layer 2, Layer 3, and internal fields. A class can include multiple **set** commands for different fields (for example, one command marks Layer 3 header, and a second command marks Layer 2 header). In general, this command applies to both input and output policies.

Tables 3-8 through 3-12 provide a summary of the marking criteria that the MQC supports.

TIP The **police** command can also mark packets. The next section describes that command in detail.

Table 3-8 *Marking Criteria for IP and MPLS Packets*

Syntax	Marking Criteria
set precedence *value*	IPv4 and IPv6 precedence
set precedence tunnel *value*	Precedence to be used by IP header
set dscp *value*	IPv4 and IPv6 DSCP
set dscp tunnel *value*	DSCP to be used by IP tunnel header
set mpls experimental imposition *value*	EXP bits to be used by push operation
set mpls experimental topmost *value*	EXP bits in MPLS header on top of the stack

NOTE Earlier implementations of the **set mpls experimental imposition** command did not use the **imposition** keyword. If the device performs multiple simultaneous push operations, all headers receive the EXP value.

NOTE Earlier implementations of the **set precedence** command used the **set ip precedence** syntax. Similarly, earlier implementations of the **set dscp** command used the **set ip dscp** syntax.

A node automatically marks MPLS and IP tunnel packets by default during some encapsulation operations. For MPLS, a node performing a label push operation will set the MPLS EXP in all imposed labels according to the marking in the encapsulated packet. That marking will correspond to the existing EXP for an MPLS packet, IP precedence for an IP packet and the 802.1Q user priority for an Ethernet frame. A label swap operation always preserves the existing MPLS EXP. A label pop operation does not have any effect on the marking of the exposed header. For IP tunnels, the DSCP in the tunnel header will reflect the encapsulated DSCP for IP over GRE or the encapsulated (topmost) EXP for MPLS over GRE. Those IP tunnels using L2TP will use a DSCP of default (zero) unless you configure reflection explicitly. The tunnel decapsulation will not modify the exposed header in any case. Note that the behavior described in this paragraph represents the default behavior when you do not configure marking explicitly. You can use the commands in Table 3-8 to override this behavior. Tables 3-38 and 3-39 summarize the default marking actions for MPLS and IP tunnels.

Table 3-9 *Default MPLS EXP Marking Actions*

MPLS Forwarding Operation	Default Marking Action
Push	Set MPLS EXP on all imposed labels using marking in encapsulated header (MPLS EXP, IP Precedence or Ethernet 802.1Q user priority).
Swap	Maintain MPLS EXP value.
Pop	Do not modify marking in exposed header.

NOTE The set mpls experimental topmost command on an input policy always marks MPLS packets before the node performs all label forwarding operations (push, swap, or pop). When invoked in an output policy, the command marks MPLS packets after all label forwarding operations.

Table 3-10 *Default IP Tunnel Marking Actions*

IP Tunnel Operation	Default Marking Action
Tunnel Encapsulation	Set tunnel header DSCP using the encapsulated DSCP for IP over GRE or encapsulated EXP for MPLS over GRE. For L2TP, set DSCP to default (zero).
Tunnel Decapsulation	Do not modify DSCP in exposed header.

Table 3-11 *Criteria for Marking of Internal Device Fields*

Syntax	Marking Criteria
set qos-group *value*	Internal field for packet class
set discard-class *value*	Internal field for packet drop profile

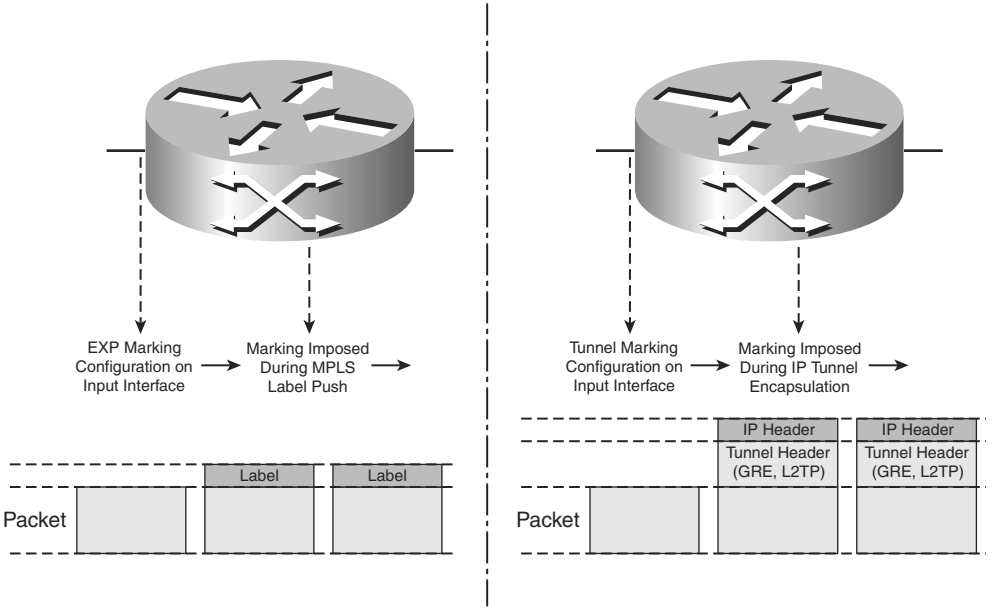
Table 3-12 *Marking Criteria for Ethernet, ATM, and Frame Relay*

Syntax	Marking Criteria
set cos *value*	Ethernet 802.1Q user priority
set atm-clp	ATM CLP bit
set fr-de	Frame Relay DE bit

The MQC uses a QoS group ID and a discard class as internal fields that a device can associate with a packet. The QoS group ID field represents a class identifier. The discard class corresponds to a drop profile identifier on drop precedence. A device can set those fields without altering the packet contents. Both fields use integer numbers. The information is lost as soon as the device transmits the packet through the output interface. In most cases, the input policy sets the values and the output policy makes use of them. The section "Active Queue Management" in this chapter shows how to configure *weighted random early detection* (WRED) to select drop profiles using the value set in the discard class. Tables 3-4 and 3-11 showed how to use them to classify traffic and how to set these internal fields, respectively.

A policy can define the marking of a future packet header in advance. This is the case when you want to define the MPLS EXP bits in an input policy for a push operation in an input policy. The input policy indicates the upcoming MPLS EXP marking using the **set mpls experimental imposition** command. The marking does not take effect until the device performs the push operation and imposes a new MPLS header. A similar situation occurs when a packet is about to ingress an IP tunnel. In that case, you can use the **set dscp tunnel** and **set precedence tunnel** commands. The marking action does not affect the contents of the original packet. Figure 3-6 illustrates this beforehand marking for MPLS and IP tunnels.

Figure 3-6 *Marking During MPLS Push and IP Tunneling Operation*



You can also use the **set** command to implement a mapping between two markings. You can define mappings between DSCP, IP precedence, MPLS EXP, internal markings, and 802.1Q user priority. By default, the command implements a one-to-one mapping. However, you can configure an arbitrary mapping using a *table map* that groups a series of **map** statements. Each statement specifies a map between two values. The **default** command defines a default mapping for values without and explicit map. Table 3-13 illustrates how to use the **set** command to map markings. In addition, Table 3-14 summarizes the **map** and **default** commands that are part of a table map.

Table 3-13 *Mapping Between Marking Criteria*

Syntax	Description
set to-field from-field [**table** *name*]	Mapping between two packet fields (for instance, DSCP, IP precedence, MPLS EXP, internal markings, 802.1Q user priority)

Table 3-14 *Mapping Statements in a Table Map*

Syntax	Description
map from *value* **to** *value*	Statement mapping two values
default {*value*|**copy**|**ignore**}	Default mapping action

Example 3-5 demonstrates where four different policies mark traffic:

- POLICY1 classifies IP traffic using the DSCP field and defines the MPLS EXP value to mark during an upcoming label push for each class. POLICY1 is valid only as an input policy.
- POLICY2 classifies MPLS packets using their EXP value and marks the packet locally using a QoS group ID value. POLICY2 is valid only as an input policy.
- POLICY3 illustrates a policy with multiple marking actions that marks all traffic with an Ethernet 802.1Q user priority value of 5 and an IP DSCP of EF.
- POLICY4 defines a mapping between MPLS EXP and QoS group ID using table map FROM-EXP-TO-QoS-GROUP.

Example 3-5 *Policies Performing Traffic Marking*

```
class-map match-all CLASS1
  match  dscp ef
class-map match-all CLASS2
  match mpls experimental topmost  5
class-map match-all CLASS3
  match mpls experimental topmost  3  4
!
table-map FROM-EXP-TO-QoS-GROUP
 map from 1 to 1
 map from 2 to 1
 map from 3 to 3
 map from 4 to 3
 map from 5 to 5
 default 0
!
policy-map POLICY1
  class CLASS1
   set mpls experimental imposition 5
  class class-default
   set mpls experimental imposition 0
!
policy-map POLICY2
  class CLASS2
   set qos-group 5
  class CLASS3
   set qos-group 3
  class class-default
   set qos-group 0
!
policy-map POLICY3
  class class-default
   set dscp ef
   set cos 5
!
policy-map POLICY4
 class class-default
  set qos-group mpls experimental topmost table FROM-EXP-TO-QoS-GROUP
!
```

Examples 3-6 and 3-7 illustrate the accounting for packet marking in a policy. Some platforms provide marking counters that indicates the number of packets the policy has marked. Example 3-6 presents the output of the **show policy-map** command in Cisco IOS for the POLICY3 defined in Example 3-5. In this case you have explicit marking counters. The policy has received and successfully marked 104,993 packets. Some platforms may not display specific marking counters. In those cases, the classification counters serve as an indication of the number of packets the policy marked.

Example 3-6 *Marking Counters in Cisco IOS*

```
Router#show policy-map interface fastEthernet1/1/1.1
 FastEthernet1/1/1.1

  Service-policy output: POLICY3

    Class-map: class-default (match-any)
      104993 packets, 157489500 bytes
      5 minute offered rate 3196000 bps, drop rate 0 bps
      Match: any
        104993 packets, 157489500 bytes
        5 minute rate 3196000 bps
      QoS Set
        dscp ef
          Packets marked 104993
        cos 5
          Packets marked 104993
Router#
```

Example 3-7 shows the output in Cisco IOS XR for the policy POLICY1 in Example 3-5. The counters that show the number of transmitted packets indicates implicitly the number of marked packets. In the case of CLASS1, the policy marked 70,000 packets corresponding to 103,740,000 bytes. Similarly, the policy marked 140,000 packets in the default class (class-default) that correspond to 207,480,000 bytes. A separate marking counter shows the number of software-switched packets that the policy marked. In this example, no packets have been switched in software.

Example 3-7 *Marking Counters in Cisco IOS XR*

```
RP/0/4/CPU0:Router#show policy-map interface pos0/3/0/3
POS0/3/0/3 input: POLICY1
Class CLASS1
  Classification statistics          (packets/bytes)     (rate - kbps)
    Matched              :               70000/103740000            1325
    Transmitted          :               70000/103740000            1325
    Total Dropped        :                   0/0                    0
  Marking statistics (S/W only)      (packets/bytes)
    Marked               :                   0/0
  Queueing statistics
    Vital           (packets)            : 0
    Queue ID                             : None (Bundle)
    Taildropped(packets/bytes)           : 0/0
```

continues

Example 3-7 *Marking Counters in Cisco IOS XR (Continued)*

```
Class class-default
  Classification statistics          (packets/bytes)     (rate - kbps)
    Matched              :              140000/207480000            2650
    Transmitted          :              140000/207480000            2650
    Total Dropped        :                   0/0                    0
  Marking statistics (S/W only)      (packets/bytes)
    Marked               :                   0/0
  Queueing statistics
    Vital           (packets)            : 0
    Queue ID                             : None (Bundle)
    Taildropped(packets/bytes)           : 0/0
RP/0/4/CPU0:Router#
```

Traffic Policing

The **police** command configures traffic policing to meter a traffic stream against a profile and process packets based on comparison. Policing is another of the actions of the pre-queuing component in the TMN and, therefore, it does not cause packet queuing. In its simplest form, the **police** command defines a rate threshold for a class and drops the traffic if it exceeds the rate.

The **police** command has a great number of options and provides great flexibility. It always includes a traffic profile, in terms of one or two token buckets (rate and burst), and a group of actions (implicitly or explicitly specified). The command has a single-line format (see Example 3-8) or a multiple-line format (see Example 3-9).

Example 3-8 *Single-Line Format for the **police** Command*

```
policy-map POLICY1
 class class-default
  police <traffic profile> <conform-action> <exceed-action> <violate-action>
!
```

Example 3-9 *Multiple-Line Format for the **police** Command*

```
policy-map POLICY1
 class class-default
  police <traffic profile>
    <color-definition>
    <conform-action>
    <exceed-action>
    <violate-action>
!
```

Table 3-15 shows the traffic profile definitions for single-rate policers. The command can use a compact syntax to define the profile rate and bursts. Alternatively, the **cir** and **bc** keywords define the first token bucket. The **be** keyword and the overflow of the first bucket

define the second token bucket. You can define a single-rate policer with a single token bucket if you do not define an excess burst value. The **police cir** and **police rate** syntax is equivalent. The **rate** keyword is more general and supports ATM policing. The **rate** and **burst** keywords are equivalent to **cir** and **bc**. All rates are in bits per second, and bursts are in bytes by default. The device computes default bursts if not entered explicitly.

Table 3-15 *Single-Rate Policer Traffic Profile*

Syntax	Profile Definition
police *rate-value* [*bc-value* [*be-value*]]	Absolute terms with compact syntax
police cir *value* [**bc** *value* [**be** *value*]]	Absolute terms with keywords
police rate *value* [**burst** *value* [**peak-burst** *value*]]	Absolute terms with keywords (alternative syntax)
police cir percent *value* [***bc*** *value* **ms** [**be** *value* **ms**]]	Relative to underlying bandwidth
police rate percent *value* [**burst** *value* **ms** [**peak-burst** *value* **ms**]]	Relative to underlying bandwidth (alternative syntax)

Table 3-16 shows the traffic profile definitions for dual-rate policers. As with the single-rate policer, the **cir** and **bc** keywords define the first token bucket. However, the **pir** and **be** keywords define the second token bucket. The equivalence between the **police cir** and **police rate** syntax also applies to the dual-rate policer, too. However, the keywords **peak-rate** and **peak-burst** are equivalent to **pir** and **be**. As with all forms of the **police** command, rates are in bits per second and bursts are in bytes by default. The device computes default bursts if not entered explicitly.

Table 3-16 *Dual-Rate Policer Traffic Profile*

Syntax	Profile Definition
police cir *value* [**bc** *value*] **pir** *value* [**be** *value*]	Absolute terms
police rate *value* [**burst** *value*] **peak-rate** *value* [**peak-burst** *value*]	Absolute terms (alternative syntax)
police cir percent *value* [**bc** *value* **ms**] **pir percent** *value* [**be** *value* **ms**]	Relative to underlying bandwidth
police rate percent *value* [**burst** *value* **ms**] **peak-rate percent** *value* [**peak-burst** *value* **ms**]	Relative to underlying bandwidth (alternative syntax)

You can define the policer traffic profile in relative terms. In this case, you specify a rate as a percentage of the underlying bandwidth rate of the policy attachment point. Similarly, you can specify burst sizes in time units (milliseconds by default) relative to the policer rate. The device computes the effective rate and burst sizes in bits per second and bytes, respectively. The **percent** keyword enables the definition of relative traffic profiles. The section "Percentage-Based Rates" explains what constitutes the underlying bandwidth rate that

nodes use to interpret relative profile definitions. In its simplest form, the underlying bandwidth rate for a policy that you attach to a physical interface corresponds to the interface bandwidth rate.

TIP The **police percent** command helps reuse policies across interfaces of different speeds. The reuse of policies has significant operational benefits on devices with a large number of interfaces.

A policer executes different actions depending on the traffic patterns it receives. There are three actions types: conform, exceed, and violate. Table 3-17 summarizes the events that trigger these actions. The section "Traffic Policing" in Chapter 1 previously illustrated the flowchart that both the single-rate and the dual-rate policers follow.

Table 3-18 lists all the specific actions that a policer can invoke. When you use the multiple-line format, you can configure more than one conform, exceed, and violate action. This option proves useful when you want to apply simultaneously more than one marking to the same packet (for example, Ethernet 802.10 user priority and DSCP). The default conform action is to transmit the packet as normal. The default exceed action is to drop the packet. The default violate action is to track the exceed action.

Table 3-17 *Policer Action Types*

Syntax	Trigger for Single-Rate Policer	Trigger for Dual-Rate Policer
conform-*action*	Enough tokens in first bucket	Enough tokens in both buckets
exceed-*action*	Enough tokens in second bucket only	Enough tokens in second bucket only
violate-*action*	Not enough tokens in both buckets	Not enough tokens in both buckets

Table 3-18 *Policer Actions*

Syntax	Description
drop	Drops packet
transmit	Transmits packet without modifications
set-prec-transmit *value*	IPv4 and IPv6 precedence
set precedence *value*	IPv4 and IPv6 precedence (alternative syntax)
set-prec-tunnel-transmit *value*	Precedence to be used by IP tunneling operation
set precedence tunnel *value*	Precedence to be used by IP tunneling operation (alternative syntax)
set-dscp-transmit *value*	IPv4 and IPv6 DSCP
set dscp *value*	IPv4 and IPv6 DSCP (alternative syntax)

Table 3-18 *Policer Actions (Continued)*

Syntax	Description
set-dscp-tunnel-transmit *value*	DSCP to be used by IP tunneling operation
set dscp tunnel *value*	DSCP to be used by IP tunneling operation (alternative syntax)
set-mpls-exp-imposition-transmit *value*	EXP bits to be used by push operation
set mpls experimental imposition *value*	EXP bits to be used by push operation (alternative syntax)
set-mpls-exp-topmost-transmit *value*	EXP bits in MPLS header on top of the stack
set mpls experimental topmost *value*	EXP bits in MPLS header on top of the stack (alternative syntax)
set-qos-transmit *value*	Internal field for packet class
set qos-group *value*	Internal field for packet class (alternative syntax)
set-discard-class-transmit *value*	Internal field for packet drop profile
set discard-class *value*	Internal field for packet drop profile (alternative syntax)
set-cos-transmit *value*	Ethernet 802.1Q user priority
set cos *value*	Ethernet 802.1Q user priority (alternative syntax)
set-clp-transmit	ATM CLP bit
set atm-clp	ATM CLP bit (alternative syntax)
set-frde-transmit	Frame Relay DE bit
set fr-de	Frame Relay DE bit (alternative syntax)

The color-aware policers use the **conform-color** and **exceed-color** commands. You can use these commands in the multiple-line format of the **police** command. Those commands reference a class previously defined using a class map. For a single-rate policer with one token bucket, you define only the conforming color. The policer automatically associates all other traffic with the exceeding color. For a single-rate policer with two token buckets or a dual-rate policer, you define the conforming and exceeding color. The policer automatically associates all other traffic with the violating color. POLICY4 in Example 3-10 illustrates an example of a color-aware policer. Table 3-19 summarizes the commands that define the traffic colors for color-aware policers.

Table 3-19 *Color Definition for Color-Aware Policers*

Syntax	Description
conform-color *name*	Class associated with conforming color
exceed-color *name*	Class associated with exceeding color

You can also use the **police** command to configure traffic policing in compliance with the ATM Forum Traffic Management (TM) specification version 4.0. You can use this command to enforce the different ATM conformance definitions (for example, *Constant Bit Rate* 1 [CBR.1], *Variable Bit Rate* 1 [VBR.1], VBR.2). Some of those definitions require the configuration of color-aware policing. You can specify the profile as a dual-token bucket with rates in cells per second and bursts in number of cells. Alternatively, you can define the policing profile in ATM terms (sustained cell rate, maximum burst size, peak cell rate, cell delay variation tolerance). ATM policing can also make use of the **percent** keyword. Table 3-20 shows the configuration alternatives for ATM traffic profiles.

Table 3-20 *ATM Traffic Profiles*

Syntax	Profile Definition
police rate *value* **cps** [**burst** *value* **cells**] [**peak-rate** *value* **cps**] [**peak-burst** *value* **cells**]	Absolute cells per second and cell units
police rate *value* **cps atm-mbs** *value* [**peak-rate** *value* **cps**] [**delay-tolerance** *value*]	ATM TM 4.0 terms
police rate percent *value* [**burst** *value* **ms**] [**peak-rate percent** *value*] [**peak-burst** *value* **ms**]	Cells per second and cell units relative to underlying bandwidth
police rate percent *value* **atm-mbs** *value* **ms|us** [**peak-rate** *value* **cps**] [**delay-tolerance** *value* **ms|us**]	ATM TM 4.0 terms relative to underlying bandwidth

Example 3-10 illustrates four different policies performing different types of traffic policing:

- POLICY1 specifies a single-rate and a dual-rate policer. The single-rate policer in CLASS1 uses the default actions. The dual-rate policer in CLASS2 uses default burst sizes but explicit actions that drop violating traffic and transmits all other traffic.
- POLICY2 uses a dual-rate policer with a profile specified in relative terms and with multiple actions for conforming traffic.
- POLICY3 shows an example of a policer that uses an ATM traffic profile specified in cells per second and number of cells.
- POLICY4 includes a color-aware dual-rate policer for CLASS5 and a color-blind dual-rate policer for all other traffic.

Example 3-10 *Policies Performing Traffic Policing*

```
class-map match-all CLASS1
  match dscp ef
class-map match-all CLASS2
  match dscp af11  af12  af13
class-map match-all CLASS3
  match dscp af31
class-map match-all CLASS4
  match dscp af32
class-map match-all CLASS5
  match dscp af31  af32  af33
!
policy-map POLICY1
  class CLASS1
   police rate 1000000 burst 31250
  class CLASS2
   police rate 2000000 peak-rate 4000000
     conform-action transmit
     exceed-action transmit
!
policy-map POLICY2
  class class-default
   police rate percent 10 peak-rate percent 20
     conform-action set-mpls-exp-imposition-transmit 5
     conform-action set-qos-transmit 5
     exceed-action drop
!
policy-map POLICY3
  class class-default
   police rate 10000 cps atm-mbs 2500 peak-rate 20000 cps
     conform-action set-mpls-exp-imposition-transmit 1
     exceed-action set-mpls-exp-imposition-transmit 2
!
policy-map POLICY4
  class CLASS5
   police rate 100000 peak-rate 200000
     conform-color CLASS3 exceed-color CLASS4
     conform-action set-dscp-transmit af31
     exceed-action set-dscp-transmit af32
     violate-action set-dscp-transmit af33
  class class-default
   police rate percent 10 peak-rate percent 20
!
```

Example 3-11 illustrates the counters displayed for policers in Cisco IOS. The output corresponds to POLICY4 Example 3-10. A basic set of counters specify the number of packets (and related bytes) on which the policy executed the conform, exceed, and violate actions. In this example, the CLASS5 policer had 22,153 conforming, 22,617 exceeding, and 46,066 violating packets. In the case of the default class (class-default), the policer executed the conform action on 76,858 packets. There were no exceeding or violating packets. The

conforming packets represented 3,381,752 bytes. In addition, policers display the current rate of conforming, exceeding, and violating packets. CLASS5 shows 32,000 bps of conforming, 32,000 bps of exceeding, and 59,000 bps of violating traffic. The policer in the default class is currently receiving 85,000 bps of conforming traffic.

Example 3-11 *Policer Counters in Cisco IOS*

```
Router#show policy-map interface pos0/0/0
 POS0/0/0

  Service-policy input: POLICY4

    Class-map: CLASS5 (match-all)
      90836 packets, 3996784 bytes
      5 minute offered rate 112000 bps, drop rate 0 bps
      Match:  dscp 26  28  30  (1281)
      police:
         rate 100000 bps, burst 3125 bytes
         peak-rate 200000 bps, peak-burst 6250 bytes
          conformed 22153 packets, 974732 bytes; action:
            set-dscp-transmit af31
          exceeded 22617 packets, 995148 bytes; action:
            set-dscp-transmit af32
          violated 46066 packets, 2026904 bytes; action:
            set-dscp-transmit af33
        conform color
          conform action 22153 packets, 974732 bytes
          exceed action 19705 packets, 867020 bytes
          violate action 36691 packets, 1614404 bytes
        exceed color
          exceed action 2912 packets, 128128 bytes
          violate action 6030 packets, 265320 bytes
        violate color
          violate action 3345 packets, 147180 bytes
          conformed 32000 bps, exceeded 32000 bps violated 59000 bps

    Class-map: class-default (match-any)
      76858 packets, 3381752 bytes
      5 minute offered rate 85000 bps, drop rate 0 bps
      Match: any  (1284)
        76858 packets, 3381752 bytes
        5 minute rate 85000 bps
      police:
         rate 10 %
           (15500000 bps, burst 484375 bytes)
         peak-rate 20 %
           (31000000 bps, peak-burst 968750 bytes)
          conformed 76858 packets, 3381752 bytes; action:
            transmit
          exceeded 0 packets, 0 bytes; action:
            drop
          violated 0 packets, 0 bytes; action:
```

Example 3-11 *Policer Counters in Cisco IOS (Continued)*

```
            drop
          conformed 85000 bps, exceeded 0 bps violated 0 bps
Router#
```

The color-aware policer includes an additional set of counters that capture the number of packets (and bytes) per type of action according to their initial color classification. Out of all the packets classified initially as of conforming color, the policer executed the conform action on 22,153, the exceed action on 19,705, and the violate action on 36,691. Similarly, the policer executed the exceed action on 2912 packets and the violate action on 6030 packets that arrived with the exceed color, respectively. Finally, the policer executed the violate action on 3345 packets that arrived with the violate color. Each packet counter has an associated byte counter.

NOTE Remember that in color-aware mode, the policer will not execute the conform action on packets that arrive with the exceed or violate colors. Similarly, the policer will not execute the exceed action on packets that arrive with the violate color.

Example 3-12 illustrates the counters that the **show policy-map** command displays for policers in Cisco IOS XR. The sample output corresponds to POLICY1 in Example 3-10. Both policers maintain the same set of counters. That is, packet, byte, and rate counts for the conform, exceed, and violate actions. In this example, the CLASS1 policer has had 3123 conforming packets (4,628,286 bytes) with a current rate of 60 kbps. The policer has measured 66,877 packets exceeding the profile for a total of 99,111,714 bytes. The current rate of exceeding packets is 1266 kbps. The policer has not executed the violate action for any packet. The CLASS2 policer has found 6,196 conforming packets (9,182,472 bytes) and is currently receiving 118 kbps of those packets. It has also measured 28,804 exceeding packets (42,687,528 bytes) with a current rate of 546 kbps. There have not been violating packets.

Example 3-12 *Policer Counters in Cisco IOS XR*

```
RP/0/4/CPU0:Router#show policy-map interface pos0/3/0/3
POS0/3/0/3 input: POLICY1

Class CLASS1
  Classification statistics          (packets/bytes)     (rate - kbps)
    Matched             :               70000/103740000            1325
    Transmitted         :               70000/103740000            59
    Total Dropped       :                   0/0                    1266
  Policing statistics                (packets/bytes)     (rate - kbps)
    Policed(conform)    :                 3123/4628286             60
    Policed(exceed)     :                66877/99111714            1266
    Policed(violate)    :                   0/0                    0
```

Example 3-12 *Policer Counters in Cisco IOS XR (Continued)*

```
    Policed and dropped :               66877/99111714
  Queueing statistics
    Vital           (packets)            : 0
    Queue ID                             : None (Bundle)
    Taildropped(packets/bytes)           : 0/0

Class CLASS2
  Classification statistics          (packets/bytes)     (rate - kbps)
    Matched             :               35000/51870000             663
    Transmitted         :               35000/51870000             663
    Total Dropped       :                   0/0                    0
  Policing statistics                (packets/bytes)     (rate - kbps)
    Policed(conform)    :                6196/9182472              118
    Policed(exceed)     :               28804/42687528             546
    Policed(violate)    :                   0/0                    0
    Policed and dropped :                   0/0
  Queueing statistics
    Vital           (packets)            : 0
    Queue ID                             : None (Bundle)
    Taildropped(packets/bytes)           : 0/0

Class default
  Classification statistics          (packets/bytes)     (rate - kbps)
    Matched             :             105000/155610000            1987
    Transmitted         :             105000/155610000            1987
    Total Dropped       :                   0/0                    0
  Queueing statistics
    Vital           (packets)            : 0
    Queue ID                             : None (Bundle)
    High watermark  (bytes)              : 0
    Taildropped(packets/bytes)           : 0/0
RP/0/4/CPU0:Router#
```

Traffic Shaping

The **shape** command configures traffic shaping and defines a maximum bandwidth rate for a class. Shaping implements the maximum bandwidth attribute in the queuing component of the TMN. It causes packet queuing when the arriving traffic pattern exceeds a traffic profile. You define the profile using a rate and one or two bursts. The rate is in bits per second, and the bursts are in bits by default.

The shaper enforces the rate during a time interval. Within the interval, the traffic can exceed the shaper rate. The smaller the interval, the smoother the shaper output. This interval also defines how frequently the shaper replenishes tokens in the bucket. Some

forms of the **shape** command allow you to control this interval. Table 3-21 summarizes the configuration options for the **shape** command.

Table 3-21 *Average and Peak Packet Shaping*

Syntax	Description
shape average *rate-value* [*burst*]	Average shaper with token bucket definition in absolute terms and fixed shaping interval
shape average *rate-value* [*bc-value* [*be-value*]]	Average shaper with token bucket definition in absolute terms and configurable shaping interval
shape peak *rate-value* [*bc-value* [*be-value*]]	Peak shaper with token bucket definition in absolute terms and configurable shaping interval
shape average percent *rate-value* [*burst*] **ms**	Average shaper with token bucket definition relative to underlying bandwidth and fixed shaping interval
shape average percent *rate-value* [*bc-value* **ms** [*be-value* **ms**]]	Average shaper with token bucket definitions relative to underlying bandwidth and configurable shaping interval
shape peak percent *rate-value* [*bc-value* **ms** [*be-value* **ms**]]	Peak shaper with token bucket definition in relative to underlying bandwidth and configurable shaping interval

You use the **shape average** command to enforce a maximum average rate. There is a two-parameter and three-parameter version of this command. In the two-parameter version, the **shape average** command uses a rate and a burst to define a token bucket. The underlying implementation selects the shaping interval automatically. In the three-parameter version, the command uses **rate** (**bc** and **be**) values. The **rate** and (**bc+be**) define a token bucket. In this case, the shaper implements an interval of **bc** divided by the **rate**. That is, every interval, the shaper replenishes **bc** tokens into a bucket of size **bc+be**. In both cases, the shaper serves packets if the bucket holds enough tokens; otherwise, the packet waits in a queue. The device computes default bursts if you do not configure them explicitly.

The **shape peak** command enforces a maximum peak rate. This command uses three parameters: **rate**, **bc**, and **be**. The device computes default **bc** and **bc** values if you do not configure them explicitly. This shaper implements an interval of **bc** divided by the **rate**, but effectively replenishes **bc+be** tokens at each interval. This implies that the shaper can offer a peak rate that exceeds the configured rate.

You control the peak rate with the value of **be**. This shaping behavior is useful for Frame Relay environments making use of a *committed information rate* (CIR), an *excess information rate* (EIR), and a *peak information rate* (PIR). In this case, the shape rate equals the CIR. If **tc** is the shaper interval, the following relationships hold:

tc = bc / CIR
PIR = (bc + be) / tc
PIR = CIR + CIR (be / bc)
PIR = CIR + EIR
EIR = CIR (be / bc)

You can also define the shaping parameters in relative terms. In this case, you specify the shaper rate as a percentage of the underlying bandwidth rate of the policy attachment point. Similarly, you specify the burst, **bc**, and **be** values in time units (milliseconds by default) relative to the shaper rate. The device computes the effective parameters in absolute values. The **percent** keyword enables the definition of relative traffic profiles. Both the **shape average** and **shape peak** commands support this keyword. The section "Percentage-Based Rates" explains what constitutes the underlying bandwidth rate that the device uses to interpret relative profile definitions.

Figure 3-7 shows the output of three sample shapers for a given packet-arrival pattern. Each black box represents a packet, and each gray box represents a token. A stream of packets arrives at an average rate of 200 *packets per second* (pps). In this example, all parameters are normalized in packets and packets have the same size. These assumptions will help you understand the operation of the shapers, which in reality operate in bits and bits per second. The first configuration (from top to bottom) uses a two-parameter average shaper. This particular shaper implementation uses a 5-ms shaping interval (one token every 5 ms). The second configuration uses a three-parameter average shaper. The last configuration uses peak shaping. Notice how the first shaper smoothes traffic the most, and the last one has the least smoothing effect. These are the sequence of events for the two-parameter average shaper:

- **Initial state**—Bucket holds two tokens.
- **(0 ms, 5 ms)**—Three packets arrive. Two tokens are consumed and one packet is queued. Bucket becomes empty.
- **(5 ms, 10 ms)**—One token accumulates and is used to serve the queued packet. No new packets arrive. Bucket becomes empty.
- **(10 ms, 15 ms)**—One token accumulates. No new packets arrive. Bucket holds one token.
- **(15 ms, 20 ms)**—One token accumulates. No new packets arrive. Bucket holds two tokens.

- **(20 ms, 25 ms)**—Additional token discarded because bucket is full. One packet arrives and consumes one token. Bucket holds one token.
- **(25 ms, 30 ms)**—One token accumulates. No new packet arrives. Bucket holds two tokens.
- **(30 ms, 35 ms)**—Additional token discarded because bucket is full. One packet arrives and consumes one token. Bucket holds one token.
- **(35 ms, 40 ms)**—One token accumulates. One packet arrives and consumes one token. Bucket holds one token.
- **(40 ms, 45 ms)**—One token accumulates. Four packets arrive and consume two tokens. Two packets are queued. Bucket becomes empty.
- **(45 ms, 50 ms)**—One token accumulates and is used to serve one queued packet. Four packets arrive. Five packets are queued. Bucket becomes empty.
- **(50 ms, 55 ms)**—One token accumulates and is used to serve one queued packet. No new packets arrive. Four packets are queued. Bucket becomes empty.
- **(55 ms, 60 ms)**—One token accumulates and is used to serve one queued packet. No new packets arrive. Three packets are queued. Bucket becomes empty.
- **(60 ms, 65 ms)**—One token accumulates and is used to serve one queued packet. No new packets arrive. Two packets are queued. Bucket becomes empty.
- **(65 ms, 70 ms)**—One token accumulates and is used to serve one queued packet. No new packets arrive. One packet is queued. Bucket becomes empty.
- **(70 ms, 75 ms)**—One token accumulates and is used to serve one queued packet. No new packets arrive. No packets are queued. Bucket becomes empty.

The **shape adaptive** command adjusts the shaper rate in response to congestion notification. This command defines a reduced shaping rate. Adaptive shaping is useful for a Frame Relay environment where a device learns about network congestion from frames that arrive with the *backward explicit congestion notification* (BECN) flag set. When a device receives a congestion notification, the shaper decreases the shaping rate until it reaches the configured reduced rate. When the arrival of congestion notifications ceases, the shaper increases the shaping rate back to the original maximum rate. You can configure adaptive shaping with either the average or the peak shaping discussed earlier. Table 3-22 summarizes the **shape adaptive** command.

Figure 3-7 *Comparison Between Average and Peak Shaping*

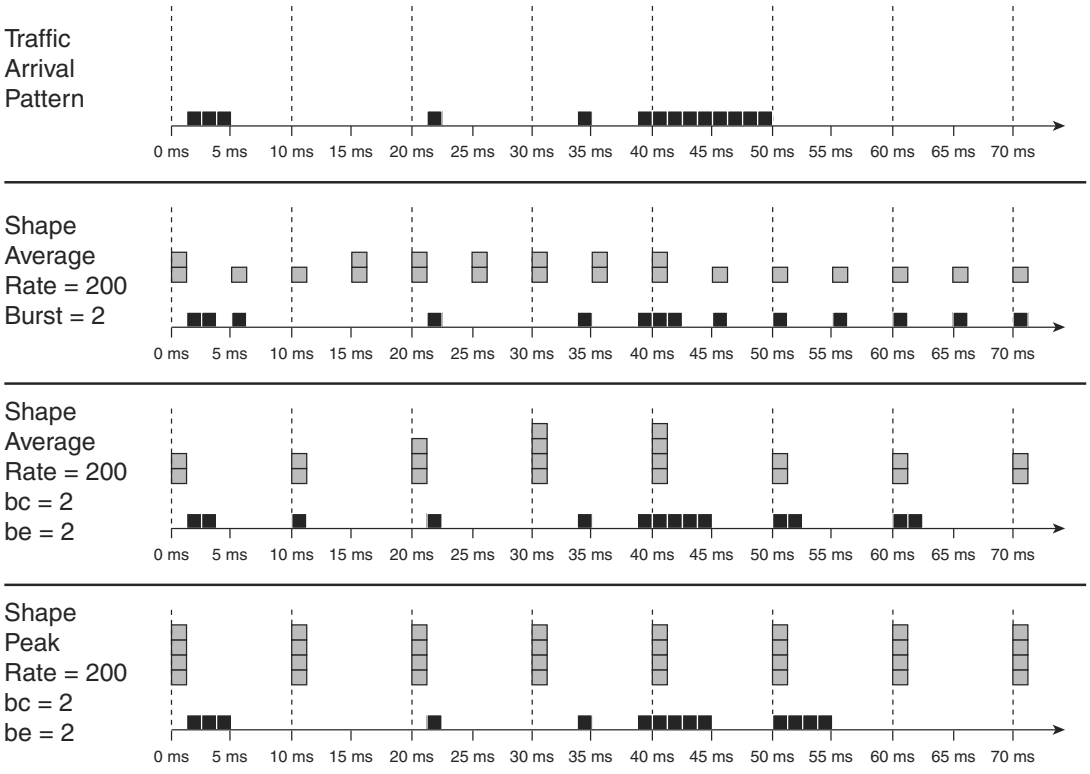


Table 3-22 *Adaptive Shaping for Frame Relay*

Syntax	Description
shape adaptive *value*	Reduce shaping rate upon arrival of congestion notifications
shape adaptive percent *value*	Reduce shaping rate (relative to underlying bandwidth) upon arrival of congestion notifications

Example 3-13 displays three different shaping policies:

- POLICY1 enforces an average rate of 1,000,000 bps on all traffic. That policy uses a two-parameter shaper with an implicit default burst size.
- POLICY2 describes an adaptive shaper with a peak rate for a Frame Relay circuit. The shaper uses a committed rate of 1,024,000 bps and a peak rate of 2,048,000 bps. When the Frame Relay network notifies of a congestion condition, the shaper adjusts the rate to 1,024,000 bps.

- POLICY3 uses average shaping for two classes. The policy classifies the traffic using the Ethernet 802.1Q user priority. Both classes use two-parameter average shapers that define the shaping rate in relative terms and rely on the default burst size.

Example 3-13 *Policies Performing Traffic Shaping*

```
class-map match-all CLASS1
  match cos  3  4
class-map match-all CLASS2
  match cos  1  2
!
policy-map POLICY1
  class class-default
    shape average 1000000
!
policy-map POLICY2
  class class-default
    shape peak 1024000 4096 4096
    shape adaptive 1024000
!
policy-map POLICY3
  class CLASS1
    shape average percent 5
  class CLASS2
    shape average percent 10
!
```

Example 3-14 illustrates the shaper counters available in Cisco IOS. The counters are not specific to shapers; they relate to the queue that the shaper enables. This example shows the output of **show policy-map** for POLICY2 in Example 3-13. A first set of counters provide information about the shaped queue. A second group of counters provides details about the number of transmitted packets and their respective byte count. For POLICY2, 235 packets are queued, and the shaper has dropped 54 packets because of the queue overflowing. (The maximum queue size is 256 packets.) There have not been packet drops due to buffer starvation. The second set of counters shows that the shaper has transmitted 56,493 packets or 83,947,146 bytes. The sum of transmitted and dropped packets matches the packet count for the policy (56,547 packets).

Example 3-14 *Shaper Counters in Cisco IOS*

```
Router#show policy-map interface pos0/0/0

 POS0/0/0

  Service-policy output: POLICY2

    Class-map: class-default (match-any)
      56547 packets, 84027390 bytes
      5 minute offered rate 882000 bps, drop rate 4000 bps
      Match: any
        56547 packets, 84027390 bytes
```

Example 3-14 *Shaper Counters in Cisco IOS (Continued)*

```
        5 minute rate 882000 bps
      Queueing
      queue limit 256 packets
      (queue depth/total drops/no-buffer drops) 235/54/0
      (pkts output/bytes output) 56493/83947146
      shape (peak) cir 1024000, bc 4096, be 4096
      target shape rate 2048000
        lower bound cir 1024000,  adapt to fecn 0
Router#
```

NOTE Some platforms display a reduced number of counters that include the current, maximum, and average queue depths (that is, number of packets in the queue).

Example 3-15 shows the counters associated with traffic shaping in Cisco IOS XR. This example uses policy POLICY1 that Example 3-13 introduced. As in the preceding example, the counters most relevant to the shaper are associated with the shaping queue. The first queue counters shows a high watermark of 43,636 bytes. The next two counters show the instantaneous and average queue length (also called queue depth). For this policy, these two counters show 32 and 15 packets, respectively. The last counter shows the number of packets lost due to tail dropping. In this case, 340 packets found the queue full. The number of dropped plus transmitted packets equals the number of packets that the class matched.

Example 3-15 *Shaper Counters in Cisco IOS XR*

```
RP/0/4/CPU0:Router#show policy-map interface pos0/3/0/4
POS0/3/0/4 output: POLICY1

Class class-default
  Classification statistics          (packets/bytes)     (rate - kbps)
    Matched             :               42000/62244000              540
    Transmitted         :               41660/62244000              540
    Total Dropped       :                 340/0                     0
  Queueing statistics
    Vital           (packets)            : 0
    Queue ID                             : 8
    High watermark  (bytes)              : 43636
    Inst-queue-len  (packets)            : 32
    Avg-queue-len   (packets)            : 15
    Taildropped(packets/bytes)           : 340/0
RP/0/4/CPU0:Router#
```

Congestion Management

The **bandwidth**, **bandwidth remaining percent**, and **priority** commands are the three main mechanisms that define a queuing policy in the MQC. These commands configure the minimum-bandwidth, excess-bandwidth, and priority attributes that the section "Dequeuing Subcomponent" described. The underlying implementation allocates the queues and configures the packet scheduling mechanisms to satisfy the bandwidth allocation and traffic prioritization that the policy defines. The **shape** command complements these commands by allowing you to define maximum bandwidth allocations.

The **bandwidth** command can define the minimum bandwidth that a queue receives. The simplest form of the **bandwidth** command specifies a minimum-bandwidth guarantee in absolute terms. The rates are in kilobits per second by default. You can also define the guarantee as a percentage of the underlying bandwidth rate using the **bandwidth percent** syntax. The **bandwidth remaining percent** command performs excess-bandwidth allocation. The excess bandwidth includes the bandwidth that is not part of minimum guarantees or bandwidth that other classes are not using within their minimum guarantees at a particular point in time. The explicit configuration of minimum- and excess-bandwidth allocations are mutually exclusive in platforms with two-parameter schedulers. See the section "Dequeuing Subcomponent" for a discussion of two-parameter and three-parameter schedulers. Table 3-23 summarizes the syntax of the **bandwidth** and **bandwidth remaining percent** command.

Table 3-23 *Bandwidth Allocation and Traffic Prioritization During Congestion*

Syntax	Description
bandwidth *value*	Minimum-bandwidth allocation
bandwidth percent *value*	Minimum-bandwidth allocation relative to the underlying bandwidth
bandwidth remaining percent *value*	Excess-bandwidth allocation
priority [**level** *value*][*rate-value* [*burst-value*]]	Low-latency prioritization with optional conditional policer
priority [**level** *value*] **percent** [*rate-value* [*burst-value*]]	Low-latency prioritization with optional conditional policer at a rate relative to the underlying bandwidth

The **priority** command indicates that a class requires low latency. The scheduler should serve the traffic with strict priority (that is, at the underlying full rate of the policy attachment point). The priority traffic is not part of the rate-allocation process that the scheduler performs for nonpriority classes. Therefore, the configuration of the **priority** and **bandwidth** commands is mutually exclusive within the same class. A policer can limit the amount of bandwidth that the priority traffic consumes. The policer acts as pre-queuing operation that does not affect the rate at which the scheduler serves the priority packets. The policer will limit the amount of packets that enter the priority queue. It does not reduce the service rate of the priority queue, which the scheduler will always serve at the full rate of the policy attachment point.

The configuration of a priority class influences the configuration of bandwidth to nonpriority classes. In its simplest form, the **priority** command does not use any parameters, and no upper bandwidth limit applies to the priority traffic. Therefore, you cannot allocate minimum-bandwidth guarantees to other classes in the same policy. However, you can allocate excess bandwidth using the **bandwidth remaining percent** command. Alternatively, you can configure an explicit policer to enforce a bandwidth limit on the priority traffic. In that case, other classes can receive minimum-bandwidth guarantees equal to the underlying bandwidth of the policy attachment point minus the sum of the policer rates of all priority classes.

The **priority** command may include an implicit conditional policer. You can define this command with an associated traffic profile in the form of a token bucket: rate and burst. These parameters can be in absolute terms (bits per second and bytes) or relative terms (rate percentage and milliseconds) with respect to the underlying bandwidth using the **priority percent** syntax. During periods of congestion, this conditional policer enforces the traffic profile. When congestion is not present, no limit applies to the amount of priority traffic. This behavior differs from the scenario that uses an explicitly configured policer. The explicit policer limits the priority traffic regardless of whether there is congestion. Table 3-21 summarized the syntax of the **priority** and **priority percent** commands.

A packet may experience an additional stage of queuing after the scheduler selects it for transmission. This additional stage controls the delivery of packets to the interface hardware for final transmission. It commonly uses a circular queue that receives the name of transmit ring due to its circular structure. The exact structure, size, and operation of the transmit ring is transparent to the user in most cases. In some exceptional cases, you may need to adjust its size using the **tx-ring-limit** command. A proper size will minimize the introduction of additional latency to the packet while avoiding a negative impact on bandwidth utilization of the output interface. In most cases, nodes select an optimal size automatically based on the interface characteristics and the configured output policy. Consult the platform documentation for details.

In addition, the **queue-limit** command defines the maximum size of a particular queue. When a queue reaches its limits, the enqueuing process drops new arriving packets. The queue limit uses packets at its default configuration unit. You can define different queue limits according to particular packet markings to implement weighted tail dropping. Tables 3-24 and 3-25 list the different forms that the **queue-limit** command can use.

Table 3-24 *Maximum Queue Size*

Syntax	Description
queue-limit [*value*] [**packets**|**bytes**|**cells**|**ms**|**us**]	Maximum queue size

Table 3-25 *Maximum Queue Size for Specific Packet Markings*

Syntax	Weighting Field
queue-limit precedence *value limit-value* [**packets** | **bytes** | **ms**]	IPv4 precedence, IPv6 precedence, or MPLS EXP
queue-limit dscp *value limit-value* [**packets** | **bytes** | **ms**]	IPv4 DSCP, IPv6 DSCP, or MPLS EXP
queue-limit discard-class *value limit-value* [**packets** | **bytes** | **ms**]	Discard class
queue-limit cos *value limit-value* [**packets** | **bytes** | **ms**]	Ethernet 802.1Q user priority
queue-limit clp *value* limit-*value* [**packets** | **bytes** | **ms**]	ATM CLP bit

Example 3-16 illustrates four different queuing policies:

- POLICY1 classifies traffic using the MPLS EXP field. The policy guarantees low latency to CLASS1. An explicit unconditional policer limits the CLASS1 traffic to 20,000,000 bps with a burst size of 25,000 bytes. CLASS2 and the default class, receives a minimum-bandwidth guarantee of 80,000 and 10,000 kbps respectively.
- POLICY2 specifies a queuing policy that requires a three-parameter scheduler. The policy defines all rates and queue limits in relative terms. CLASS2 receives both a minimum and an excess-bandwidth guarantee. The traffic in the default class (class-default) gets only excess-bandwidth allocation.
- POLICY3 illustrates a third example that has two priority classes and allocates bandwidth to two nonpriority classes in the form of excess bandwidth. POLICY4 shows a policy similar to POLICY3. In this case, CLASS3 and CLASS4 have different priority levels and both use explicit policers.

Example 3-16 *Queuing Policies*

```
class-map match-all CLASS1
 match mpls experimental topmost 5
class-map match-all CLASS2
 match mpls experimental topmost 3 4
class-map match-all CLASS3
  match  dscp ef
  match access-group 1
class-map match-all CLASS4
  match  dscp ef
  match access-group 2
class-map match-all CLASS5
  match dscp af11  af12  af13
!
policy-map POLICY1
  class CLASS1
    priority
    police rate 20000000 burst 25000
```

continues

Example 3-16 *Queuing Policies (Continued)*

```
  class CLASS2
    bandwidth 80000
    queue-limit 7500
  class class-default
    bandwidth 10000
    queue-limit 1250
!
policy-map POLICY2
  class CLASS1
    priority
    police rate percent 20
  class CLASS2
    bandwidth percent 50
    bandwidth remaining percent 25
    queue-limit 100 ms
  class class-default
    bandwidth remaining percent 75
    queue-limit 200 ms
!
policy-map POLICY3
  class CLASS3
    priority percent 5
  class CLASS4
    priority percent 20
  class CLASS5
    bandwidth remaining percent 50
  class class-default
    bandwidth remaining percent 50
!
policy-map POLICY4
  class CLASS3
    priority level 1
    police rate percent 5
  class CLASS4
    priority level 2
    police rate percent 20
  class CLASS5
    bandwidth remaining percent 50
  class class-default
    bandwidth remaining percent 50
!
```

Example 3-17 illustrates the counters available in queuing policies in Cisco IOS. This example shows the output for POLICY3 in Example 3-16. A first set of counters provide the queue depth (packets in the queue) and the number of packet dropped. A second group of counters show the number of packets transmitted from the queue and their byte count. In this example, CLASS3 and CLASS4 share a single priority queue. This queue is currently empty, but shows 104 dropped packets. The individual class counters shows that all dropped priority packets belonged to CLASS3. The queue for CLASS5 is empty and has not experienced any packet drops. The scheduler has serviced 11,667 packets (or

17,337,162 bytes) of this class. If you take a closer look at the default class (class-default), you will notice that queue currently holds 10 packets and has (tail) dropped 222 packets. The queue has processed a total of 32,297 packets (or 47,991,890 bytes). The sum of transmitted and dropped packets matches the classification counter (32,519 packets).

Example 3-17 *Queuing Counters in Cisco IOS*

```
Router#show policy-map interface serial1/0:0

 Serial1/0:0

  Service-policy output: POLICY3

    queue stats for all priority classes:

      queue limit 64 packets
      (queue depth/total drops/no-buffer drops) 0/104/0
      (pkts output/bytes output) 6883/10228138

    Class-map: CLASS3 (match-all)
      320 packets, 475520 bytes
      30 second offered rate 44000 bps, drop rate 15000 bps
      Match: dscp ef (46)
      Match: access-group 1
      Priority: 5% (76 kbps), burst bytes 1900, b/w exceed drops: 104

    Class-map: CLASS4 (match-all)
      6667 packets, 9907162 bytes
      30 second offered rate 187000 bps, drop rate 0 bps
      Match: dscp ef (46)
      Match: access-group 2
      Priority: 20% (307 kbps), burst bytes 7650, b/w exceed drops: 0

    Class-map: CLASS5 (match-all)
      11667 packets, 17337162 bytes
      30 second offered rate 324000 bps, drop rate 0 bps
      Match: dscp af11 (10) af12 (12) af13 (14)
      Queueing
      queue limit 64 packets
      (queue depth/total drops/no-buffer drops) 0/0/0
      (pkts output/bytes output) 11667/17337162
      bandwidth remaining 50% (576 kbps)

    Class-map: class-default (match-any)
      32519 packets, 48321782 bytes
      30 second offered rate 920000 bps, drop rate 26000 bps
      Match: any
        32519 packets, 48321782 bytes
        30 second rate 920000 bps
      Queueing
      queue limit 64 packets
      (queue depth/total drops/no-buffer drops) 10/222/0
      (pkts output/bytes output) 32297/47991890
      bandwidth remaining 50% (576 kbps)
Router#
```

Example 3-18 shows the queuing counters available in Cisco IOS XR. This output corresponds to POLICY1 in Example 3-16. The queuing counters are similar to those that Example 3-15 described. Each queue displays a high watermark, the instant queue length (number of packets in the queue), the average queue length, and the number of packets dropped. CLASS1 shows no current queuing activity as all counters are zero. CLASS2 has a high watermark of 5,120 bytes and one queued packet. In the case of the default class (class-default), the watermark is 232,448 bytes, there are 908 in the queue, the average queue length is 851 packets, and 8220 have been tail dropped.

Example 3-18 *Queuing Counters in Cisco IOS XR*

```
RP/0/4/CPU0:Router#show policy-map interface pos0/3/0/4
POS0/3/0/4 output: POLICY1

Class CLASS1
  Classification statistics          (packets/bytes)     (rate - kbps)
    Matched             :              222054/329972244            5923
    Transmitted         :              222054/329972244            5923
    Total Dropped       :                   0/0                    0
  Policing statistics                (packets/bytes)     (rate - kbps)
    Policed(conform)    :              222054/329972244            2080
    Policed(exceed)     :                   0/0                    0
    Policed(violate)    :                   0/0                    0
    Policed and dropped :              8220/1221492
  Queueing statistics
    Vital           (packets)            : 0
    Queue ID                             : 18
    High watermark  (bytes)              : 0
    Inst-queue-len  (packets)            : 0
    Avg-queue-len   (packets)            : 0
    Taildropped(packets/bytes)           : 0/0

Class CLASS2
  Classification statistics          (packets/bytes)     (rate - kbps)
    Matched             :             1361878/2023750708          13265
    Transmitted         :             1361878/2023750708          13265
    Total Dropped       :             8220/1221492                0
  Queueing statistics
    Vital           (packets)            : 0
    Queue ID                             : 16
    High watermark  (bytes)              : 5120
    Inst-queue-len  (packets)            : 1
    Avg-queue-len   (packets)            : 0
    Taildropped(packets/bytes)           : 0/0

Class class-default
  Classification statistics          (packets/bytes)     (rate - kbps)
    Matched             :             1872234/2782139724          18672
    Transmitted         :             1872234/2782139724          18672
    Total Dropped       :                   0/0                    0
  Queueing statistics
    Vital           (packets)            : 0
```

Example 3-18 *Queuing Counters in Cisco IOS XR (Continued)*

```
    Queue ID                                : 17
    High watermark  (bytes)                 : 232448
    Inst-queue-len  (packets)               : 908
    Avg-queue-len   (packets)               : 851
    Taildropped(packets/bytes)              : 8220/12214920
RP/0/4/CPU0:Router#
```

Active Queue Management

The MQC uses the **random-detect** command to configure *Active Queue Management* (AQM) using the WRED algorithm. This function is part of the queuing component of the Cisco QoS behavioral model. Active queue management is only possible on classes with an underlying queue.

The configuration of WRED defines two main elements: weighting field and thresholds. You need to specify the weighting field first (for example, IP precedence, DSCP, discard class). Then, you can specify the thresholds for a particular marking of the weighting field. Notice that the WRED implementation will use the MPLS EXP markings for MPLS packets when you configure WRED to use IP precedence or DSCP as the weighting field. Table 3-26 summarizes the weighting fields that can control the operation of WRED.

Table 3-26 *WRED Using Different Weighting Fields*

Syntax	Weighting Field
random-detect precedence-based	IPv4 precedence, IPv6 precedence, and MPLS EXP
random-detect dscp-based	IPv4 DSCP, IPv6 DSCP, and MPLS EXP
random-detect discard-class-based	Internal field for packet drop profile
random-detect cos-based	Ethernet 802.1Q user priority
random-detect clp-based	ATM CLP bit

You can define the WRED thresholds for specific packet markings. The underlying implementation provides default thresholds. However, you can override those defaults using the **random-detect** command and specifying the thresholds for a particular marking value (or range of values) of the weighting field. You can define the thresholds in absolute terms (packets or bytes) or in relative time units. The default threshold units correspond to packets. Table 3-27 shows the syntax to define the WRED thresholds. When defining the thresholds for a marking, the last optional parameter is a probability denominator, d. This value determines the maximum drop probability, p_{max}, for a given marking with the following equation:

$$p_{max} = 1 / d$$

See the section "Active Queue Management" in Chapter 1 for a review of the parameters that control the behavior of WRED.

Table 3-27 *WRED Thresholds for Specific Packet Markings*

Syntax	Weighting Field
random-detect precedence *range min-value* [**packets** | **bytes** | **ms**] *max-value* [**packets** | **bytes** | **ms** | **us**] *prob-den-value***]**	IPv4 precedence, IPv6 precedence, or MPLS EXP
random-detect dscp *range min-value* [**packets** | **bytes** | **ms**] *max-value* [**packets** | **bytes** | **ms** | **us**] *prob-den-value*	IPv4 DSCP, IPv6 DSCP, or MPLS EXP
random-detect exp *range min-value* [**packet** | **bytes** | **ms** *max-value* [**packet** | **bytes** | **ms** [*prob-den-value*]	MPLS EXP
random-detect discard-class *range min-value* [**packets** | **bytes** | **cells** | **ms**] *max-value* [**packets** | **bytes** | **cells** | **ms**] *prob—den-value*	Discard class
random-detect cos *range min-value* [**packets** | **bytes** | **ms** | **us**] *max-value* [**packets** | **bytes** | **ms**] *prob-den-value*	Ethernet 802.1Q user priority
random-detect clp *value min-value* [**cells** | **ms**] *max-value* [**cells** | **ms** | **us**] *prob-den-value*	ATM CLP bit

NOTE Some platforms may accept only a single value for the weighting field rather than a range when you define a WRED threshold.

The **random-detect** command also provides control over the computation of the average queue size. The section "Active Queue Management" in Chapter 1 describes the equation that computes the average queue size. You can define an exponential weighting constant, c, to compute the averaging weight in that equation with the following equation:

$$w = 1 / 2^c$$

A high constant value results in a low averaging weight. Low weights make the average queue size less responsive to changes in the instantaneous queue size. A high weight causes the average computation to more closely track the instantaneous queue size. Table 3-28 shows the syntax that you can use to define the exponential weighting constant.

Table 3-28 *Weighting Constant Controlling Queue Size Averaging*

Syntax	Description
random-detect exponential-weighting-constant *value*	Weighting constant to compute the average queue size

You can also configure WRED to perform *explicit congestion notification* (ECN) for IP traffic. ECN affects the operation of WRED between the minimum threshold and maximum threshold. WRED checks the ECN field before deciding the proper action to take on a packet when it has selected that packet for dropping. If the ECN field indicates that the packet endpoints are ECN capable, WRED marks the congestion indication in the ECN field, and the packet enters its respective queue. If the ECN field already contains a congestion indication, WRED also allows the packet to enter its queue. On the other hand, if the ECN field indicates that the endpoints are not ECN capable, WRED proceeds to drop the packet as it normally would. Table 3-29 shows the syntax to enable ECN for IP traffic using WRED.

Table 3-29 *ECN Using WRED*

Syntax	Description
random-detect ecn	Explicit congestion notification for IP traffic based on WRED drop profiles

Example 3-19 includes three policies that perform active queue management with WRED:

- In POLICY1, both CLASS2 and the default class (class-default) make use of precedence-based WRED. They define explicitly the thresholds in terms of number of packets. The policy will apply the thresholds using the MPLS EXP value for CLASS2. For the default class, the policy will use the precedence value for IP packets and the EXP value for MPLS packets to apply the thresholds.
- POLICY2 enables WRED based on the discard class of each packet. The policy specifies explicit thresholds in milliseconds for DSCP values zero, one, and two.
- POLICY3 enables WRED based on the discard class of each packet. The policy specifies explicit thresholds in milliseconds for DSCP values CS1, CS2, and default.
- POLICY4 enables congestion notification for IP traffic using precedence-based WRED and ECN. This policy does not define any threshold explicitly. Therefore, WRED uses default threshold values for the eight different IP precedence values.

Example 3-19 *Queuing Policies with WRED*

```
class-map match-all CLASS1
  match mpls experimental topmost 5
class-map match-all CLASS2
  match mpls experimental topmost 3  4
class-map match-all CLASS3
 match dscp cs1 cs2
!
policy-map POLICY1
  class CLASS1
    priority
    police rate 2000000
  class CLASS2
    bandwidth 10000
    random-detect
```

Example 3-19 *Queuing Policies with WRED (Continued)*

```
    random-detect precedence 3 2000 4000 1
    random-detect precedence 4 4000 6000 1
  class class-default
    random-detect
    random-detect precedence 0 4000 6000 1
!
policy-map POLICY2
  class class-default
    random-detect discard-class-based
    random-detect discard-class 0 75 ms 150 ms 1
    random-detect discard-class 1 25 ms 150 ms 1
    random-detect discard-class 2 75 ms 150 ms 1
!
policy-map POLICY3
  class CLASS3
    bandwidth percent 40
    random-detect dscp-based
    random-detect dscp cs1 25 ms 75 ms
    random-detect dscp cs2 50 ms 100 ms
  class class-default
    bandwidth percent 40
    bandwidth remaining percent 60
    random-detect dscp-based
    random-detect dscp default 25 ms 100 ms
!
policy-map POLICY4
 class class-default
  random-detect
  random-detect ecn
!
```

NOTE The WRED configuration and behavior in Cisco IOS XR may differ from the description in this section. First, you may not require defining the weighting field explicitly using one of the commands in Table 3-24. The threshold definitions may define implicitly that field. Also, you may not rely on default thresholds. If a packet arrives with a marking that does not match an explicitly configured WRED threshold, the packet may be subject to tail dropping. Last, DSCP or IP precedence thresholds may not apply to MPLS packets. The definition of WRED thresholds for MPLS packets may always require the use of the **random-detect exp** command. Consult the Cisco IOS XR documentation for details.

Example 3-20 shows the counters that policies maintain for WRED using POLICY2 in Example 3-19. There are transmitted, random drops, and tail drop counters, in packets and bytes, for each of the packet markings that a class can serve. In this example, the default class (class-default) serves all traffic and uses WRED based on the discard class. For packets with a discard class value of zero, the policy has transmitted 14,390 packets (or

21,382,088 bytes) and has randomly dropped 30 packets (or 44,580 bytes). For packets with discard class one, the policy has transmitted 7,059 packets (or 10,489,674 bytes). No packets with this discard class value have experienced a random drop. For a discard class value of two, the policy has transmitted 9398 packets (or 13,965,428 bytes). It has randomly dropped 12 packets (or 17,832 bytes). The policy has not tail dropped any packets. The sum of transmitted packets matches the queue output counter (30,847 packets), and the sum of random and tail drops matches the queue total drops (42 packets).

Example 3-20 *WRED Counters in Cisco IOS*

```
Router#show policy-map interface serial1/0:0

 Serial1/0:0

  Service-policy output: POLICY2

    Class-map: class-default (match-any)
      30889 packets, 45899602 bytes
      30 second offered rate 3000 bps, drop rate 0 bps
      Match: any
        30889 packets, 45899602 bytes
        30 second rate 3000 bps

      queue limit 83 ms/ 16000 bytes
      (queue depth/total drops/no-buffer drops) 0/42/0
      (pkts output/bytes output) 30847/45837190
        Exp-weight-constant: 9 (1/512)
        Mean queue depth: 0 ms/ 0 bytes
      discard-class   Transmitted   Random drop   Tail drop   Minimum   Maximum   Mark
                 pkts/bytes       pkts/bytes    pkts/bytes  thresh    thresh    prob
                                                                ms/bytes  ms/bytes
              0    14390/21382088   30/44580     0/0   50/9600    150/28800   1/1
              1    7059/10489674    0/0          0/0   100/19200  150/28800   1/1
              2    9398/13965428    12/17832     0/0   50/9600    150/28800   1/1
              3    0/0              0/0          0/0   20/4000    41/8000     1/10
              4    0/0              0/0          0/0   23/4500    41/8000     1/10
              5    0/0              0/0          0/0   36/7000    41/8000     1/10
              6    0/0              0/0          0/0   31/6000    41/8000     1/10
              7    0/0              0/0          0/0   26/5000    41/8000     1/10
Router#
```

Example 3-21 illustrates the WRED counters in Cisco IOS XR. The example uses POLICY3 in Example 3-19. A set of counters (in packets and bytes) shows the number of WRED drops for each queue. These counters include random drops and drops that happened when the average queue depth reached the maximum threshold. In the case of CLASS3, WRED dropped 3,780 packets (or 5,601,960 bytes) randomly. It also dropped 851 packets (or 1,261,182 bytes) because of the maximum threshold. In addition to these counters, each WRED threshold has a second set of counters. These counters capture the number of packets and bytes that WRED transmitted, dropped randomly, and dropped because of the maximum threshold. For DSCP CS1 (numeric value 8), those counters show

2,311,124 packets (or 3,425,085,768 bytes), 2100 packets (or 3,112,200 bytes), and 515 packets (or 763,230 bytes), respectively. For DSCP CS2 (numeric value 16), the counters are 3,466,687 packets (or 5,137,630,134 bytes), 1,680 packets (or 2489760 bytes), and 336 packets (497,952 bytes) respectively. The default class shows 6,700,982 packets transmitted (or 9,930,855,324 bytes) and 1141 packets (or 1,690,962 bytes) randomly dropped. No packets have been dropped due to the maximum threshold in that class.

Example 3-21 *WRED Counters in Cisco IOS XR*

```
RP/0/4/CPU0:Router#show policy-map interface pos0/3/0/4
POS0/3/0/4 output: POLICY3

Class CLASS3
  Classification statistics          (packets/bytes)     (rate - kbps)
    Matched             :             5782442/8569579044           2952
    Transmitted         :             5777811/8562715902           2952
    Total Dropped       :                4631/6863142              0
  Queueing statistics
    Vital           (packets)            : 0
    Queue ID                             : 16
    High watermark  (bytes)              : 3361176
    Inst-queue-len  (packets)            : 2268
    Avg-queue-len   (packets)            : 2264
    Taildropped(packets/bytes)           : 0/0
    RED random drops(packets/bytes)      : 3780/5601960
    RED maxthreshold drops(packets/bytes): 851/1261182


    WRED profile for DSCP 8
    RED Transmitted (packets/bytes)      : 2311124/3425085768
    RED random drops(packets/bytes)      : 2100/3112200
    RED maxthreshold drops(packets/bytes): 515/763230

    WRED profile for DSCP 16
    RED Transmitted (packets/bytes)      : 3466687/5137630134
    RED random drops(packets/bytes)      : 1680/2489760
    RED maxthreshold drops(packets/bytes): 336/497952

Class class-default
  Classification statistics          (packets/bytes)     (rate - kbps)
    Matched             :             6702123/9932546286           3471
    Transmitted         :             6700982/9930855324           3471
    Total Dropped       :                1141/1690962              0
  Queueing statistics
    Vital           (packets)            : 0
    Queue ID                             : 17
    High watermark  (bytes)              : 1482000
    Inst-queue-len  (packets)            : 960
    Avg-queue-len   (packets)            : 950
    Taildropped(packets/bytes)           : 0/0
    RED random drops(packets/bytes)      : 1141/1690962
    RED maxthreshold drops(packets/bytes): 0/0
```

Example 3-21 *WRED Counters in Cisco IOS XR (Continued)*

```
    WRED profile for DSCP 0
    RED Transmitted (packets/bytes)      : 6700982/9930855324
    RED random drops(packets/bytes)      : 1141/1690962
    RED maxthreshold drops(packets/bytes): 0/0
RP/0/4/CPU0:Router#
```

Link Fragmentation and Interleaving

Cisco IOS supports LFI with Multilink PPP (MLP) and Frame Relay encapsulation. You can use MLP for LFI on serial interfaces, dialer interfaces, ATM PVCs, or Frame Relay PVCs. Cisco Frame Relay also support native fragmentation using FRF.11 and FRF.12.

The configuration of *link fragmentation and interleaving* (LFI) requires the definition of a fragment size. The configuration is specific to the type of fragmentation that you are using (MLP or Frame Relay FRF.12). The **ppp multilink fragment delay** command defines the fragment size (in milliseconds or bytes) for MLP. The **ppp multilink interleave** command enables LFI. In the case of Frame Relay links, the **frame-relay fragment** command defines the fragment size (in bytes). LFI does not require explicit configuration in this case. These commands require the simultaneous use of a policy with a priority class on the interface or PVC where you have enabled fragmentation. Table 3-30 summarizes the LFI commands.

Table 3-30 *LFI with MLP and Frame Relay FRF.12 Fragmentation*

Syntax	Description
ppp multilink interleave	LFI for MLP
ppp multilink fragment {delay *value* | **size** *value*}	Fragment size for LFI with MLP encapsulation
frame-relay fragment *value* **end-to-end**	Fragment size for LFI with Frame Relay encapsulation

NOTE The definition of a fragment size for LFI is one of the few QoS features that you configure outside of the MQC.

Example 3-22 displays the configuration for LFI using MLP and Frame Relay FRF.12 fragmentation. POLICY1 defines a simple queuing policy with the CLASS1 queue serving priority traffic and the default class (class-default) serving all other traffic. Interface Serial1/0:0 uses MLP for LFI purposes. The interface is part of the multilink group one associated with interface Multilink1. This interface enables interleaving, and defines the fragment size as 480 bytes and serves as the attachment for POLICY1. Similarly, interface Serial1/0:1 implements LFI for a Frame Relay PVC. The interface also serves as the attachment point for POLICY1 and defines a fragment size of 480 bytes (corresponding to 10 milliseconds on a 384 kbps link speed).

Example 3-22 *Policies with LFI*

```
class-map match-all CLASS1
  match  dscp ef
!
policy-map POLICY1
  class CLASS1
    priority
    police rate percent 25 burst 10 ms
!
interface Multilink1
 ip address 192.168.2.1 255.255.255.252
 ppp multilink
 ppp multilink interleave
 ppp multilink group 1
 ppp multilink fragment delay size 480
 service-policy output POLICY1
!
interface Serial1/0:0
 no ip address
 encapsulation ppp
 ppp multilink
 ppp multilink group 1
!
interface Serial1/0:1
 ip address 192.168.2.5 255.255.255.252
 encapsulation frame-relay
 frame-relay interface-dlci 16
 frame-relay fragment 480 end-to-end
 service-policy output POLICY1
!
```

Header Compression

The **compression** command enables header compression in a policy. Header compression is an action of the pre-queuing component of the Cisco QoS behavioral model. You can configure either RTP and TCP header compression for bandwidth efficiency. The policy will perform compression on both protocols if you do not configure one of the two explicitly. Notice that header compression is a point-to-point technology and requires that both ends of a point-to-point link participate in the operation. The underlying encapsulation of the link should be Frame Relay, PPP, or *High-Level Data Link Control* (HLDC). Table 3-31 illustrates the complete syntax of the **compression** command.

Table 3-31 *RTP and TCP Header Compression*

Syntax	Description
compression header ip [**rtp** | **tcp**]	Compress RTP/TCP headers

NOTE Some platforms may use an earlier implementation that relies on the **ip** {**rtp** | **tcp**} **header-compression** interface command.

Example 3-23 illustrates a policy using header compression. CLASS1 uses RTP header compression only. On the other hand, CLASS2 performs both RTP and TCP header compression. Any packet matching the default class (class-default) is not subject to any types of header compression.

Example 3-23 *Policy Using Header Compression*

```
class-map match-all CLASS1
 match  dscp ef
class-map match-all CLASS2
 match  dscp cs4
!
policy-map POLICY1
 class CLASS1
   priority percent 25
   compress header ip rtp
 class CLASS2
   bandwidth percent 50
   compress header ip
!
```

Hierarchical Configurations

You can extend the capabilities of the MQC with hierarchical configurations. These configurations enable you to reference a policy within another policy. Similarly, a class map can reference other existing class maps. Hierarchical policies makes it possible to perform different actions on subclasses of traffic at different levels of granularity. In addition, a hierarchical approach enables you to create configuration modules that you can reuse repeatedly in other policies. Hierarchical policies are useful and popular in actual deployments. The following sections describe how traffic classification and policies operate in hierarchical configurations.

Hierarchical Classification

Hierarchical class map configurations make possible elaborate classification criteria using logical operations between matching criteria. The **match class-map** command in Table 3-7 enables this type of hierarchical configurations. You can define complex logical operations between matching criteria in combination with the **match-any** and **match-all** keywords.

CLASS1 in Example 3-24 has a hierarchical configuration that references CLASS2. In this example, an IP packet will belong to CLASS1 if it has a DSCP value of EF or if it satisfies the classification criteria of CLASS2. A packet belongs to CLASS2 if it has a DSCP value of CS5 and satisfies access list ACL1.

Example 3-24 *Hierarchical Classification*

```
class-map match-any CLASS1
 match  dscp ef
 match class-map CLASS2
class-map match-all CLASS2
 match  dscp cs5
 match access-group name ACL1
!
```

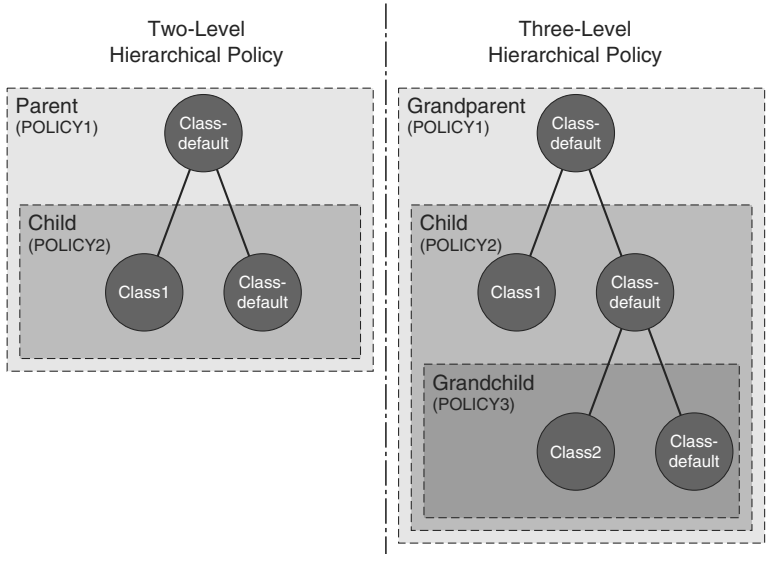
Hierarchical Policies

The MQC supports the configuration of hierarchical policies where a class within a policy becomes the attachment point for another policy. Many combinations of actions are possible within a hierarchical policy (for example, hierarchical policing, hierarchical queuing, or queuing and shaping).

The implementations of hierarchical policies typically limit the hierarchy to two or three levels. A policy including another policy receives the name of a parent policy. The policy that the parent policy includes receives the name of a child policy.

In a three-level hierarchy, a policy can be a grandparent or a grandchild of another policy. You apply a child policy using the **service-policy** command. The child policy automatically inherits the policy direction from its parent. Figure 3-8 illustrates the class and policy relationships in two hierarchical policies. The diagram on the left represents a two-level hierarchical policy and the diagram on the right shows a three-level hierarchical policy.

Figure 3-8 *Two-Level and Three-Level Hierarchical Policies*



Hierarchical policies use a single classification step. Therefore, the classification of a packet remains unchanged even if an action in a child or grandchild policy re-marks it. The new marking will not result in the reclassification of the packet. However, the new marking will affect the operation of WRED or weighted queue limits.

Actions have a particular order of execution in a hierarchical configuration. After classification, hierarchical policies execute actions in decreasing level of granularity. For example, in a three-level policy, the grandchild policy executes its actions on the packet before the parent policy. Similarly, the latter will execute its actions before the grandparent policy. This ordering applies to all actions with the exception of the **set** command. For example, in a policy that uses this command at all levels, the final marking of the packet will correspond to the value that the grandchild instance of the **set** command indicates.

Example 3-25 and 3-26 show two hierarchical policies. In Example 3-25, POLICY1 defines a two-level hierarchical policy. POLICY1 shapes all traffic to 10,000,000 bps and invokes POLICY2 as the child policy. POLICY2 defines a queuing policy that provides low latency to traffic with a DSCP value of EF and enables WRED on remaining traffic.

Example 3-25 *Two-Level Hierarchical Policy*

```
class-map match-all CLASS1
  match  dscp ef
!
policy-map POLICY1
  class class-default
   shape average 10000000 40000 40000
   service-policy POLICY2
!
policy-map POLICY2
  class CLASS1
    priority percent 20
  class class-default
    random-detect dscp-based
!
```

Example 3-26 expands the hierarchy one level to produce a three-level hierarchical policy. In this example, POLICY2 invokes a POLICY3 as a child policy. POLICY3 marks CLASS2 using a policer and all other traffic with a **set** command. POLICY3 will act only on packets that do not have a DSCP of EF because of its attachment point. POLICY2 uses the new packet marking when performing WRED on the default class (class-default).

Example 3-26 *Three-Level Hierarchical Policy*

```
class-map match-all CLASS1
  match  dscp ef
class-map match-all CLASS2
  match access-group name ACL1
!
policy-map POLICY1
```

Example 3-26 *Three-Level Hierarchical Policy (Continued)*

```
  class class-default
   shape average 10000000 40000 40000
   service-policy POLICY2
!
policy-map POLICY2
  class CLASS1
   priority percent 20
  class class-default
   random-detect dscp-based
   service-policy POLICY3
!
policy-map POLICY3
  class CLASS2
   police rate percent 50
     conform-action set-dscp-transmit af21
     exceed-action set-dscp-transmit af22
  class class-default
   set dscp af21
!
```

Percentage-Based Rates

The attachment point of a policy determines the actual rate that the **bandwidth**, **shape**, and **police** commands use when you configure percentage-based rates. The **bandwidth percent** command defines a minimum-bandwidth guarantee relative to the minimum-bandwidth guarantee of the policy attachment point in the parent policy. The **shape** and **police** commands use the maximum rate of the attachment point as a reference. The presence of a **shape** or **police** command in the parent policy defines such maximum rate. In the absence of those commands in the parent policy, the parent policy inherits the maximum from its parent (grandparent policy) and eventually from the interface that serves as attachment point for the hierarchical policy.

NOTE The **priority percent** command uses the same logic of the **bandwidth percent** command to compute the actual rate of the conditional policer.

Interfaces generally have an implicit bandwidth definition that policies can use as a reference. In some cases, the interface will not have an associated bandwidth amount, and you may need to specify the interface rate. This situation can be particularly common on logical subinterfaces (for example, Ethernet, Frame Relay, or ATM subinterfaces). The **bandwidth qos-reference** command specifies the bandwidth amount that policies should use as a reference on an interface. You apply this command directly under the interface configuration, and any policy that you attach to the interface will use automatically make use of that bandwidth reference. Table 3-30 illustrates the complete syntax of the **bandwidth qos-reference** command.

Table 3-32 *Bandwidth Reference for QoS*

Syntax	Description
bandwidth qos-reference [**input** | **output**] *value*	Maximum queue size

Parameter Units

Tables 3-33 and 3-34 summarize the default parameter units for the MQC commands in this chapter. Both tables include a simplified syntax of the commands. Table 3-33 includes commands that have rates or bursts as parameters. Table 3-34 includes commands that have a queue size as parameters.

Table 3-33 *Default Units for the MQC Commands with Rate or Burst Parameters*

Command	Rate Units	Burst Units
police	Bits per second	Bytes
police cir	Bits per second	Bytes
police rate	Bits per second	Bytes
police cir percent	Not applicable	Milliseconds
police rate percent	Not applicable	Milliseconds
shape average	Bits per second	Bits
shape average	Bits per second	Bits
shape peak	Bits per second	Bits
shape average percent	Not applicable	Milliseconds
shape peak percent	Not applicable	Milliseconds
shape adaptive	Bits per second	Not configurable
shape adaptive percent	Not applicable	Not configurable
bandwidth	Kilobits per second	Not configurable
bandwidth percent	Not applicable	Not configurable
bandwidth remaining percent	Not applicable	Not configurable
priority	Kilobits per second	Bytes
priority percent	Not applicable	Milliseconds

Table 3-34 *Default Units for the MQC Commands with Queue Size Parameters*

Command	Queue Size Units
queue-limit	Packets
random-detect	Packets

Some platforms support the explicit configuration of parameter units in their implementation of the MQC. The flexible definition of units facilitates network operation and contributes to fewer configuration mistakes. Their benefits become more obvious as link speeds increase and the default units for a parameter become less adequate. Table 3-35 lists the different keywords for rate units. These keywords prove useful in the configuration of policers and shapers or when you perform bandwidth allocation for congestion management. Table 3-36 shows the keywords for memory units. These keywords facilitate the configuration of burst sizes for policers and shapers. They also facilitate the definition of the maximum size for a queue or thresholds for active queue management. Finally, Table 3-37 includes time units that help define burst sizes for policers and shapers.

Table 3-35 *Configurable Rate Units in the MQC*

Command Keyword	Units
bps	Bits per second
kbps	Kilobits per second
mbps	Megabits per second
gbps	Gigabits per second
pps	Packets per second
cps	ATM cells per second

Table 3-36 *Configurable Memory Units in the MQC*

Command Keyword	Units
bytes	Bytes
kbytes	Kilobytes
mbytes	Megabytes
gbytes	Gigabytes
packets	Packets per second
cells	ATM cells

Table 3-37 *Configurable Time Units in the MQC*

Command Keyword	Units
ms	Milliseconds
us	Microseconds

Example 3-27 illustrates a policy that relies on explicit configuration of parameter units. CLASS1 uses a policer with a rate in megabits per second and a burst in kilobytes. CLASS2

has a minimum-bandwidth guarantee in megabits per second. Both CLASS2 and the default class (class-default) have a maximum queue size in packets.

Example 3-27 *Policy with Explicit Parameter Units*

```
class-map match-all CLASS1
 match mpls experimental topmost 5
class-map match-all CLASS2
 match mpls experimental topmost 3 4
!
policy-map POLICY1
 class CLASS1
  priority
  police rate 1 mbps burst 3 kbytes
class CLASS2
  bandwidth 10 mbps
  queue-limit 1000 packets
 class class-default
  queue-limit 8700 packets
!
```

Processing of Local Traffic

Processing of local traffic represents a special case in the configuration of QoS. This traffic represents mostly control- and management-plane packets that a node receives and sends. Nodes identify the most crucial control- and management-plane packets with a priority flag. These packets include mainly hello and keepalive messages for Layer 2 and Layer 3 protocols (for example, PPP/HLDC keepalives, ATM OAM cells, *Open Shortest Path First / Intermediate System-to-Intermediate System* [OSPF/IS-IS] Hellos, *Bidirectional Forwarding Detection* [BFD]). Interface QoS policies do not affect these packets. For example, policers or AQM do not drop packets that have a priority flag. Interface policies generally classify and process all other local traffic.

NOTE In Cisco IOS, you can force the priority flag for all *Label Distribution Protocol* (LDP) packets over TCP sessions using the **mpls ldp tcp pak-priority** command. In addition, IP *service level agreement* (SLA) jitter probes will have the priority flag if you configure the **probe-packet priority high** command. In all other cases, the node automatically decides which packets receive this flag.

Similarly, marking of local IP traffic represents a special case in the configuration of QoS. The node automatically marks some of that traffic. In some cases, you can also preconfigure the marking you want outside of the MQC using protocol or application commands outside of the MQC. Table 3-38 lists the IP local traffic sources that use a non-best-effort marking by default.

Table 3-38 *Default Marking for Locally Generated IP Traffic*

Protocol	Default IP Marking
Bidirectional Forwarding Detection (BFD)	CS6
Border Gateway Protocol (BGP)	CS6
Data-link switching (DLSw)	CS5 (TCP port 2065) CS4 (TCP port 1981) CS3 (TCP port 1982) CS2 (TCP port 1981)
Distance Vector Multicast Routing Protocol (DVMRP)	CS6
Enhanced Interior Gateway Routing Protocol (EIGRP)	CS6
Gateway Load Balancing Protocol (GLBP)	CS6
Generic routing encapsulation (GRE)	CS6 (CDP and GRE keepalives)
Hot Standby Router Protocol (HSRP)	CS6
Internet Control Message Protocol (ICMP)	CS6 (UDP port unreachable, time exceeded, echo reply for LSP ping)
Internet Group Management Protocol (IGMP)	CS6
Layer 2 Tunneling Protocol (L2TP)	CS6 (control messages)
Label Distribution Protocol (LDP)	CS6
Mobile IP (MIP)	CS6
Multicast Source Discovery Protocol (MSDP)	CS6
Next Hop Resolution Protocol (NHRP)	CS6
Network Time Protocol (NTP)	CS6
Open Shortest Path First (OSPF)	CS6
Protocol-Independent Multicast (PIM)	CS6
Rate Based Satellite Control Protocol (RBSCP)	CS6
Router Port Group Management Protocol (RGMP)	CS6
Routing Information Protocol (RIP)	CS6
Resource Reservation Protocol Traffic Engineering (RSVP-TE)	CS6
Stack Group Bidding Protocol (SGBP)	CS6 (keepalive and hello messages)
Secure Shell (SSH)	CS6
Stateful Network Address Translation (NAT)	CS6

Table 3-38 *Default Marking for Locally Generated IP Traffic (Continued)*

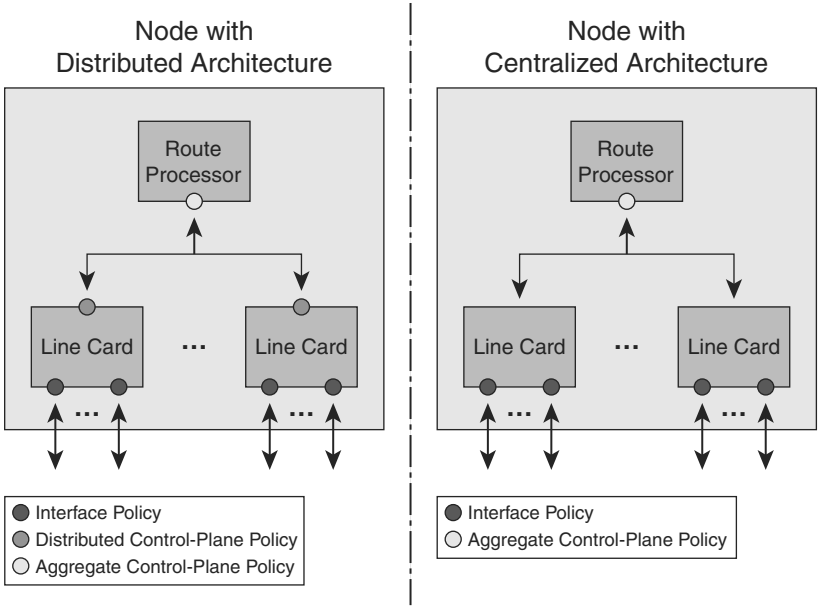
Protocol	Default IP Marking
Telnet	CS6
Virtual Router Redundancy Protocol (VRRP)	CS6

NOTE Cisco IOS XR supports a subset of the protocols listed in the preceding table. For those protocols it supports, the default marking behavior in Cisco IOS and Cisco IOS XR is the same.

NOTE The details of the processing of local traffic can vary slightly depending on software, hardware, and platform specifics. These differences can be particularly true regarding bandwidth allocation to local traffic in the presence of interface congestion. Consult your platform documentation for details.

Some platforms support the definition of a QoS policy to control local traffic as it flows from and to the route processor. The policies generally classify the traffic and define what packets to transmit, drop, or police. There are two main types of policy: aggregate and distributed. An aggregate control-plane policy acts on the all route processor traffic. Platforms with a distributed architecture can support a set of distributed control-plane policies that act on traffic that flows between line cards and the route processor. Figure 3-9 illustrates the different attachment points for centralized and distributed architectures. The distributed control-plane policies process only traffic that needs to reach the route processor. The line card may process some local traffic (for instance, generating a ping reply) without involving the route processor.

Figure 3-9 *Policies Controlling Local Traffic from and to the Route Processor*



NOTE The support for control-plane policies can vary significantly depending on the hardware and software specifics. These differences include the type of actions that the policies support and the policy direction (input only, or input and output). Consult your platform documentation for details.

The **control-plane** command defines the attachment points for control-plane policies. In its simplest form, this command enables the attachment point for an aggregate policy. The longer command syntax, **control-plane slot**, defines the attachment point for a distributed control-plane policy on a specific line-card slot. Table 3-39 summarizes the syntax of these two commands.

Table 3-39 *Commands for Control-Plane Policy Attachment*

Syntax	Policy Attachment Description
control-plane	Traffic to/from route processor
control-plane slot *value*	Traffic from/to line card to/from route processor

Example 3-28 illustrates the configuration of aggregate and distributed control-plane policies. Both POLICY1 and POLICY2 police ICMP echo requests and replies associated with the IP ping application. POLICY1 polices ping traffic to 128 kbps with a burst of 16 KBps (1 second) from each line-card slot to the route process. POLICY2 limits the aggregate ping traffic reaching the route processor to a rate of 384 kbps with a burst of 48 KBps (1 second). This configuration is valid on a platform with a distributed architecture. The centralized platform will have only the aggregate control-plane policy.

Example 3-28 *Control-Plane Policies*

```
class-map match-all CLASS1
  match access-group 100
!
policy-map POLICY1
  class CLASS1
   police rate 128000 burst 16000
policy-map POLICY2
  class CLASS1
   police rate 384000 burst 48000
!
access-list 100 permit icmp any any echo
access-list 100 permit icmp any any echo-reply
!
control-plane slot 1
 service-policy input POLICY1
!
control-plane slot 2
 service-policy input POLICY1
!
control-plane slot 3
 service-policy input POLICY1
!
control-plane
 service-policy input POLICY2
!
```

Summary

Cisco QoS uses a behavioral model that abstracts the QoS implementation details. This behavioral model defines the concept of a TMN. This abstraction groups the QoS actions that a device performs at a given point during packet forwarding. The TMN has four components: classification, pre-queuing, queuing, and post-queuing. All components are optional and user configurable. The classification component associates each packet with a class. The pre-queuing component includes policing, marking, dropping, and compression. The queuing component manages queue sizes and packet scheduling. The post-queuing groups any actions that depend on packet sequencing.

The MQC provides the user interface to the QOS behavioral model. Three commands define the configuration components: **class-map**, **policy-map**, and **service-policy**. The

class-map commands control traffic classification and corresponds to the classification component of the TMN. The **policy-map** command defines a policy template that group QoS actions (including marking, policing, shaping, congestion management, active queue management, and so on). These policies may define any of the other three components of the TMN. The **service-policy** command instantiates a previously defined QoS policy and defines its direction. The MQC provides a template-based, hardware-independent configuration model for QoS across different Cisco platforms.

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