Control Plane Policing Implementation Best Practices

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Introduction: Network Device Operations

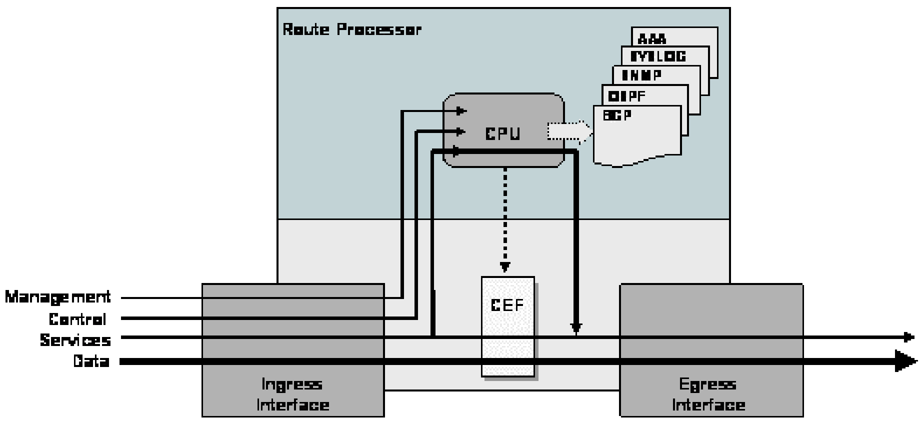
IP networks provide users with connectivity to networked resources such as corporate servers, extranet partners, multimedia content, the Internet, and any other application envisioned within IP networks. While these networks function to carry data plane (user-generated) packets, they are also created and operated by control plane and management plane packets. Unlike legacy network technologies such as ISDN, Frame Relay, and ATM that defined separate data and control channels, IP carries all packets within a single pipe. Thus, IP network devices such as routers and switches must be able to distinguish between data plane, control plane, and management plane packets to treat each packet appropriately.

From an IP traffic plane perspective, packets may be divided into four distinct, logical groups:

1. Data plane packets – End-station, user-generated packets that are always forwarded by network devices to other end-station devices. From the perspective of the network device, data plane packets always have a transit destination IP address and can be handled by normal, destination IP address-based forwarding processes.
2. Control plane packets – Network device generated or received packets that are used for the creation and operation of the network itself. From the perspective of the network device, control plane packets always have a receive destination IP address and are handled by the CPU in the network device route processor. Examples include protocols such as ARP, BGP, OSPF, and other protocols that glue the network together.
3. Management plane packets – Network device generated or received packets, or management station generated or received packets that are used to manage the network. From the perspective of the network device, management plane packets always have a receive destination IP address and are handled by the CPU in the network device route processor. Examples include protocols such as Telnet, Secure Shell (SSH), TFTP, SNMP, FTP, NTP, and other protocols used to manage the device and/or network.
4. Services plane packets – A special case of data plane packets, services plane packets are also user-generated packets that are also forwarded by network devices to other end-station devices, but that require high-touch handling by the network device (above and beyond normal, destination IP address-based forwarding) to forward the packet. Examples of high-touch handling include such functions as GRE encapsulation, QoS, MPLS VPNs, and SSL/IPsec encryption/decryption, etc. From the perspective of the network device, services plane packets may have a transit destination IP address, or may have a receive destination IP address (for example, in the case of a VPN tunnel endpoint).

Each of these types represents a specific group of packets that a network device will receive on ingress from network interfaces and be required to process. This concept is illustrated in Figure 1.

Figure 1. IP Network Traffic Planes and Their Handling within the Router



From the local perspective of the network device, three general types of packets exist:

1. Transit packets – These include data plane and some services plane packets that are subjected to standard, destination IP-based forwarding functions. In most networks and under normal operating conditions, transit packets are typically forwarded by Cisco Express Forwarding mechanisms, either in the interrupt process within CPU-based (software switched) platforms, or within specialized high-speed forwarding hardware (ASICs, FPGAs, or NPs) on high-end platforms. “Fast path” is most often used to describe this type of packet handling.
2. Receive packets – These include control plane and management plane packets that are destined to the network device itself. Receive packets must be handled by the CPU within the route processor, as they are ultimately destined to and handled by applications running at the process level within IOS or IOS XR. “Punt” is often used to describe

the action of moving a packet from the fast path to the route processor for handling.

3. Exception IP and Non-IP packets – One special set of packets includes both exception IP packets and non-IP packets. Exception IP packets include, for example, IPv4 packets containing IP header options, IP packet TTL expires, and IP packets with unreachable destinations. Layer 2 keepalives, ISIS packets, Cisco Discovery Protocol (CDP) packets, and PPP Link Control Protocol (LCP) packets are examples of non-IP packets. All of the packets in this set must be handled by the route processor.

Under normal network operating conditions, the vast majority of packets handled by network devices are data plane packets. These packets are handled in the fast path. Network devices are optimized to handle these fast path packets efficiently. Typically, considerably fewer control and management plane packets are required to create and operate IP networks. Thus, the punt path and route processor are significantly less capable of handling the kinds of packets rates experienced in the fast path since they are never directly involved in the forwarding of data plane packets.

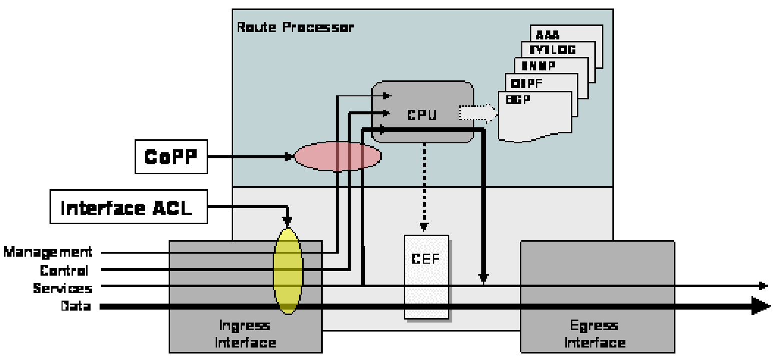
When high packet rates overload the control and/or management plane, route processor resources can be overwhelmed, reducing the availability of these resources for tasks critical to the operation and maintenance of the network. For example, if a high volume of rogue packets generated by a virus or worm is presented to the control plane, the router will spend an excessive amount of time processing and discarding unnecessary traffic. The route processor is thus not available to support its required tasks such as computing periodic routing table updates, maintaining the CEF table, which is actually used for the forwarding of data plane packets, and maintaining interface link states (see Figure 1).

When considering route processor attack scenarios, it is natural to think only of malicious events. However, both malicious and non-malicious events can overwhelm route processor resources. Malicious events include crafted packet attacks or simply high rates of packets directed at the control plane. Non-malicious events may result from router or network misconfigurations, software bugs, or in some circumstances, network failure reconvergence events. From the perspective of the router, the underlying condition is irrelevant when the result is the same. It is important to take appropriate steps to protect the route processor from being overwhelmed, whether by malicious or non-malicious events.

Many Cisco IOS and Cisco IOS XR software security features are available to protect the route processor of networking devices. Some of these features are generic and applicable to a broad range of security functions. Others are specifically designed to protect the route processor. In brief, important features include the following:

- Interface ACL – The interface access control list (iACL) is the traditional and most generally available approach for managing all packets entering or exiting a network device. The iACLs are well understood and are generally applicable to data, services, control, and management plane packets. However, as illustrated in Figure 2, iACLs are applied at the interface level to each packet ingressing (or egressing) the interface—not just control plane packets, for example. In addition, iACLs must be applied to every individual interface to which the policy is to be applied. On large routers, this can be an onerous task.
- Receive ACL – The receive path ACL (rACL) feature was developed for Cisco 7500 and Cisco 12000 Series routers as the initial step toward achieving a Cisco IOS-wide route processor protection mechanism. These routers are widely deployed in very large service provider networks, can have an extensive number of interfaces, and can see very high packet rates. Thus, the rACL concept was developed as an efficient mechanism to protect the route processor on these high-end routers. Unlike iACLs, which are applied on individual interfaces, rACLs are applied once to the receive path of the router. In this way, only a single instance of the rACL must be configured and applied only to those packets with receive destination IP addresses. This covers most (but not all) packets that may punt and require handling by the route processor. In addition, as with all ACLs, rACLs only provide permit and deny granularity in their actions. (Considering Figure 2, rACLs operate where Control Plane Policing (CoPP) is shown in the figure, but only on IP packets with a receive destination IP address.)
- Control Plane Policing (CoPP) – CoPP is the Cisco IOS-wide route processor protection mechanism. As illustrated in Figure 2, and similar to rACLs, CoPP is deployed once to the punt path of the router. However, unlike rACLs that only apply to receive destination IP packets, CoPP applies to all packets that punt to the route processor for handling. CoPP therefore covers not only receive destination IP packets, it also exceptions IP packets and non-IP packets. In addition, CoPP is implemented using the Modular QoS CLI (MQC) framework for policy construction. In this way, in addition to simply permit and deny functions, specific packets may be permitted but rate-limited. This behavior substantially improves the ability to define an effective CoPP policy. (Note: that "Control Plane Policing" is something of a misnomer because CoPP generally protects the punt path to the route processor and not solely the control plane.)
- Local Packet Transport Services – Cisco IOS XR is the newest Cisco router operating system and is designed for the CRS-1 and XR 12000 routers. The Local Packet Transport Services (LPTS) feature is only implemented in Cisco IOS XR and takes the Cisco IOS CoPP concept to a new level by automatically applying rate limiting to all packets that must be handled by any route processor on the device. LPTS maintains tables describing all packet flows destined for the route processor and uses a set of predefined policers that are applied based on the flow type of the incoming control traffic. Automated control is vital to network health as it becomes increasingly difficult to rely on network engineers and operators to configure these functions manually in such large-scale, high-speed networks.

Figure 2. The Impact of Interface ACLs and Control Plane Policing Mechanism on Each IP Network Traffic Plane



These features and others are all part of the Cisco Network Foundation Protection (NFP), which is an umbrella strategy encompassing Cisco IOS and Cisco IOS XR software security features that provide the tools, technologies, and services that enable organizations to secure their network foundations. NFP helps to establish a methodical approach to protecting router planes, forming the foundation for continuous service delivery. Cisco IOS and Cisco IOS XR software both provide a rich set of security features to address complexity of attacks and help ensure the availability of network elements under any circumstances.

The remainder of this white paper provides deployment and operational guidance for the Cisco IOS CoPP feature. A short overview for comparison purposes is also provided for the Cisco IOS XR LPTS feature.

Control Plane Policing Feature Description

General Overview

Control Plane Policing (CoPP) is a Cisco IOS-wide feature designed to allow users to manage the flow of traffic handled by the route processor of their network devices. CoPP is designed to prevent unnecessary traffic from overwhelming the route processor that, if left unabated, could affect system performance. Route processor resource exhaustion, in this case, refers to all resources associated with the punt path and route processor(s) such as Cisco IOS process memory and buffers, and ingress packet queues.

More than just control plane packets can punt and affect the route processor and system resources. Management plane traffic, as well as certain data plane exceptions IP packets and some services plane packets, may also require the use of route processor resources. Even so, it is common practice to identify the resources associated with the punt path and route processor(s) as the Control Plane. The feature in Cisco IOS is CoPP.

CoPP protects the route processor on network devices by treating route processor resources as a separate entity with its own ingress interface (and in some implementations, egress also). Because of this behavior, a CoPP policy can be developed and applied only to those packets within the control plane. Unlike interface ACLs, for example, no effort is wasted investigating data plane (transit) packets that will never reach the control plane. This action has a significant simplifying implication on the construction of policies for CoPP.

CoPP is implemented using the Cisco IOS Modular QoS CLI (MQC), a highly flexible framework that allows users to create and attach traffic polices to interfaces The Cisco Modular QoS CLI (MQC) mechanisms are used by CoPP to define the classification and policing descriptions for its policies. In this way, in addition to the limited permit and deny actions associated with simple ACLs, specific packets may be permitted but rate-limited when using the MQC structure. For example, you may wish to permit certain ICMP packet types, but rate limit them so that the route processor is not adversely impacted. This action adds tremendously to the capabilities and flexibility of developing and deploying a useable CoPP policy.

In general, the configuration information presented here represents the basic set of CoPP functions that should be available across all platforms. Where appropriate, references will be made to areas that may have different behavior or enhanced feature availability. The remainder of this section covers the operational aspects involved with successful CoPP policy construction and deployment.

CoPP Policy Construction and Deployment Concepts

Before describing the details of CoPP policy construction and deployment, some of the important details related to MQC and its operation, especially within the context of CoPP are discussed.

In MQC, the **class-map** command is used to define a traffic class. A traffic class contains three major elements: a name, one or a series of match commands, and an instruction on how to evaluate these match commands. Match commands are used to specify various criteria for classifying packets. Packets are checked to see whether they match the criteria specified in the match commands. If a packet matches the specified criteria, that packet is considered a member of the class and is treated according to the QoS specifications set in the service policy. Packets that fail to meet any of the matching criteria are classified as members of the default class.

The instruction for evaluating match commands is specified as either **match-any** or **match-all**. When more than one match statement is included, match-any requires that a packet match at least one of the statements to be included in the class. If match-all is used, a packet must match all of the statements to be included in the class.

The **policy-map** command is used to associate a traffic class, defined by the **class-map** command, with one or more QoS policies. The result of this association is called a service policy. A service policy contains three elements: a name, a traffic class (specified with the **class** command), and the QoS policies. The purpose of the service policy is to associate a traffic class with one or more QoS policies. Classes included within policy maps are processed top-down. When a packet is found to match a class, no further processing is performed. That is, a packet can only belong to a single class, and it is the first one to which a match occurs. When a packet does not match any of the defined classes, it is automatically placed in the class **class-default**. The default class is always applied, whether it is explicitly configured or not.

The **service-policy** command is used to attach the service policy, as specified with the **policy-map** command, to an interface. In the case of CoPP, this is the control-plane interface. Because the elements of the service policy can be applied to packets entering, or in some versions of CoPP, leaving the interface, users are required to specify whether the service policy characteristics should be applied to incoming or outgoing packets.

It is important to note that MQC is a general framework used for enabling all QoS throughout Cisco IOS, and not exclusively for CoPP. Not all features available within the MQC framework are available or applicable to CoPP policies. For example, only certain classification (match) criteria are applicable to CoPP. In some instances, there are MQC platform and/or IOS-dependencies that may apply to CoPP. Consult the appropriate product references and configuration guides for any CoPP-specific dependencies.

1. Constructing the CoPP Policy
2. Deploying the CoPP Policy
3. Verifying the CoPP Policy
4. Tuning the CoPP Policy

Each of these steps is discussed in detail below. For each step, guidance based on deployment experience is provided.

1. Constructing the CoPP Policy

For CoPP policy construction, several steps are required to create the MQC classification and policing functions. These include: **access-list** construction, **class-map** construction, and finally, **policy-map** construction.

Access List Construction

To define appropriate policies for your CoPP configuration, you need to identify all of the traffic flows and packet rates for those flows that may be seen by CoPP. Typically, ACLs are used for the traffic flow identification task and, in most cases, the protocols as well as the source and destination IP addresses are well known. It is still quite likely that some surprise traffic flows will arise. The definition of these ACLs is one of the most critical steps in the CoPP process. MQC uses these ACLs to define the traffic classes, which in turn become the object of the policy actions (policing). Appropriate granularity in the distribution of protocols within these ACLs allows for better protection of the RP.

By recognizing that certain classes will be created, you will see that it is important to define distinct, granular access lists that will be used to define the CoPP classes. Some traffic types are easy; BGP is critical, for example. Other traffic types may not be as straightforward. The typical approach involves grouping traffic flows based on function within the network. Such an approach may include classes:

- Routing: Routing protocol traffic is crucial to the creation and operation of the network. BGP (TCP/179), OSPF, and EIGRP are all potential candidates. LDP (TCP/646) and MSDP (TCP/639) may also be required (implementation specific). (IS-IS cannot be classified, however, as it is not an IP protocol).
- Management: Management protocols necessary for the day-to-day operation of the network includes protocols such as: SSH (TCP/22), HTTP/HTTPS (TCP/80 and TCP/443), TFTP (UDP/69), SNMP (UDP/161), NTP (UDP/123), DNS (UDP/53), etc.
- Normal: Other less essential traffic can also be expected to be required, but would be prudent to rate-limit. This class mainly includes ICMP protocol packets such as ICMP Time-Exceeded, Echo-Request, Echo-Reply, Packet-too-big, Port-unreachable, etc. This class might also include things like GRE traffic, etc.
- Undesirable: This class covers explicitly bad or malicious traffic that should always be denied access to the RP. This includes all IP fragments (fragments should never be seen in the control plane), certain TCP RESET packets, and other specific, identifiable attack packets (such as SQL-Slammer) that may randomly target router receive

addresses.

- Catch-All-IP: A catch-all IP class is required to collect any remaining traffic that has not matched any other class and that is destined for the RP. This class prevents these packets from ending up in class-default. (This is discussed in further detail under the **policy-map** discussion).

There are several caveats and key points to keep in mind when constructing your access lists.

- The **log** or **log-input** keywords must never be used in access-lists that are used within MQC policies for CoPP. The use of these keywords may cause unexpected result in the functionality of CoPP.
- The use of the deny rule in access lists used in MQC is somewhat different to regular interface ACLs. Packets that match a deny rule are excluded from that class and cascade to the next class (if one exists) for classification. This is in contrast to packets matching a permit rule, which are then included in that class and no further comparisons are performed.

Based on the above guidance, you can create ACLs to define traffic. Separate ACLs with unique numbers (or names, if allowed) should be used to represent each class. For initial or pilot CoPP deployments, you may wish to be less restrictive on IP source and destination addresses. Over time and with more experience, refinements may be appropriate. Example ACLs for the above categories follow.

Routing – ACL 120

```
!-- ACL for CoPP Routing class-map
!
access-list 120 permit tcp any gt 1024 <router receive block> eq bgp
access-list 120 permit tcp any eq bgp <router receive block> gt 1024 established
access-list 120 permit tcp any gt 1024 <router receive block> eq 639
access-list 120 permit tcp any eq 639 <router receive block> gt 1024 established
access-list 120 permit tcp any <router receive block> eq 646
access-list 120 permit udp any <router receive block> eq 646
access-list 120 permit ospf any <router receive block>
access-list 120 permit ospf any host 224.0.0.5
access-list 120 permit ospf any host 224.0.0.6
access-list 120 permit eigrp any <router receive block>
access-list 120 permit eigrp any host 224.0.0.10
access-list 120 permit udp any any eq pim-auto-rp
---etc--- for other routing protocol traffic...
!
```

Management – ACL 121

```
! – ACL for CoPP Management class
!
access-list 121 permit tcp <NOC block> <router receive block> eq telnet
access-list 121 permit tcp <NOC block> eq telnet <router receive block> established
access-list 121 permit tcp <NOC block> <router receive block> eq 22
access-list 121 permit tcp <NOC block> eq 22 <router receive block> established
access-list 121 permit udp <NOC block> <router receive block> eq snmp
access-list 121 permit tcp <NOC block> <router receive block> eq www
access-list 121 permit udp <NOC block> <router receive block> eq 443
access-list 121 permit tcp <NOC block> <router receive block> eq ftp
access-list 121 permit tcp <NOC block> <router receive block> eq ftp-data
access-list 121 permit udp <NOC block> <router receive block> eq syslog
access-list 121 permit udp <DNS block> eq domain <router receive block>
access-list 121 permit udp <NTP block> <router receive block> eq ntp
---etc--- for known good management traffic...
!
```

Normal – ACL 122

```
!-- ACL for CoPP Normal class-map
!
access-list 122 permit icmp any <router receive block> echo
access-list 122 permit icmp any <router receive block> echo-reply
access-list 122 permit icmp any <router receive block> ttl-exceeded
access-list 122 permit icmp any <router receive block> packet-too-big
access-list 122 permit icmp any <router receive block> port-unreachable
access-list 122 permit icmp any <router receive block> unreachable
access-list 122 permit pim any any
access-list 122 permit igmp any any
access-list 122 permit gre any any
---etc--- for other known good traffic...
!
```

Undesirable – ACL 123

```
! -- ACL for CoPP Undesirable class-map
!
access-list 123 permit icmp any any fragments
access-list 123 permit udp any any fragments
access-list 123 permit tcp any any fragments
access-list 123 permit ip any any fragments
access-list 123 permit udp any any eq 1434
access-list 123 permit tcp any any eq 639 rst
access-list 123 permit tcp any any eq bgp rst
--- etc. all other known bad things here–
!
```

Catch-All IP – ACL 124

```
! -- ACL for CoPP Catch-All class-map
!
access-list 124 permit tcp any any
access-list 124 permit udp any any
access-list 124 permit icmp any any
access-list 124 permit ip any any
!
```

The next step in CoPP policy construction is that of class-map construction.

Class Map Construction

In MQC, the **class-map** statement defines the classes by name, and includes one or several match statements that indicate the classification mechanisms to be used to determine which packets are in the class. The **match** keyword supports the following classification mechanisms for CoPP:

- Standard and extended numbered or named IP access lists (ACLs) using the match access-group keyword. (In certain Cisco IOS releases, named ACLs may not be available for CoPP use).
- IP TOS values, including match ip dscp and match ip precedence keywords.
- ARP protocol packets using match protocol arp command. (The Cisco IOS 12.2SX release does not support the match protocol arp command.)

Thus, the syntax used within MQC for creating a CoPP class map is as follows:

```
router(config) class-map [match-any | match-all] class-name
router(config-cmap) match [access-group | protocol | ip prec | ip dscp]
```

Based on the ACL construction phase, the following classes of traffic are defined for the CoPP policy.

```
!
! – CoPP Routing class-map
!
class-map match-all Routing
 match access-group 120
!
! – CoPP Management class-map
!
class-map match-all Management
 match access-group 121
!
! – CoPP Normal class-map
!
class-map match-all Normal
 match access-group 122
!
! – CoPP Undesirable class-map
!
class-map match-all Undesirable
 match access-group 123
!
! – CoPP Catch-All-IP class-map
!
class-map match-all Catch-All-IP
 match access-group 124
!
```

The final step in CoPP policy construction is that of policy-map construction.

Policy Map Construction

In MQC, the **policy-map** statement is used to define a service policy. After defining the service policy using the **policy-map** statement, the **class** command is used within the **policy-map**definition to specify the name of a class, as defined by the **class-map** phase previously, and the traffic policy to be associated with that class. For CoPP deployments, the **police** keyword is typically used to define the traffic policy. Thus, the syntax used within MQC for creating a CoPP policy map is as follows:

```
router(config) policy-map <service_policy_name>
router(config-pmap) class <traffic_class_name>
router(config-pmap-c) police [cir | rate] conform-action [transmit | drop]
 exceed-action [transmit | drop]
where:
* cir – Committed information rate (bits per second)
* rate – Policy rate in packets per second (pps)
```

When more than one class of traffic is defined within a policy-map, the order of classes is important, as traffic is compared against successive classes, top-down, until a match is recorded. Once a packet has matched a class, no further comparisons are made. If no match is found after processing all classes, packets automatically match the always-defined class, **class-default**. The class **class-default** is special in MQC because it is always automatically placed at the end of every policy map. Match criteria cannot be configured for **class-default** because it automatically includes an implied match for all packets. Only a traffic policy can be configured for **class-default**.

The following are several caveats and key points to keep in mind when constructing policy maps.

After the **class** keyword has been used to specify a class of traffic within the policy-map, if the desired policy is to permit all traffic at an unpoliced rate, it is allowable in some versions of IOS to simply omit the police keyword and action. For example:

```
!
policy-map CoPP
 class ONE
 police 10000 1500 1500 conform-action transmit exceed-action transmit
 class TWO
 police 10000 1500 1500 conform-action transmit exceed-action transmit
 class THREE
 police 10000 1500 1500 conform-action transmit exceed-action drop
```

Is equivalent to:

```
!
policy-map CoPP
 class ONE
 class TWO
 class THREE
 police 10000 1500 1500 conform-action transmit exceed-action drop
```

As shown in the example, traffic matching class **ONE** or class **TWO** is permitted without using a **police** statement with each class. Check the release notes for your version of IOS to determine whether this option is available for policing traffic.

In some versions of IOS, the keyword **drop** may be used in place of the keyword **police** when the desired action is to deny all traffic within the affected class. For example, the following policy drops all traffic matching **class ONE**:

```
!
policy-map CoPP
 class ONE
 police 10000 1500 1500 conform-action drop exceed-action drop
 class TWO
 police 10000 1500 1500 conform-action transmit exceed-action drop
```

The above is equivalent to:

```
!
policy-map CoPP
 class ONE
 drop
 class TWO
 police 10000 1500 1500 conform-action transmit exceed-action drop
```

As shown in the above example, traffic matching **class ONE** is simply dropped. Using the drop **keyword** is equivalent to using the **police** statement with both conform and exceed actions of drop. While the police statement is available in all Cisco IOS releases, the **drop** keyword is only available in certain releases. Check the release notes for your version of Cisco IOS to determine which options are available for policing traffic.

- In most versions of IOS, policing can only be accomplished on a bandwidth basis. That is, policing can only be specified according to a rate measured in bits-per-second and not on packets-per-second. Check the release notes for your version of IOS to determine which options are available for policing traffic.
- The class **class-default** is automatically placed at the end of the policy map. By the nature of CoPP matching mechanisms, certain traffic types will always end up falling into the default class. This includes traffic such as Layer 2 keepalives and non-IP traffic such as certain ISIS packets. Because these traffic types are required to maintain the network control plane,**class-default** must never be policed with both conform and exceed being set with an action of drop. It is generally considered best practice never to rate-limit the class **class-default**.

Based on this, and the class-map construction phase, the following policy-map is defined for this example CoPP policy:

```
!
policy-map RTR_CoPP
 class Undesirable
 police 8000 1500 1500 conform-action drop exceed-action drop
 class Routing
 police 1000000 50000 50000 conform-action transmitexceed-action transmit
 class Management
 police 100000 20000 20000 conform-action transmit exceed-action drop
 class Normal
 police 50000 5000 5000 conform-action transmit exceed-action drop
 class Catch-All-IP
 police 50000 5000 5000 conform-action transmit exceed-action drop
 class class-default
 police 8000 1500 1500 conform-action transmit exceed-action transmit
!
```

Note that in **policy-map RTR_CoPP**, several of the police statements include **drop** actions. This represents the type of policy that could be used in an operationally effective CoPP deployment after careful consideration, lab testing, and/or pilot deployments have determined the policy to be operationally sound. It is typical for an initial policy to be developed for lab and/or pilot deployments that includes **transmit** actions only. Such a policy would be used to assess the effectiveness of ACLs, class-map choices, and **policy-map** traffic rates for each class of traffic. Once the CoPP policy is confirmed to be operationally effective, it would then be appropriate to convert the appropriate “exceed-action” **transmit** actions to **drop** actions.

Now that the CoPP policy has been built, it is must be applied to the control plane interface.

2. Deploying the CoPP Policy

As mentioned above, the CoPP policy is applied to the control plane interface. Only traffic destined for the route processor will be affected by the CoPP policy. The following example illustrates deploying the RTR_CoPP **service policy** defined above to the control plane.

```
!
control-plane
 service-policy input RTR_CoPP
!
```

The final step in deploying CoPP has now been completed.

3. Verifying the CoPP Policy Deployment and Operation

When the CoPP policy has been deployed, there are three ways to verify that it has been deployed and is operating correctly. As with most Cisco features, the three main approaches include the use of show and debug commands and through SNMP polling. One method may be more useful than another, depending on your environment and desired information. Each method is reviewed in the section that follows.

Show Commands

Several show commands are useful for verifying a CoPP deployment. Based on the CoPP configuration developed above, the following examples illustrate the use of these **show**commands. Note that IP addresses for the <router receive block> of 10.0.1.0/24, <NOC block > of 10.0.2.0/24, <DNS block > of 10.0.3.0/24, and <NTP block > of 10.0.4.0/24 have been used.

show running-config — The **show running-config** command displays the entire router running configuration. Here, only the output relevant to the CoPP configuration is presented (edited manually):

```
RTR#show running-config
Building configuration...
 .
 . ---<skip>---
!
class-map match-all Catch-All-IP
 match access-group 124
class-map match-all Management
 match access-group 121
class-map match-all Normal
 match access-group 122
class-map match-all Undesirable
 match access-group 123
```

```
class-map match-all Routing
 match access-group 120
!
policy-map RTR_CoPP
 class Undesirable
 police 8000 1500 1500 conform-action drop exceed-action drop
 class Routing
 police 1000000 50000 50000 conform-action transmit exceed-action transmit
 class Management
 police 100000 20000 20000 conform-action transmit exceed-action drop
 class Normal
 police 50000 5000 5000 conform-action transmit exceed-action drop
 class Catch-All-IP
 police 50000 5000 5000 conform-action transmit exceed-action drop
 class class-default
 police 8000 1500 1500 conform-action transmit exceed-action transmit
!
access-list 120 permit tcp any gt 1024 10.0.1.0 0.0.0.255 eq bgp
access-list 120 permit tcp any eq bgp 10.0.1.0 0.0.0.255 gt 1024 established
access-list 120 permit tcp any gt 1024 10.0.1.0 0.0.0.255 eq 639
access-list 120 permit tcp any eq 639 10.0.1.0 0.0.0.255 gt 1024 established
access-list 120 permit tcp any 10.0.1.0 0.0.0.255 eq 646
access-list 120 permit udp any 10.0.1.0 0.0.0.255 eq 646
access-list 120 permit ospf any 10.0.1.0 0.0.0.255
access-list 120 permit ospf any host 224.0.0.5
access-list 120 permit ospf any host 224.0.0.6
access-list 120 permit eigrp any 10.0.1.0 0.0.0.255
access-list 120 permit eigrp any host 224.0.0.10
access-list 121 permit tcp 10.0.2.0 0.0.0.255 10.0.1.0 0.0.0.255 eq telnet
access-list 121 permit tcp 10.0.2.0 0.0.0.255 eq telnet 10.0.1.0 0.0.0.255 established
access-list 121 permit tcp 10.0.2.0 0.0.0.255 10.0.1.0 0.0.0.255 eq 22
access-list 121 permit tcp 10.0.2.0 0.0.0.255 eq 22 10.0.1.0 0.0.0.255 established
access-list 121 permit udp 10.0.2.0 0.0.0.255 10.0.1.0 0.0.0.255 eq snmp
access-list 121 permit tcp 10.0.2.0 0.0.0.255 10.0.1.0 0.0.0.255 eq www
access-list 121 permit udp 10.0.2.0 0.0.0.255 10.0.1.0 0.0.0.255 eq 443
access-list 121 permit tcp 10.0.2.0 0.0.0.255 10.0.1.0 0.0.0.255 eq ftp
access-list 121 permit tcp 10.0.2.0 0.0.0.255 10.0.1.0 0.0.0.255 eq ftp-data
access-list 121 permit udp 10.0.2.0 0.0.0.255 10.0.1.0 0.0.0.255 eq syslog
access-list 121 permit udp 10.0.3.0 0.0.0.255 eq domain 10.0.1.0 0.0.0.255
access-list 121 permit udp 10.0.4.0 0.0.0.255 10.0.1.0 0.0.0.255 eq ntp
access-list 122 permit icmp any 10.0.1.0 0.0.0.255 echo
access-list 122 permit icmp any 10.0.1.0 0.0.0.255 echo-reply
access-list 122 permit icmp any 10.0.1.0 0.0.0.255 ttl-exceeded
access-list 122 permit icmp any 10.0.1.0 0.0.0.255 packet-too-big
access-list 122 permit icmp any 10.0.1.0 0.0.0.255 port-unreachable
access-list 122 permit icmp any 10.0.1.0 0.0.0.255 unreachable
access-list 122 permit pim any any
access-list 122 permit udp any any eq pim-auto-rp
access-list 122 permit igmp any any
access-list 122 permit gre any any
access-list 123 permit icmp any any fragments
access-list 123 permit udp any any fragments
access-list 123 permit tcp any any fragments
access-list 123 permit ip any any fragments
access-list 123 permit udp any any eq 1434
access-list 123 permit tcp any any eq 639 rst
access-list 123 permit tcp any any eq bgp rst
access-list 124 permit tcp any any
access-list 124 permit udp any any
access-list 124 permit icmp any any
access-list 124 permit ip any any
!
control-plane
 service-policy input RTR_CoPP
!
```

show access-list — The **show access-list** command displays all of the configured ACLs on the router and any hit-counters associated with any ACL entries that have seen packet matches. By including the number or name of a specific ACL, only the specific ACL will be displayed. Here, the output for **show access-list 124** is presented:

```
RTR#show access-list 124
Extended IP access list 124
 10 permit tcp any any
 20 permit udp any any (190 matches)
 30 permit icmp any any
 40 permit ip any any
RTR#
```

You can see in the example that the ACL hit counter has incremented for UDP packets. Since this is the Catch-All-IP class, this would be an indication that certain UDP packets are unaccounted for in other traffic classes and are reaching the Catch-All-IP class. This type of occurrence could warrant further investigation and reconciliation.

show class-map — The show class-map command displays all of the configured class maps on the router. By including the name of a specific class map, only the specific policy map will be displayed. In this example, the only class maps configured are those relevant to the CoPP configuration:

```
RTR#show class-map
 Class Map match-all Catch-All-IP (id 5)
 Match access-group 124
 Class Map match-any class-default (id 0)
 Match any
 Class Map match-all Management (id 2)
 Match access-group 121
 Class Map match-all Normal (id 3)
 Match access-group 122
 Class Map match-all Undesirable (id 4)
 Match access-group 123
 Class Map match-all Routing (id 1)
 Match access-group 120
RTR#
```

show policy-map — The **show policy-map** command displays all of the configured policy maps on the router. By including the name of a specific policy map, only the specific policy map will be displayed. In this example, the only class maps configured are those relevant to the CoPP configuration:

```
RTR#show policy-map
 Policy Map RTR_CoPP
 Class Undesirable
```

```
  police cir 8000 bc 1500 be 1500
  conform-action drop
  exceed-action drop
 Class Routing
  police cir 1000000 bc 50000 be 50000
  conform-action transmit
  exceed-action transmit
 Class Management
  police cir 100000 bc 20000 be 20000
  conform-action transmit
  exceed-action drop
 Class Normal
  police cir 50000 bc 5000 be 5000
  conform-action transmit
  exceed-action drop
 Class Catch-All-IP
  police cir 50000 bc 5000 be 5000
  conform-action transmit
  exceed-action drop
 Class class-default
  police cir 8000 bc 1500 be 1500
  conform-action transmit
  exceed-action transmit
RTR#
```

show policy-map control-plane — The **show policy-map control-plane** command displays the dynamic information about the actual policy applied including rate information and the number of bytes (and packets) that conformed to or exceeded the configured policies. Here, only the output relevant to the CoPP configuration is presented:

```
RTR#show policy-map control-plane
 Control Plane
 Service-policy input: RTR_CoPP
 Class-map: Undesirable (match-all)
  0 packets, 0 bytes
  5 minute offered rate 0 bps, drop rate 0 bps
  Match: access-group 123
  police:
   cir 8000 bps, bc 1500 bytes
  conformed 0 packets, 0 bytes; actions:
   drop
  exceeded 0 packets, 0 bytes; actions:
   drop
  conformed 0 bps, exceed 0 bps
 Class-map: Routing (match-all)
  0 packets, 0 bytes
  5 minute offered rate 0 bps, drop rate 0 bps
  Match: access-group 120
  police:
   cir 1000000 bps, bc 50000 bytes
  conformed 0 packets, 0 bytes; actions:
   transmit
  exceeded 0 packets, 0 bytes; actions:
   transmit
  conformed 0 bps, exceed 0 bps
 Class-map: Management (match-all)
  0 packets, 0 bytes
  5 minute offered rate 0 bps, drop rate 0 bps
  Match: access-group 121
  police:
   cir 100000 bps, bc 20000 bytes
  conformed 0 packets, 0 bytes; actions:
   transmit
  exceeded 0 packets, 0 bytes; actions:
   drop
  conformed 0 bps, exceed 0 bps
 Class-map: Normal (match-all)
  0 packets, 0 bytes
  5 minute offered rate 0 bps, drop rate 0 bps
  Match: access-group 122
  police:
   cir 50000 bps, bc 5000 bytes
  conformed 0 packets, 0 bytes; actions:
   transmit
  exceeded 0 packets, 0 bytes; actions:
   drop
  conformed 0 bps, exceed 0 bps
 Class-map: Catch-All-IP (match-all)
  50461 packets, 24038351 bytes
  5 minute offered rate 4000 bps, drop rate 0 bps
  Match: access-group 124
  police:
   cir 50000 bps, bc 5000 bytes
  conformed 50444 packets, 24031001 bytes; actions:
   transmit
  exceeded 17 packets, 7350 bytes; actions:
   drop
  conformed 4000 bps, exceed 0 bps
 Class-map: class-default (match-any)
  16785 packets, 1183331 bytes
  5 minute offered rate 0 bps, drop rate 0 bps
  Match: any
  police:
   cir 8000 bps, bc 1500 bytes
  conformed 16658 packets, 1175711 bytes; actions:
   transmit
  exceeded 127 packets, 7620 bytes; actions:
   transmit
  conformed 0 bps, exceed 0 bps
RTR#
```

In the example, the values reported for the control plane service policy display are the same as those for any MQC-based service policy. Each class included in the service policy is reported, along with the amount of traffic matching the class (in packets and bytes), the associated offered and drop rates, and the configured match criteria for the class. The police parameters, including the number of matching packets and bytes, and the conform and exceed actions are displayed.

Debug Commands — There are no debug commands directly associated with control plane policing in Cisco IOS software releases. The command **debug control-plane** was introduced in Cisco IOS Release 12.4(4)T, but it is otherwise not widely available and is not discussed here.

SNMP Commands — The Cisco IOS Class-Based Quality of Service Management Information Base (CISCO-CLASS-BASED-QOS-MIB) (OID 1.3.6.1.4.1.9.9.166) provides read access to all QoS configurations. This MIB also provides read access to Quality of Service (QoS) configuration and dynamic QoS statistics information. Configuration information available through this MIB includes all class-map, policy-map, match statements, and action configuration parameters. Statistics available through this MIB include summary counts/rates by traffic class before and after any configured QoS policies are enforced. Detailed feature-specific statistics are available for select policy map features.

In the following example, statistics for the class Catch-All-IP are presented for the number of packets and bytes matching the class using both SNMP GET requests and the show policy-map control-plane CLI. You can see that in both cases, the values retrieved are identical.

— Using SNMP

```
Linux$ snmpget -m all 10.82.69.157 ciSco .1.3.6.1.4.1.9.9.166.1.15.1.1.2
enterprises.cisco.ciscoMgmt.ciscoCBQosMIB.ciscoCBQosMIBObjects.cbQosClassMapStats.
cbQosCMStatsTable.cbQosCMStatsEntry.cbQosCMPrePolicyPkt.1035.1037 = Counter32: 50461
Linux$ snmpget -m all 10.82.69.157 ciSco .1.3.6.1.4.1.9.9.166.1.15.1.1.5
enterprises.cisco.ciscoMgmt.ciscoCBQosMIB.ciscoCBQosMIBObjects.cbQosClassMapStats.
cbQosCMStatsTable.cbQosCMStatsEntry.cbQosCMPrePolicyByte.1035.1037 = Counter32: 24038351
Linux$
```

— Using CLI

```
RTR#show policy-map control-plane
 Control Plane
---<skip>---
 Class-map: Catch-All-IP (match-all)
  50461 packets, 24038351 bytes
  5 minute offered rate 4000 bps, drop rate 0 bps
  Match: access-group 124
  police:
   cir 50000 bps, bc 5000 bytes
  conformed 50444 packets, 24031001 bytes; actions:
   transmit
  exceeded 17 packets, 7350 bytes; actions:
   drop
  conformed 4000 bps, exceed 0 bps
RTR#
```

Cisco IOS Embedded Event Manager

Cisco IOS Embedded Event Manager (EEM) is a powerful device and system management technology integrated into specific Cisco switches and routers. EEM consists of Event Detectors, the Event Manager, and an Event Manager Policy Engine. The policy engine drives two types of policies, Applet and Tcl, that users can configure. Custom-designed policies can be defined to take specific actions when the Cisco IOS software recognizes certain events through the Event Detectors. The result is an extremely powerful, flexible set of tools to automate many network management tasks and direct the operation of Cisco IOS to increase availability, collect information, and notify external systems or personnel about critical events. EEMv1.0 was introduced in Cisco IOS Software Releases 12.0(26)S and 12.3(4)T. EEMv2.1 added the ability for users to program their own policies using Tcl.

With EEM, it is possible to create customized alerts when previously un-instrumented events take place. Alerts can be in the form of Syslog messages, SNMP messages and traps, and even e-mail alerts. The status of CoPP can be monitored using the EEM SNMP event detector and CISCO-CLASS-BASED-QOS-MIB statistics, or using more complex Tcl scripts and other EEM event detectors.

Examples for EEM scripts are outside the scope of this white paper. A number of CoPP and other security-related scripts are available on the Cisco website and are referenced at the end of this paper.

The final step in verifying the deployment of CoPP has now been completed.

4. Tuning the CoPP Policy

After the CoPP policy has been deployed, it usually necessary to refine the policy to account for traffic types and rates that were not anticipated or known at the outset and for changes in traffic patterns over time. Developing accurate CoPP policies is a normal, incremental, and iterative process. The following procedures are useful for tuning CoPP.

Tuning ACLs

At the early stages of CoPP deployments, ACLs that permit all known protocols that require access to the route processor are generally used to classify known-good traffic into the appropriate classes for policing. Initially, very little consideration may be given to source and destination IP addresses. This aids in the ability to rapidly deploy and gain experience with CoPP, but limits the available protection. As you gain experience, you should be able to restrict source and destination IP address ranges used within the ACLs to increasingly limit the sources that can communicate with the route processor. For example, only Network Management Stations (NMS) workstations assigned to the Network Operations Center (NOC) should be permitted to access the SNMP ports on a router. Further tuning should be applied by specifying the destination IP addresses (or range of addresses) to those associated with receive-interfaces of the router. Having a good IP address plan for router loopback and other infrastructure IP addresses greatly simplifies ACL construction.

It is important to note that ACLs only classify traffic into classes within MQC. That is, the ACL **permit** and **deny** statements translate into “match” and “don’t match” in MQC terms. By following the above guidance, restricting the ACL permit statements using specific source and destination IP address ranges allows you to classify and control known-good traffic with more granularity. However, as you might already see, attack traffic against these same protocols will not match these more-specific **permit** statements and will end up being unclassified. Without further modification, attack traffic will fall into the **Catch-All-IP** class (in the above example). This is not the most desirable situation because attack traffic could overwhelm the Catch-All-IP class and crowd out any legitimate transit IP traffic that happens to require route processor assistance for forwarding. The ideal approach, then, is to create a new ACL that contains **permit**entries to match all receive-destination control-plane and management-plane traffic that does not match known-good traffic for protocols previously specified by other ACLs. For example, in the above configuration, the following ACL entry was created for the Management class:

```
access-list 121 permit udp 10.0.2.0 0.0.0.255 10.0.1.0 0.0.0.255 eq snmp
```

This ACL assumes that the prefix 10.0.2.0/24 covers the NOC block and that 10.0.1.0/24 covers the router receive-IP block of addresses. Attack traffic from other source IPs destined to this same router receive-IP block will not match this ACL and cascade though to ACL 124, which places this traffic in the **Catch-All-IP** class. By creating a new ACL to associate with a new class, all attack traffic can be classified and policed to drop. As an example, the following ACL entry would complement the above ACL 121 entry:

```
access-list 129 permit udp any 10.0.1.0 0.0.0.255 eq snmp
```

Because **class-maps** are processed in order, this ACL would be associated with a new **class-map** that would be placed immediately before the class **Catch-All-IP**. This ACL (129) would include complementary **permit** entries for all known-good traffic entries included in ACLs 120, 121, and 122 that have router receive-IP block destination IP addresses.

Frequent use of the **clear access-list counters** command and **show access-list** command will be useful in tuning ACLs. These commands will help you identify traffic matching each ACL. Be especially aware of traffic matching ACL 124 in the above example, as this represents all previously unmatched traffic. Traffic falling into this class should be investigated to determine if it is legitimate receive-traffic that should have previously been classified (that is, was overlooked in ACL construction); is attack traffic that should be dropped (and potentially included in the new ACL 129); or is legitimate transit traffic and acceptable for ACL 129.

Tuning Class Maps

During the CoPP tuning phase, you may determine that the number of classes used to distinguish traffic should be increased or perhaps decreased. In general, simple policies are easier to manage, but may not adequately protect the router. When constructing classes, if you include more than one traffic type within a **class-map** as, for example, would occur using an ACL within multiple entries, or when referring to more than one ACL when using multiple **match** statements within a **class-map**, each traffic type matching an entry within a ACL could, in theory, consume the entire bandwidth allocation for that class. Consider the case where management access via SSH is included in a policy that also permits SNMP traffic and where and SNMP flood consumes the bandwidth allocated by the police statement for that class in the **policy-map**. In this scenario, it is likely that management access via SSH will be impeded since SSH will be policed along with SNMP.

It is best practice to create **class-maps** that judiciously group protocols and consider that consequences of normal traffic and attack scenarios. Use the **show class-map** command to review existing **class-maps** and the **show policy-map** command to see how these **class-maps** are used within the CoPP policy. Frequent use of the **show policy-map control-plane**command can provide useful information on the traffic-rates (in terms of number of bytes and packets) that conform or exceed the configured policies for each traffic class.

Tuning Policy Maps

At the early stages of CoPP deployments, it is common to define **police** statements for each class of traffic with actions of **conform transmit exceed transmit** so as not to inadvertently drop any critical traffic while CoPP is being tuned. Frequent use of the **show policy-map control-plane** command will aid in the development of appropriate traffic rates for tuning **police**statements. Once tuned, it is typical to modify the police statements for certain traffic classes to actions of **conform transmit exceed drop** to allow CoPP to function as it is intended.

All route processors have a maximum bandwidth, or more accurately, a packet processing rate (pps), that they are capable of supporting. CoPP does not guarantee bandwidth to the route processor for traffic matching a specific class within the policy-map. Rather, CoPP limits the bandwidth that each traffic class can consume in accordance with the **police** statements included in the **policy-map**. If several **class-maps** are included in a **policy-map** used for CoPP, the aggregate bandwidth permitted by the entire policy is the sum of the bandwidth permitted by each **police** statement within the entire policy-map. Best practice is to ensure that the CoPP policy does not greatly exceed the maximum capabilities of the route processor. By following the guidelines in the Tuning ACLs and Tuning Class Maps sections, you can limit the exposure of the router processor to attack traffic, leaving these resources for legitimate traffic. Use the**show policy-map control-plane** command to collect data about the actual policies in place. Analyze the packet count and rate information and tune rate limiting accordingly. Be sure not to just account for traffic rates observed under normal conditions, but to also consider anomalous conditions, such as failure scenarios where routing protocol updates may be flooding the network to update feasible path information, and attack conditions.

Now that your CoPP policy has been tuned, be sure to continually monitor its operation and effectiveness. High packet rates or ACL hit counts may be an indication of an attack or a misconfiguration somewhere in the network. Modify the CoPP policy when new devices and services are added to the network, and when baseline traffic conditions change.

Platform-Specific CoPP Features

CoPP is generally available on all Cisco routers and switches supporting Cisco IOS software. However, there are software-specific IOS code train and hardware-specific platform attributes that may affect the details of actual CoPP implementations. Refer to release notes, command reference guides, and configuration guides for your specific Cisco hardware and IOS release when deploying CoPP.

Due to the nature of CoPP, there are two general distinguishing characteristics of Cisco IOS software and hardware that can alter its deployment specifics, including:

1. Whether the platform uses CPU-based forwarding or some form of hardware-accelerated forwarding (such as with an ASIC, FPGA, or NP for example), and
2. Whether the platform uses centralized forwarding or distributed forwarding.

Centralized, CPU-based architectures are found on such routers as the Integrated Services Router (ISR) 3800/2800/1800 series. These represent the most general class of routers. Centralized, ASIC-based architectures include certain Catalyst 6500 series switches and 7600 series routers, and the Cisco 10000 ESR series routers. Distributed-forwarding, ASIC-based (or FPGA- or NP-based) architectures include the latest versions of the C12000-series routers (and Line Cards), certain Catalyst 6500 series switches, and the new, CRS-1 Carrier Routing System series of routers.

Some of the more important platform-specific implications for CoPP deployment for each of the above broad categories of routers are discussed in the section that follows.

Centralized, CPU-Based Platforms

Single CPU-based platforms comprise the most general case of routers. These general purpose routers include the current Integrated Services Router (ISR 3800/2800/1800 series) routers, and older 3700/2700/1700 series and 3600/2600/1600 series routers. All of the features and implementation details of CoPP as described above apply exactly to this class of router, as this is the most generic implementation.

For these types of routers, even though CoPP operates in software on the router CPU, it can make a substantial difference in protecting the CPU from DoS attacks directed at the router control plane. In testing, packet rates of nearly 10 times the unprotected rate were required to produce unacceptably high CPU utilization.

In addition to the general CoPP features described above, several additional features can be implemented on routers of these types. These are highlighted below, but are not covered in detail. References are provided for further information.

Output CoPP

Certain versions of IOS support output CoPP in addition to input CoPP. Output CoPP, sometimes referred to as silent mode, can be used to suppress responses to certain input packets and to restrict router-generated output traffic. Output CoPP is enabled as follows:

```
router(config) control-plane
router(config-cp) service-policy output policy_map_name
```

The policy-map for output CoPP is constructed the same way as it is for input CoPP, however, the only types of traffic to be considered are those generated by or forwarded by the route processor. In general, this includes the following traffic:

- Control plane traffic such as router replies to BGP, OSPF, EIGRP, and other configured routing protocols, certain ICMP error and informational reply messages, and router-generated ARP requests.
- Management plane traffic such as router-generated replies to Telnet, SSH, HTTP, etc., router-generated SNMP responses, and SNMP Traps.
- Exceptions IP traffic including certain outbound transit IP packets that required process-switching for forwarding.

When output CoPP is enabled, traffic matching classes associated with the policy map applied to the output control plane are rate-limited accordingly. Packets dropped via this mechanism are done so silently, that is, without the generation of any system messages (such as ICMP administratively prohibited messages). In addition, when output CoPP is configured, ICMP error messages are automatically not generated in the following cases:

- When traffic that is being transmitted to a port to which the router is not listening is dropped, and
- When a connection to a legitimate address and port that is rejected because of a malformed request is dropped.

Output CoPP (silent mode) functionality and output policing are supported only in Cisco IOS Release 12.2(25)S and later Cisco IOS 12.2S releases, and Cisco IOS Release 12.3(4)T and later Cisco IOS 12.3T releases.

Output CoPP and silent mode functionality are not supported for distributed control plane services.

Control Plane Protection

Cisco Control Plane Protection (CPPr), introduced in Cisco IOS Software Release 12.4(4)T, extends the CoPP feature set by enabling finer granularity classification of punted traffic based on packet destination and information provided by the forwarding plane, allowing appropriate throttling for each category of packet. CPPr creates three virtual control plane categories, known as subinterfaces, under the aggregate control plane interface for this purpose:

- Host subinterface: All control plane and management plane traffic directly destined for one of the routers physical or logical interfaces must be handled by the route processor. This also includes tunnel termination packets.
- Transit subinterface: Certain data plane traffic traversing the router and that a configured router feature requires additional processing to be completed by the route processor before it can be forwarded.
- CEF-exception subinterface: Certain traffic related to router or network operations (such as Layer 2 keepalives), and packets having certain attributes that require further processing by the route processor, such as TTL 0 or 1 (expires).

Each subinterface is mutually exclusive; a packet emerging from the classifier will only enter one subinterface. Traffic traversing each control plane subinterface can be independently classified and controlled using unique CPPr configurations.

In addition to providing the ability to limit traffic on each control plane subinterface, the CPPr feature supports Per-Protocol Queue Thresholding and Port Filtering capabilities.

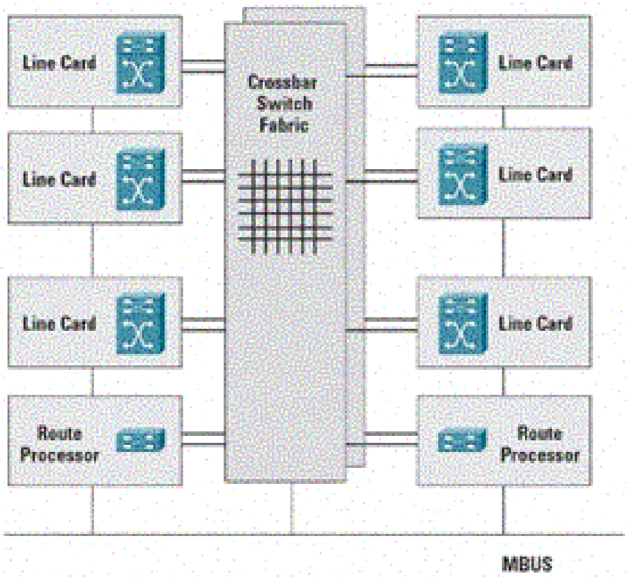
- Per-Protocol Queue Thresholding: Provides a mechanism to limit the number of packets for a given higher-level protocol in the control plane IP input queue for the host subinterface. This prevents the IP input queue from being overwhelmed by any single protocol.
- Port Filtering: Provides early policing of packets in the host subinterface to prevent them from reaching closed TCP/UDP ports, or ports to which the router is not configured to listen. This prevents unnecessary processing of packets that will ultimately be discarded, and reduces processing overhead that could potentially be exploited as an attack vector. Port filtering maintains a dynamic global database of all open TCP and UDP ports, including ports used by translators such as Network Address Translation (NAT) and Network Address Port Translation (NAPT). The registry provides network managers with a single place to look for open ports to assist them in security hardening of their network infrastructures.

Configuring Control Plane Protection is beyond the scope of this white paper. The References section contains additional information on the details of CPPr implementations.

Cisco 12000 Series Routers

The Cisco 12000 Series Gigabit Switch Router (GSR) is a premier Internet routing platform for service provider backbone and high-speed edge applications. It delivers capacity and services with a fully distributed forwarding architecture and high-efficiency crossbar switch fabric. Figure 3 illustrates this hardware-accelerated distributed forwarding architecture of the Cisco 12000 Series. The routing function is performed in the performance route processor (PRP) that is responsible for running the routing protocols and building the routing tables from the network topology. This information is then used to build the forwarding tables distributed to each Line Card (LC) installed in the chassis. The PRP is also responsible for the system control and administrative functions.

Figure 3. The Cisco 12000 Series Routers Include a Distributed Forwarding Architecture



A distributed form of CEF (dCEF) provides the same forwarding capabilities as centralized routers, but on a distributed basis. In this case, each LC has a copy of the CEF Forwarding Information Base (FIB). The FIB is computed by the PRP and pushed to each LC for local use. Thus, packet-forwarding functions are performed autonomously by each LC, and modern LCs (Engine 3-based and later) included ASIC-based hardware-acceleration to forward packets in the fast path.

As in the case of the centralized CPU-based platforms discussed above, packets received by GSR LCs are broadly handled according to the same three categories of transit, receive, and exceptions IP and Non-IP packets. However, because the GSR is a distributed system, some differences can be found in where certain packet types are handled. These are summarized as follows:

- **Transit packets** – Transit packets are forwarded in the fast path by the ASIC-based hardware acceleration components of each LC. Transit traffic is forwarded from the ingress LC to the fabric and then to the egress LC for next-hop delivery. There is no involvement by either the LC CPU or PRP. Thus, transit packets can be forwarded at the packet processing rate limit of the LC hardware.
- **Receive packets** – All control plane and management plane receive packets must be handled by the PRP because they are destined for the application layer of the IOS software itself. Hence, packets of this type are punted from the LC fast path to the PRP (using the switch fabric). Other receive packets, such as ICMP informational and error messages, may be handled directly by the LC or may require support by the PRP, depending on the type of ICMP message.
- **Exceptions IP and Non-IP packets** – Exceptions IP packets cannot be processed by standardized hardware-accelerated forwarding engines. Thus, by their nature, they must be punted for handling by the PRP. Non-IP packets also require handling by the PRP and are always punted.

The descriptions above show that packets are handled in a number of different ways in the GSR. In general, packets will all be handled by the LC forwarding hardware, LC CPU, fabric, or route processor (PRP), depending on packet type. How different types of packets are handled is summarized in Table 1.

Table 1. Cisco 12000 Series Router Packet Paths for Various Traffic Types

Figure 4	Traffic Type	Packet Path
5	Transit Data Plane Traffic	LC to fabric to LC
2	Receive Control and Management Plane Traffic	LC to LC CPU to fabric to PRP
1	Receive ICMP Echo Request (ping) Traffic	LC to LC CPU
3	Exceptions Transit IP Packets	LC to LC CPU to fabric to PRP
4	Non-IP Packets	LC to LC CPU to fabric to PRP

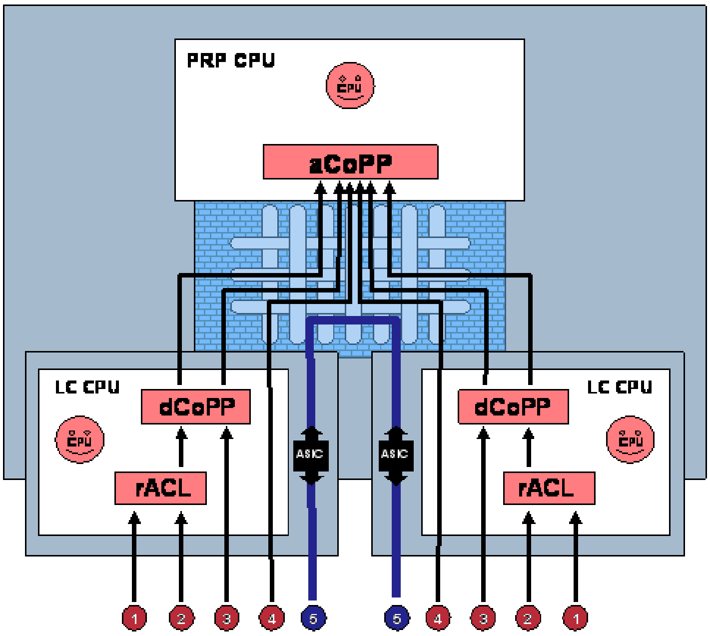
The PRP has a finite capacity to process traffic delivered from the LCs that either is destined for the PRP itself or that requires PRP support for traffic forwarding. If a high volume of data requires punting to the PRP, that traffic can overwhelm the PRP and potentially result in an effective denial-of-service (DoS) attack. When this occurs, the PRP CPU may struggle to keep up with packet processing functions. Certain automated functions such as Selective Packet Discard (SPD) are designed to minimize the impact of such conditions on the PRP resources. However, even SPD is not fully sufficient to protect the PRP from all types of attack conditions. It is considered a best practice to deploy PRP protection mechanisms in production environments. (Further discussions of SPD are outside the scope of this document. For additional details on SPD and its use and configuration, see the References section.

For the purposes of this white paper, the mechanism available for protecting the PRP includes the receive ACL (rACL) and CoPP. There are some deployment and functionality differences between these two mechanisms that are worth highlighting. At a high level, the following describes these two mechanisms.

- **IP Receive ACL** – IP Receive ACLs (rACLs) cover all IP (v4 and v6) packets that punt when the IP destination address matches a receive adjacency (CEF/FIB) of the router. Since this feature is implemented as an ACL, the granularity of the control is permit or deny only. The rACL feature only operates in a distributed fashion.
- **Control Plane Policing** – Control Plane Policing (CoPP) covers all packets punted by the router that would hit the Route Processor CPU. In the case of the GSR (only), this has certain implications since the GSR is a distributed-ASIC platform. CoPP can be implemented in distributed mode (dCoPP) on each Line Card CPU, or in aggregate mode (aCoPP) on the route processor CPU, or both.

Distributed mechanisms (like rACLs and dCoPP) are deployed and operate on the installed LCs of the GSR. These mechanisms operate on packets at the individual LC level before they are forwarded to the PRP. (Note that rACL and dCoPP inspection (and drop/rate-limiting) is performed prior to the LC to PRP rate-limiting function). Aggregate CoPP (aCoPP) is deployed and operates at the PRP-level itself. This mechanism operates on packets after they have punted to the PRP, but prior to being handled by IOS process-level applications. In combination, these mechanisms do an excellent job of protecting PRP resources. Figure 4 illustrates this logical relationship between the distributed mechanisms rACL and dCoPP and the aggregate mechanisms aCoPP.

Figure 4. Relationship Between Various Packet Types and rACLs, dCoPP, and aCoPP on Cisco 12000 Series Routers



Note that the five packet types identified in Table 1 are also illustrated in Figure 4. Four of these packet types (numbers 1 through 4) require punting for some reason and the fifth (number 5) does not. Each of the punted packet types may or may not be affected by rACL and/or CoPP functions. It is important to understand what traffic types apply in each of these four cases so that appropriate rACL and/or CoPP policies may be deployed to protect the router resources. The five packet types illustrated in Figure 4 include the following:

1. Receive ICMP Echo Request (ping) Traffic. An ICMP echo request (ping) packet with a receive destination IP address is handled directly by the LC CPU. Packets of this type never reach the PRP for handling (with limited exceptions). As illustrated in Figure 4, a rACL policy may be created to permit or deny packets of this type; however, neither dCoPP nor aCoPP can be used for these packets.
2. Receive Control and Management Plane Traffic. All control plane and management plane traffic destined to receive IP addresses is handled by the PRP. Hence, this traffic punts to the LC CPU, then crosses the switch fabric, and then is handled by Cisco IOS application processes running on the PRP CPU. As illustrated in Figure 4, a rACL policy may be created to permit or deny packets of this type. In addition, both dCoPP and aCoPP policies can be used to control these packets.
3. Exception Transit IP Packets. Transit packets that are exceptional in some way, for example IPv4 packets containing IP header options, IP packet TTL expires, and IP packets with unreachable destinations, require support from the PRP CPU for forwarding or handling. As illustrated in Figure 4, both dCoPP and aCoPP policies can be used to control these types of packets.
4. Non-IP Packets. Layer 2 keepalives, ISIS packets, Cisco Discovery Protocol (CDP) packets, and PPP Link Control Protocol (LCP) packets are examples of non-IP packets that require PRP CPU services for handling. As illustrated in Figure 4, only aCoPP policies can be used to control these types of packets.
5. Transit Data Plane Traffic. Under normal conditions, transit data plane traffic represents the vast majority of the packets handled by each LC. These packets are always forwarded by the ASIC-based hardware acceleration components of each LC and never require LC CPU or PRP support. Thus, neither rACL nor dCoPP or aCoPP mechanisms apply to or see these packets.

With the above in mind, you can see that the features available to protect PRP resources on GSR provide a great deal of flexibility in deployment options. Operational best practices derived from years of production deployment experience indicate that the best approach typically includes a combination of these features tailored for your environment since each mechanism provides distinctive benefits. The following guidance summarizes these operational best practices and may be used as a template for developing a successful implementation plan.

1. For most implementations, it is recommended that a rACL be deployed first, and then followed by the deployment of dCoPP. If additional protection not provided by these mechanisms is required, a separate aCoPP policy can then be deployed.
2. It is always recommended that a conservative approach be taken when deploying any CoPP mechanisms. Because these policies can directly impact the traffic and protocols required to operate the network, extra caution must be taken to ensure that no undue outages occur through errant policy deployment. It is always recommended that lab trials or limited pilot deployments on less-critical network segments be conducted prior to full-scale deployment. Once the policy has been proven effective, and experience has been gained with both the deployment and monitoring aspects of these mechanisms, network-wide rollout can be adopted.

rACL and CoPP Deployments

Based on this, the following guidelines are provided for the development of rACL, dCoPP, and aCoPP policies for GSR deployments.

rACL Policy

Remember that rACLs only provide permit and deny actions and only apply to IP packets with receive destination addresses. Adhering to these guidelines should allow you to construct an efficient rACL policy.

- Deny specific, unwanted traffic first in the ACL. For example, fragmented packets should never be seen in control plane or management plane traffic. Hence, the first rACL entries should deny all fragmented packets by using the **fragments** keyword.
- Permit specific, authorized sources. The construction of the rACL generally is accomplished using a specific *source address* or *source address range* for the permitted traffic, and uses the keyword **any** in the *destination* field. This is mainly because there is no need to specify the destination address since rACLs are only applied to packets punted to the PRP for a receive adjacency anyway. One exception might occur if you wish to restrict traffic to a specific receive address, say a loopback interface, as opposed to all receive addresses. This will add operational complexities since individual routers will then require individual rACL policies.
- Since a rACL only applies to receive adjacency traffic (not transit traffic), it is possible to explicitly define all traffic that should legitimately be able to reach the PRP. Thus, it is desirable to end the ACL with **deny ip any any** in the final production version. For new policy construction efforts, it is best practice to begin by including **permit ip any any** at the end of the rACL in case adequate tuning has not been completed and all traffic an protocols are not definitively known. Many times, the equivalent of a classification ACL is used at the end of the rACL to allow fine-tuning of the policy by observing the hit counts on various protocol entries. Once hits on these classification entries are no longer observed (by providing suitable permit or deny statements within the rACL policy), the **permit ip any any** can simply be removed, or replaced with a **deny ip any any** (for hit-counter purposes).

The baseline rACL policy illustrated in Table 2 is based on the above guidelines.

Table 2. Baseline IP Receive ACL Policy

```
!---Deny Fragments---
access-list 170 deny tcp any any fragments
access-list 170 deny udp any any fragments
access-list 170 deny icmp any any fragments
access-list 170 deny ip any any fragments
!---SSH and telnet--- (telnet shouldn’t be used!)
access-list 170 permit tcp <NOC block> any eq 22
access-list 170 permit tcp <NOC block> any eq 23
access-list 170 permit tcp any eq 22 any established
access-list 170 permit tcp any eq 23 any established
!---iBGP---
access-list 170 permit tcp <loopback block> gt 1024 <loopback block> eq bgp
access-list 170 permit tcp <loopback block> eq bgp <loopback block> gt 1024 established
!---eBGP---
! for OpEx reasons, typically leave this generic
! first - deny reset to protect eBGP session
access-list 170 deny tcp any any eq bgp rst
access-list 170 permit tcp any gt 1024 any eq bgp
access-list 170 permit tcp any eq bgp any gt 1024 established
!---IGP--- If OSPF used, add OSPF lines
access-list 170 permit ospf <loopback block> any
!--SNMP--- (may be one or several entries)
access-list 170 permit udp <NOC server block >  <loopback block> eq snmp
!---DNS--- (may be one or several entries)
access-list 170 permit udp host <DNS server> eq domain any
!---TACACS+-- (may be one or several entries)
access-list 170 permit tcp host <TAC server> <loopback block> established
!---NTP--- (may be one or several entries)
access-list 170 permit udp host <NTP server> <loopback block> eq ntp
!---FTP/TFTP--- (may be one or several entries)
access-list 170 permit tcp host <FTP server> eq ftp any
access-list 170 permit tcp host <FTP server> any established
access-list 170 permit udp host <FTP server> eq tftp any
!---APS--- If used. (may be one or several entries)
access-list 170 permit udp <infrastructure block> any eq 1972
!---MSDP--- If used. (may be one or several entries)
access-list 170 deny tcp any any eq 639 rst
access-list 170 permit tcp any any eq 639
access-list 170 permit tcp any eq 639 any gt 1024 established
!---IGMP/PIM--- If used. (may be one or several entries)
access-list 170 permit igmp any any
access-list 170 permit pim any any
!---ICMP---
access-list 170 permit icmp any any echo-reply
access-list 170 permit icmp any any ttl-exceeded
access-list 170 permit icmp any any unreachable
access-list 170 permit icmp any any echo
!---TRACEROUTE---(this plus above icmp)
access-list 170 permit udp any gt 10000 any gt 10000
!---HSRP--- If used.
access-list 170 permit udp any host 224.0.0.2 eq 1985
!---Deny the rest ---
access-list 170 deny tcp any any
access-list 170 deny udp any any
access-list 170 deny icmp any any
access-list 170 deny ip any any
. etc.
!
```

The rACL is deployed by applying it to the receive interface, a logical construct within IOS CLI specifically created for this purpose. An example of how the rACL shown above in Table 2 is applied is as follows:

```
RTR# config term
Enter configuration commands, one per line. End with CNTL/Z.
RTR(config)# ip receive access-list 170
RTR(config)# exit
RTR#
```

The use of a rACL is always a best-practice recommendation for GSRs as a simply way of controlling at the permit/deny level of granularity, direct access to the route processor receive path. Deploying a well-constructed rACL will also simplify CoPP (either dCoPP, aCoPP, or both) policy construction by taking advantage of the fact that the rACL will deny bad receive traffic. Thus, the dCoPP (and aCoPP) policies can be constructed to rate-limit the remaining receive traffic, as well as the IP exceptions and non-IP traffic that the rACL won’t cover. In addition, deploying both a rACL and CoPP policy provides an excellent approach that follows the principles of defense in depth and breadth. Defense in depth and breadth concepts are covered in detail in the Cisco Press book *Router Security Strategies: Securing IP Network Traffic Planes* that is listed in the References section.

CoPP Policies

Both dCoPP and aCoPP policy construction approaches follow the guidelines provided above for general CoPP policy construction. However, because the GSR has both distributed and aggregate CoPP policies, some variations must be considered during policy construction and deployment. Adhering to these guidelines will allow you to construct an efficient dCoPP and/or aCoPP policy.

- CoPP on the GSR only supports IPv4 packets and ARP packets. No other protocols are supported, even though MQC provides mechanisms for matching many other protocols and conditions. Only a subset of the MQC infrastructure is available for use with CoPP. Using unsupported features will produce inconsistent, erroneous results.
  - For IOS 12.0(32)S and prior images, only numbered standard and extended ACLs are allowable in CoPP policies. Beginning with IOS 12.0(33)S, named ACLs may also be used. The ability to modify named ACLs dynamically (without removing and reapplying the ACL) is also added in 12.0(33)S.
  - The log **keyword** must never be included in ACL entries used for MQC policies for CoPP.
  - MQC IP precedence value match mechanisms may be used.
  - MQC interface match mechanisms may not be used.
  - Only the protocol ARP is allowable within MQC protocol matching mechanisms when used for CoPP, even though MQC supports other protocol types). For example, CLNS, CDP and IPv6 are not allowable matches.
  - When constructing **policy-map** statements, each **class-map** must have an accompanying **police** statement. It is not acceptable to have class statements following one another without an associated **police** statement. If the desired action is to permit all traffic matching the class without rate limits, the police action should simply be provided as **conform-action transmit exceed-action transmit**. If the desired action is to drop all traffic matching the class, the police action should simply be provided as **conform-action drop exceed-action drop**.
- Unlike rACLs that only see receive traffic, CoPP can see exception transit traffic. An example of this is transit traffic with IPv4 header options (Router Alert (RA) and Source Route (SR). Thus, traffic of these types must be accounted for in the policy.
- dCoPP and aCoPP can, in some cases, see different packets (see Figure 4 above). Hence, it may be necessary to deploy both dCoPP and aCoPP to fully protect the route processor CPU.
- Certain traffic types, namely L2 keepalives, CLNS, and other non-IP packets, are never seen by dCoPP (not even within **class-default**) but will be seen by aCoPP (only in **class-default**). These traffic types cannot be classified by MQC for CoPP and hence, will always fall into the aCoPP **class-default** class. If aCoPP is configured, it is best practice to never rate limiting **class-default** so that L2 keepalives and other essential control plane traffic are not dropped. This is the primary reason for always configuring a "catch all" IP class in the CoPP**policy-map** just prior to **class-default**.
- The GSR is capable of supporting line cards (LCs) based on several versions of engines. Older versions, such as Engine E0 and E1 LCs are CPU-based, while new generations such as E4/E4+, E3, and E5-based LCs are ASIC-based. Each LC engine type has different packet handling and processing characteristics, including packet per second (PPS) processing rates for punted packets, and number and speed of punt path raw queues for example. These characteristics may be important in determining the appropriate dCoPP policy policing rates. If a mix of LCs is included within the same GSR chassis, it is conceivable that different policies could be used for slots related to different LC engines. For example, a high-speed uplink (backbone-facing) slot may have a different dCoPP policy as compared with a low-speed aggregation (customer-facing) slot.
- When both dCoPP and aCoPP are deployed at the same time, it is not required to construct separate policies (ACLs, class maps, and policy maps) for both mechanisms. It may be advantageous from an operational and troubleshooting perspective to have separate policies for each mechanism however. In addition, the rate limits for dCoPP and aCoPP policies will most likely differ since GSRs have multiple slots (the focus of dCoPP policies) which can contribute packets to the aggregate flow that reaches the PRP (the focus of aCoPP polices). Thus, the rate limits for the aCoPP policy might easily be higher than that provided at the slot level.

The baseline dCoPP policy illustrated in Table 3 is based on the above guidelines.

Table 3. Baseline Distributed CoPP Policy

```
!
! -- ACL for CoPP-malicious class-map
!
access-list 111 permit icmp any any fragments
access-list 111 permit udp any any fragments
access-list 111 permit tcp any any fragments
access-list 111 permit ip any any fragments
access-list 111 permit udp any any eq 1434
access-list 111 permit tcp any any eq 639 rst
access-list 111 permit tcp any any eq bgp rst
--- etc. include all –known bad things here–
!
! – ACL for CoPP-positive-mgmt class
!
access-list 112 permit tcp <NOC block> <router receive block> eq telnet
access-list 112 permit tcp <NOC block> eq telnet <router receive block> established
access-list 112 permit tcp <NOC block> <router receive block> eq 22
access-list 112 permit tcp <NOC block> eq 22 <router receive block> established
access-list 112 permit udp <NOC block> <router receive block> eq snmp
access-list 112 permit tcp <NOC block> <router receive block> eq ftp
access-list 112 permit tcp <NOC block> <router receive block> eq ftp-data
access-list 112 permit udp <NOC block> <router receive block> eq syslog
access-list 112 permit udp <DNS block> eq domain <router receive block>
access-list 112 permit udp <NTP block> <router receive block> eq ntp
---etc--- for known good traffic...
!
! -- ACL for CoPP-negative-mgmt class

! (If known-good mgmt traffic can be id'd per above,
! add this policy to drop all other traffic to mgmt ports...)
access-list 113 permit tcp any <router receive block> eq telnet
access-list 113 permit tcp any <router receive block> eq 22
access-list 113 permit udp any <router receive block> eq snmp
access-list 113 permit tcp any <router receive block> eq ftp
access-list 113 permit tcp any <router receive block> eq ftp-data
access-list 113 permit udp any <router receive block> eq syslog
access-list 113 permit udp any eq domain <router receive block>
access-list 113 permit tcp any <router receive block>
access-list 113 permit udp any <router receive block>
---etc--- note: this is <receive block> only
!
!-- ACL for CoPP-routing class-map

!
access-list 114 permit tcp any gt 1024 <router receive block> eq bgp
access-list 114 permit tcp any eq bgp <router receive block> gt 1024 established
access-list 114 permit tcp any gt 1024 <router receive block> eq 639
access-list 114 permit tcp any eq 639 <router receive block> gt 1024 established
access-list 114 permit tcp any <router receive block> eq 646
access-list 114 permit udp any <router receive block> eq 646
access-list 114 permit ospf any <router receive block>
access-list 114 permit eigrp any <router receive block>
access-list 114 permit udp any <router receive block> eq rip
```

```
!
!-- ACL for CoPP-positive-icmp class-map
!
access-list 115 permit icmp any <router receive block> echo
access-list 115 permit icmp any <router receive block> echo-reply
access-list 115 permit icmp any <router receive block> ttl-exceeded
access-list 115 permit icmp any <router receive block> packet-too-big
access-list 115 permit icmp any <router receive block> port-unreachable
access-list 115 permit icmp any <router receive block> unreachable
access-list 115 permit icmp any <router receive block> packet-too-big
---etc--- for known good icmp traffic...
!
!-- ACL for CoPP-negative-icmp class-map
!
access-list 116 permit icmp any <router receive block>
---etc--- note: this is <receive block> only
!
! -- ACL for CoPP-other class-map
!
access-list 117 permit pim any any
access-list 117 permit udp any any eq pim-auto-rp
access-list 117 permit igmp any any
access-list 117 permit gre any any
!
! -- ACL for CoPP-catch-all class-map
access-list 118 permit tcp any any
access-list 118 permit udp any any
access-list 118 permit icmp any any
access-list 118 permit ip any any
!
!
class-map match-all CoPP-malicious
 match access-group 111
!
class-map match-all CoPP-positive-mgmt
 match access-group 112
!
class-map match-all CoPP-negative-mgmt
 match access-group 113
!
class-map match-all CoPP-routing
 match access-group 114
!
class-map match-all CoPP-positive-icmp
 match access-group 115
!
class-map match-all CoPP-negative-icmp
 match access-group 116
!
class-map match-all CoPP-other
 match access-group 117
!
class-map match-all CoPP-catch-all
 match access-group 118
!
class-map match-all CoPP-arp
 match protocol arp
!
!
policy-map CoPP_slots
 class CoPP-malicious
 police 8000 4470 4470 conform-action drop exceed-action drop
 class CoPP-routing
 police 1000000000 5000000 5000000 conform-action transmit exceed-action transmit
 class CoPP-positive-mgmt
 police 4000000 125000 125000 conform-action transmitexceed-action drop
 class CoPP-negative-mgmt
 police 8000 4470 4470 conform-action drop exceed-action >drop
 class CoPP-positive-icmp
 police 10000 4470 4470 conform-action transmit exceed-action drop
 class CoPP-negative-icmp
 police 8000 4470 4470 conform-action drop exceed-action drop
 class CoPP-arp
 police 500000 4470 4470 conform-action transmit exceed-action drop
 class CoPP-other
 police 200000 4470 4470 conform-action transmit exceed-action drop
 class CoPP-catch-all
 police 64000 4470 4470 conform-action transmit exceed-action drop
 class class-default
 police 8000 1500 1500 conform-action transmit exceed-action transmit
!
```

The general commands for deploying dCoPP and aCoPP are similar, with the exception being that dCoPP is applied on a per-slot basis. The general form for deploying dCoPP is as follows:

```
RTR# config term
Enter configuration commands, one per line. End with CNTL/Z.
RTR(config)# control-plane slot <slot #>
RTR(config-cp-slot)# service-policy input <policy-map-name>
```

An illustration of how the dCoPP policy **CoPP_slots** shown in Table 3 above is applied to slots 0 through 7 for example is as follows

```
RTR# config term
Enter configuration commands, one per line. End with CNTL/Z.
RTR(config)# control-plane slot 0
RTR(config-cp-slot)# service-policy input CoPP_slots
RTR(config-cp-slot)# control-plane slot 1
RTR(config-cp-slot)# service-policy input CoPP_slots
RTR(config-cp-slot)# control-plane slot 2
RTR(config-cp-slot)# service-policy input CoPP_slots
RTR(config-cp-slot)# control-plane slot 3
RTR(config-cp-slot)# service-policy input CoPP_slots
RTR(config-cp-slot)# control-plane slot 4
RTR(config-cp-slot)# service-policy input CoPP_slots
RTR(config-cp-slot)# control-plane slot 5
RTR(config-cp-slot)# service-policy input CoPP_slots
RTR(config-cp-slot)# control-plane slot 6
```

```
RTR(config-cp-slot)# service-policy input CoPP_slots
RTR(config-cp-slot)# control-plane slot 7
RTR(config-cp-slot)# service-policy input CoPP_slots
```

Note that dCoPP can be applied to every LC slot on the chassis, or just on selected slots of your choice. A valid dCoPP policy may be applied regardless of whether or not a LC is installed in the slot to which the policy is applied at the time of configuration. This may occur in cases where a script is used to update IOS configurations across multiple routers and that may have dissimilar LC arrangements. If a LC is present, the policy is executed on the LC. If a LC is not present, the configuration will be accepted and retained. In the event that a LC is then installed, the dCoPP configuration will automatically be pushed to the LC and executed. If a LC is removed from a slot to which a dCoPP policy has been deployed, the policy will remain in the configuration for that slot. If the same or a different LC type is reinserted in the slot, the same dCoPP policy will be re-applied to newly inserted LC.

The general form for deploying an aCoPP policy is as follows:

```
RTR# config term
Enter configuration commands, one per line. End with CNTL/Z.
RTR(config)# control-plane
RTR(config-cp)# service-policy input <policy-map-name>
```

Assuming the creation of an aCoPP policy named CoPP_PRP (in a similar manner as that defined in Table 3 above), this aCoPP policy would be applied as follows:

```
RTR# config term
Enter configuration commands, one per line. End with CNTL/Z.
RTR(config)# control-plane
RTR(config-cp)# service-policy input CoPP_PRP
```

Monitoring CoPP

Monitoring of aCoPP is consistent with the techniques and methods shown in the general section above. However, since dCoPP is deployed on a per-slot basis, dCoPP monitoring does require additional effort. In the case of dCoPP, the control plane policy-map statistics can be monitored on a per-slot basis. The following illustrates this technique using slot 10 as an example.

```
RTR# show policy-map control-plane slot 10
 Control Plane - slot 10
 Service-policy input: copp (1753)
 Class-map: copp-routing (match-any) (1754/4)
  99634 packets, 5381436 bytes
  5 minute offered rate 0 bps, drop rate 0 bps
  Match: access-group 143 (1755)
  police:
   cir 1000000 bps, bc 31250 bytes
  conformed 99634 packets, 5381436 bytes; actions:
   transmit
  exceeded 0 packets, 0 bytes; actions:
   transmit
  conformed 0 bps, exceed 0 bps
 Class-map: copp-management (match-any) (1757/2)
  237 packets, 28686 bytes
  5 minute offered rate 0 bps, drop rate 0 bps
  Match: access-group 141 (1758)
  police:
   cir 504000 bps, bc 15625 bytes
  conformed 237 packets, 28686 bytes; actions:
   transmit
  exceeded 0 packets, 0 bytes; actions:
   transmit
  conformed 0 bps, exceed 0 bps
 Class-map: copp-low-priority (match-any) (1760/3)
  1250 packets, 4246733 bytes
  5 minute offered rate 0 bps, drop rate 0 bps
  Match: access-group 140 (1761)
  police:
   cir 1000000 bps, bc 31250 bytes
  conformed 1146 packets, 3309901 bytes; actions:
   transmit
  exceeded 104 packets, 936832 bytes; actions:
   drop
  conformed 0 bps, exceed 0 bps
 Class-map: copp-rest-IP (match-any) (1763/1)
  95 packets, 4632 bytes
  5 minute offered rate 0 bps, drop rate 0 bps
  Match: access-group 142 (1764)
  Match: protocol arp (1765)
  police:
   cir 504000 bps, bc 15625 bytes
  conformed 95 packets, 4632 bytes; actions:
   transmit
  exceeded 0 packets, 0 bytes; actions:
   drop
  conformed 0 bps, exceed 0 bps
 Class-map: class-default (match-any) (1767/0)
  0 packets, 0 bytes
  5 minute offered rate 0 bps, drop rate 0 bps
  Match: any (1768)
  police:
   cir 1000000 bps, bc 31250 bytes
  conformed 0 packets, 0 bytes; actions:
   transmit
  exceeded 0 packets, 0 bytes; actions:
   transmit
  conformed 0 bps, exceed 0 bps
```

The use of EEM for monitoring CoPP will not be useful on GSRs. Only EEMv1.0 is available in Cisco IOS Software Release version 12.0S and this version does not include support for Tcl scripts. EEMv1.0 can be used along with the SNMP event detector to monitor the CISCO-CLASS-BASED-QOS-MIB statistics.

These guidelines provide operationally derived best practices for rACL, dCoPP, and aCoPP deployments within the context of achieving an overall level of infrastructure security. Other mechanisms are available and contribute to the full protection of the PRP, punt-path resources, and overall infrastructure security of the GSR.

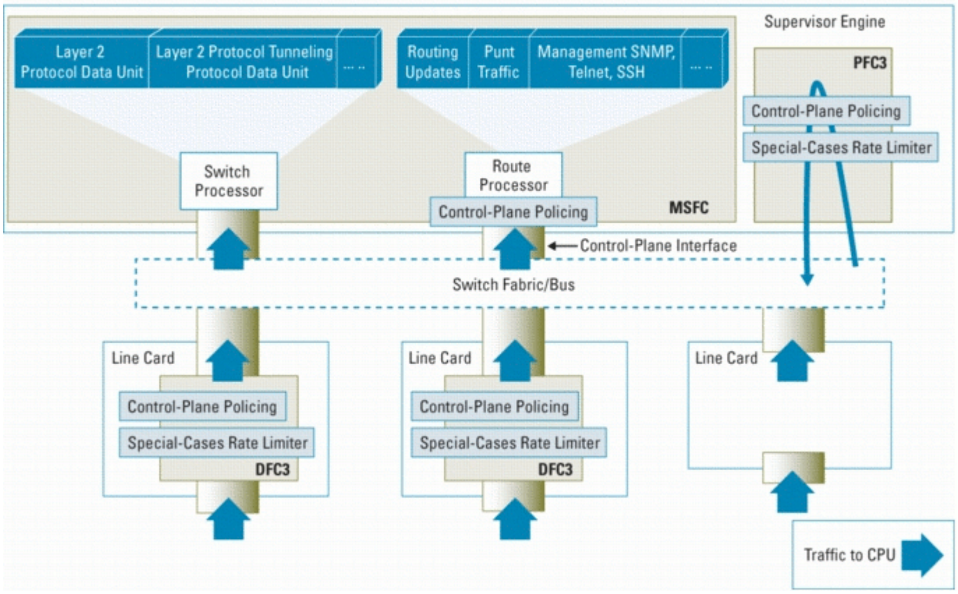
Cisco Catalyst 6500 Switches and Cisco 7600 Series Routers

The Cisco Catalyst 6500 Series switches and Cisco 7600 Series routers (referred to herein as 6500/7600) are premier intelligent, multilayer modular platforms. They deliver secure, converged, end-to-end services, from the wiring closet to the core network, the data center, and the WAN edge. A supervisor engine performs control operations centrally on processors that run Cisco IOS, and special-purpose, ASIC-based hardware performs bridging and routing (based on CEF), QoS marking and policing, and access control. This gives these platforms distribute forwarding capabilities in a manner similar to the GSR.

As with the GSR, 6500/7600 platforms use several features to address the protection needs of the control plane. Specifically, 6500/7600 platforms employ CoPP and special-cases hardware-based rate-limiters in this capacity. CoPP operates simultaneously in both distributed and aggregate modes with the CoPP policy being applied in hardware on a per-forwarding-engine basis (I.e. distributed) on each Distributed Forwarding Card [DFC] as well as the Policy Feature Card [PFC]. This same CoPP policy is also applied in software on the Multilayer Switching Feature Card (MSFC) on an aggregate basis. In addition, special-cases hardware-based rate-limiters are also available on 6500/7600 platforms to police certain traffic going to the switch processor or route processor. When deploying an overall router protection plan, the deployment of both CoPP and hardware rate-limiters must be considered in combination.

Figure 5 depicts a Cisco Catalyst 6500 Series, the two Multilayer Switching Feature Card (MSFC) processors, and the location of CoPP and hardware-based rate-limiters that protect the switch processor and route processor against high packet rates.

Figure 5. Relationship and Point of Impact of Hardware and Software Control Plane Policing, and Special-Case Rate-limiters for Catalyst 6500 Series Switches

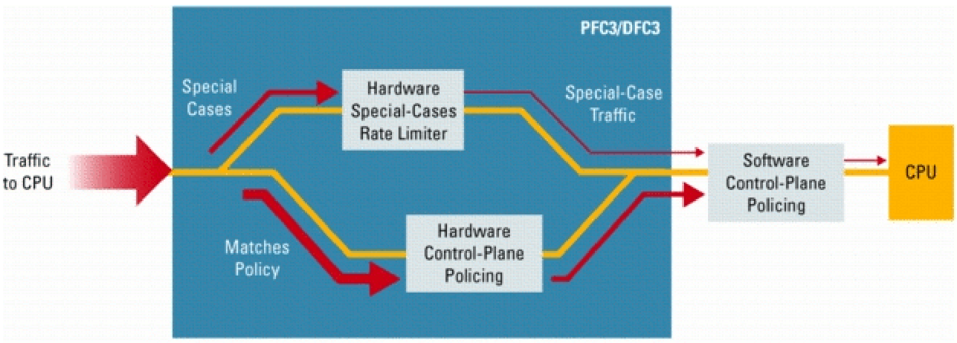


As illustrated in Figure 5, each DFC-based LC and PFC is capable of independently mitigating a line-rate attack in hardware using CoPP and hardware-based special-cases rate-limiters. On the MSFC, CoPP is enforced in software at interrupt level to make sure that only the exact rate configured in the control-plane policy is forwarded to the route processor. Unlike the GSR which can support individual CoPP policies for any LC or the PRP, only a single, global CoPP policy is applied on 6500/7600 platforms. That is, all DFCs and PFCs, as well as the MSFC, are programmed with the same global CoPP policy even though they each police traffic independently.

In addition to CoPP, DFCs and Supervisor Engine 32 (Sup32) and Supervisor Engine 720 (Sup720) PFCs support special-cases hardware-based rate-limiters. These rate-limiters cover a specific set of predefined of IPv4, IPv6, unicast, multicast, and Layer 2 traffic flows that may be used in DoS attacks against the platform. The special-cases packet types covered include for example, TTL expires (packets with TTL equal to 1), packets that fail the maximum transmission unit (MTU) check, packets with IPv4 header options, packets with IP header errors, multicast packets for which a destination prefix cannot be found in the routing table, and many others that may affect the route processor CPU.

Even though CoPP and the hardware-based rate-limiters are deployed as separate configurations, best practice is to deploy both in a coordinated configuration, because each handles different traffic types. As illustrated in Figure 6, traffic matching any configured special-cases rate-limiter automatically bypasses the hardware-based CoPP policy. Traffic that does not match any special-cases rate-limiter is compared against the hardware-based CoPP policy. All traffic permitted by either of these two policies is then compared against the software CoPP policy.

Figure 6. Relationship between Control Plane Policing and Special-Case Rate-limiters for 6500/7600 Platforms



CoPP Deployments

CoPP policy construction approaches in generally follows the guidelines provided above for CoPP policy construction. As with other platform types however, there are certain platform-dependent deployment considerations with CoPP deployments for 6500/7600 platforms. The following guidelines are provided.

- CoPP is supported in hardware on platforms with either the Supervisor Engine 720 or Supervisor Engine 32 beginning with Cisco IOS Software Release 12.2(18)SXD1. However, CoPP is not enforced in hardware unless Multilayer Switching (MLS) QoS is enabled globally. MLS QoS is enabled globally using the following command:

  ```
  Switch(config)# mls qos
  ```

  Unless the mls qos global command-line interface (CLI) is not entered, CoPP will only operate in software.
- CoPP support in hardware is provided for unicast IPv4 and IPv6 traffic, but not for multicast and broadcast traffic. CoPP is supported in software for multicast and broadcast traffic and may still be used to mitigate DoS attacks targeted at the route processor CPU. Hardware support for multicast and broadcast traffic is provided by special-cases hardware-based rate-limiters. When used in conjunction with CoPP and security ACLs, these provide comprehensive protection against line-rate multicast and broadcast DoS attacks (see next section).
- ARP traffic is not covered by CoPP (neither hardware nor software) at all on 6500/7600 platforms. However, an ARP special-cases hardware-based rate-limiter is available and should be applied (see next section) to when ARP-based attack mitigation is required.
- ACLs used for classification under MQC and hence used for CoPP are QoS ACLs. QoS ACLs are compiled and stored in dedicated QoS ACL TCAM locations. The following Cisco IOS command can be used to verify the TCAM utilization:

  ```
  Switch# show tcam utilization
  ```

  QoS ACLs supported in hardware are IPv4 standard, extended, and named. Starting with 12.2(18)SXE1, IPv6 ACLs are also supported in hardware.
- Prior to 12.2(18)SXE1, only one match command in a single class-map is allowed. In addition, the only policy-map action supported is **policy** (i.e., the **drop** action is not supported).
- Always set a policy action for each class. CoPP will ignore a class that does not have a corresponding policing action. If a policy action is not set for a class, the traffic will skip the class and will be matched against the subsequent classes.
- MQC class class-default is not supported until 12.2(18)SXE1.
- CoPP does not support ACL entries with log keyword.
- Only the “input” direction is supported for CoPP.
- As illustrated in Figure 6, be aware that the special-cases hardware-based rate-limiters will override the hardware CoPP policy for packets matching the rate-limiters criteria. Best practice, therefore, is to disable the Cisco Express Forwarding (CEF) Receive rate-limiter (see next section) when using CoPP. The CEF Receive rate-limiter is disabled by default but if enabled, it can be disabled by issuing the following command:

  ```
  RTR(config)# no mls rate-limit unicast cef receive
  ```

- A common CoPP policy applies to all hardware-based (DFC/PFC) CoPP instances, as well as the software-based (MSFC) CoPP instance. When setting CoPP policy rates, it is critical to recognize that the aggregate traffic rate capable of hitting the software-based (MSFC) CoPP instance is the sum total of all traffic passing through the hardware-based (DFC/PFC) CoPP policies and the special-cases hardware-based rate-limiters.

In general, note that 6500/7600 platforms can deny packets in hardware using security ACLs before they reach the CPU punt path. Because security ACLs are applied in hardware using the TCAM, long security ACLs can be used without impacting the throughput of other traffic. When used in conjunction with CoPP and hardware-based rate-limiters, comprehensive protection against line-rate DoS attacks is provided.

Special-Cases Rate-Limiter Deployments

The special-cases hardware-based rate-limiters, in general, do not provide the same level of granularity as CoPP. However, they are especially useful for cases where hardware CoPP cannot be used to classify particular types of traffic.

Tables 4 through 7 list the available special-cases hardware-based rate-limiters, grouped by category for unicast (Table 4), multicast (Table 5), all (Table 6), and Layer 2 (Table 7) traffic types. Each table includes a listing and description of each available rate-limiter, the default settings, and a configuration example. (Note that IPv6 rate-limiters are not discussed).

Table 4. Unicast Special-Case Rate-limiters

<table>
<tr><th>Rate-limiter</th><th>Default</th><th>Description</th></tr>
<tr><td>Ingress ACL Bridged Packets</td><td rowspan="2">OFF</td><td rowspan="2">Limits packets punted to the route processor CPU because of an Ingress/Egress ACL bridge result. Ingress/Egress ACL rate-limiters can be used independently. However, if both rate-limiters are turned on, they must share the same value and are limited in aggregate. Examples of ACL bridged packets include packets hitting ACEs with the "log" keyword, packets requiring special ACL features, and unsupported hardware packet types such as IPX and AppleTalk. When a CoPP policy is present, it is better to disable the Ingress ACL bridged rate-limiter because these may overlap.<pre>Switch(config)# mls rate-limit unicast acl input ?
  <10-1000000> packets per second
Switch(config)# mls rate-limit unicast acl output ?
  <10-1000000> packets per second</pre></td></tr>
<tr><td>Egress ACL Bridged Packets</td></tr>
<tr><td>Cisco Express Forwarding (CEF) Receive Packets</td><td>OFF</td><td>Rate limits all packets that contain any route processor IP address as the destination address. This type of traffic can be legitimate traffic, e.g., BGP, telnet, SNMP, etc., but could also be a form of a DoS attack if excessive packets are flooded to the RP CPU for processing. It is better to use CoPP than to use this rate-limiter since this aggregate value can’t distinguish between classes of traffic; do not use both mechanisms simultaneously.<pre>Switch(config)# mls rate-limit unicast cef receive ?
  <10-1000000> packets per second</pre>Do not enable the CEF receive rate-limiter if you are using CoPP. The FIB receive rate-limiter overrides the CoPP policies.</td></tr>
<tr><td></td><td></td><td>Limits traffic that is punted to the CPU when no ARP entry exists for the destination host, and the CPU thus needs to ARP for a next hop. Note that this does not affect ARP traffic but just traffic that requires</td></tr>
</table>

Cisco Express Forwarding (CEF) Glean Packets	OFF	address resolution. Switch(config)# mls rate-limit unicast cef glean ? <10-1000000> packets per second
IP Features	OFF	Limits traffic requiring special software feature processing. Software features include Authentication proxy, IPSec, and Inspection in the Native implementation. Note that the Cisco Catalyst OS feature rate-limiter is used to rate limit dot1x, DHCP, and ARP Inspection traffic. Do not use this rate-limiter unless you are using one of these features. Switch(config)# mls rate-limit unicast ip features ? <10-1000000> packets per second
ICMP Redirect	OFF	Limits traffic requiring generation of ICMP redirect messages. ICMP redirect packets are sent back to the originating hosts to advertise optimal routes. Switch(config)# mls rate-limit unicast ip icmp redirect ? <0-0> no packets up to the RP <10-1000000> packets per second
ICMP Unreachable-no route	ON 100 PPS	Limits traffic requiring generation of ICMP unreachable messages due to FIB miss, ACL drop, or uRPF failure. The IP Error rate-limiter limits bad IP traffic with invalid L2/L3 length or L3 checksums that needs to be sent to the route processor for further processing. All four rate-limiters share a single hardware rate-limiter and should any of these rate-limiters be enabled, all the rate-limiters in this group will share the same value and state (ON/ON/ON/ON). Switch(config)# mls rate-limit unicast ip icmp unreachable acl-drop ? <0-0> no packets up to the RP <10-1000000> packets per second Switch (config)# mls rate-limit unicast ip icmp unreachable no-route ? <0-0> no packets up to the RP <10-1000000> packets per second Switch(config)# mls rate-limit unicast ip errors ? <10-1000000> packets per second Switch(config)# mls rate-limit unicast ip rpf-failure ? <0-0> no packets up to the RP <10-1000000> packets per second
ICMP Unreachable-ACL drop		
IP Errors		
IP RPF Failures		
IP Options	OFF	Packets with IP Options are sent to the CPU for further processing. This special-case rate-limiter limits unicast packets with IP Options punted to the CPU. This option is only supported on the Cisco Catalyst 6500 Series policy feature cards 3B and 3BXL (PFC3B, PFC3BXL). Switch(config)# mls rate-limi unicast ip options ? <10-1000000> packets per second
VACL Log	ON 2000 PPS	Limits packets punted to the CPU because of VLAN ACL logging. VACLs are processed in hardware, but the logging function is done by the route processor. This rate-limiter is enabled by default. Do not use this rate-limiter unless VACL Log is configured. Switch(config)# mls rate-limi unicast acl vacl-log ? <10-5000> packets per second

Table 5. IPv4 Multicast Special-Case Rate-limiters

Rate-limiter	Default	Description
Multicast Directly Connected	OFF	The multicast directly connected rate-limiter limits the multicast packets from directly connected sources. Switch(config)# mls rate-limit multicast ipv4 connected ? <10-1000000> packets per second
Multicast Partial-SC	ON 100Kpps	Some multicast flows can be partially software switched if special processing is required. It is desirable to rate limit these flows destined to the Multilayer Switching Feature Card (MSFC). Note that this rate-limiter uses a special register that is not accounted for in the available ten hardware registers and it is applied globally, not on a per-forwarding-engine basis. Switch(config)# mls rate-limit multicast ipv4 partial ? <10-1000000> packets per second
Multicast IPv4 FIB Miss (Multicast Dflt Adj)	ON 100Kpps	Limits multicast traffic requiring special software processing because of an FIB miss if the traffic does not match an entry in the hardware mroute table. That is, this rate-limiter Limits traffic punted to establish the multicast control plane state (e.g. new S, G traffic). Switch(config)# mls rate-limit multicast fib-miss ? <10-1000000> packets per second

		Note that this rate-limiter shows up as MCAST DFLT ADJ in the output of the show mls rate-limit command.

Multicast Non-RPF	OFF	Same as unicast RPF Failure rate-limiter, but applies to multicast traffic.
		`Switch(config)# mls rate-limit multicast ipv4 non-rpf ?`
		`<10-1000000>  packets per second`

Multicast IP Options	OFF	Same as unicast IP Options rate-limiter, but applies to multicast traffic. This option is only supported on the Cisco Catalyst 6500 Series PFC3B and PFC3BXL.
		`Switch(config)#mls rate-limit multicast ipv4 ip-options ?`
		`<10-1000000>  packets per second`

Table 6. Unicast and Multicast ("All") Special-Case Rate-limiters

Rate-limiter	Default	Description

TTL Failure	OFF	Limits all packet types punted to the route processor CPU because of a time-to-live (TTL) check failure. Do not use this rate-limiter in conjunction with Layer 2 multicast in a system with the Cisco Catalyst 6500 Series PFC3A. Doing so would break multicast bridging.
		`Switch(config)# mls rate-limit all mtu-failure ?`
		`<10-1000000>  packets per second`

MTU Failure	OFF	Limits packets that are punted to the route processor CPU because of to maximum transmission unit (MTU) failure. Do not use this rate-limiter in conjunction with Layer 2 multicast in a system with the Cisco Catalyst 6500 Series PFC3A.
		`Switch(config)# mls rate-limit all ttl-failure ?`
		`<10-1000000>  packets per second`

Table 7. Layer 2 Special-Case Rate-limiters

Rate-limiter	Default	Description

L2 PDU	OFF	Limits Layer 2 control protocol data unit (PDU) packets destined for the switch processor. That includes bridge protocol data units (BPDUs), VTP, UDLD, PagP, and LACP. Being too aggressive with the rate-limiter could have adverse effects on the Layer 2 network stability. This rate-limiter is not supported when the switch is in the truncated fabric-switching mode.
		`Switch(config)# mls rate-limit layer2 pdu ?`
		`<10-1000000>  packets per second`

L2 Protocol Tunneling	OFF	Limits Layer 2 protocol tunneled PDUs destined for the switch processor (Cisco Discovery Protocol, Spanning Tree Protocol, and VTP). This rate-limiter is not supported when the switch is in the truncated fabric-switching mode (See footnote).
		`Switch(config)# mls rate-limit layer2 l2pt ?`
		`<10-1000000>  packets per second`

Multicast IGMP	OFF	Limits IGMP control messages sent to the CPU for IGMP snooping. This rate-limiter should be used when IGMP Snooping is enabled. A switch with IGMP Snooping enabled will listen for IGMP messages to optimize the flow of multicast traffic at Layer 2. This rate-limiter is not supported when the switch is in the truncated fabric-switching. Truncated switching is used when a mix of fabric enabled and classic/non-fabric enabled linecards are installed, or if the system has classic linecards and redundant Cisco Catalyst 6500 Series Supervisor Engine 720s.
		`Switch(config)# mls rate-limit multicast ipv4 igmp ?`
		`<10-1000000>  packets per second`

The following output shows all available rate-limiters as of Cisco IOS Software Release 12.2(18)SXE1, with default settings.

```
Router#sh mls rate-limit
Sharing Codes: S - static, D - dynamic
Codes dynamic sharing: H - owner (head) of the group, g - guest of the group
   Rate-limiter Type     Status       Packets/s   Burst  Sharing
---------------------   ----------   ---------   -----  -------
         MCAST NON RPF   Off                  -       -     -
        MCAST DFLT ADJ   On              100000     100  Not sharing
      MCAST DIRECT CON   Off                  -       -     -
        ACL BRIDGED IN   Off                  -       -     -
       ACL BRIDGED OUT   Off                  -       -     -
           IP FEATURES   Off                  -       -     -
          ACL VACL LOG   On                2000       1  Not sharing
           CEF RECEIVE   Off                  -       -     -
             CEF GLEAN   Off                  -       -     -
```

```
       MCAST PARTIAL SC   On             100000     100  Not sharing
         IP RPF FAILURE   On                100      10  Group:0 S
            TTL FAILURE   Off                -        -     -
 ICMP UNREAC. NO-ROUTE    On                100      10  Group:0 S
 ICMP UNREAC. ACL-DROP    On                100      10  Group:0 S
          ICMP REDIRECT   Off                -        -     -
            MTU FAILURE   Off                -        -     -
         MCAST IP OPTION  Off                -        -     -
         UCAST IP OPTION  Off                -        -     -
            LAYER_2 PDU   Off                -        -     -
             LAYER_2 PT   Off                -        -     -
              IP ERRORS   On                100      10  Group:0 S
            CAPTURE PKT   Off                -        -     -
             MCAST IGMP   Off                -        -     -
 MCAST IPv6 DIRECT CON    Off                -        -     -
 MCAST IPv6 ROUTE CNTL    Off                -        -     -
 MCAST IPv6 *G M BRIDG    Off                -        -     -
   MCAST IPv6 SG BRIDGE   Off                -        -     -
   MCAST IPv6 DFLT DROP   Off                -        -     -
 MCAST IPv6 SECOND. DR    Off                -        -     -
   MCAST IPv6 *G BRIDGE   Off                -        -     -
         MCAST IPv6 MLD   Off                -        -     -
```

Note that the rate-limiter CAPTURE PKT limits packets punted to the CPU when Optimized ACL Logging (OAL) is configured or when Lawful Intercept (LI) is configured. Unlike the other rate-limiters, OAL rate-limiting is not configured via the mls rate-limit commands. Instead, it is configured as follows:

```
Switch(config)#logging ip access-list cache rate-limit <value>
```

Since the OAL and LI features both share the same rate-limiter, only one can use the rate-limiter at any time. For example, when LI is enabled, OAL rate-limiting is disabled and LI will use the rate-limiter.

It is important to note that some of rate-limiters share common hardware registers. The following output shows the current state of hardware register usage by a rate-limiter type. If the register is not used by any rate-limiter type, “Free” is displayed in the output. If the register is used by a rate-limiter type, “Used” and the rate-limiter type(s) are displayed. If several rate-limiters share a common hardware register, all rate-limiters using that register are listed.

```
Switch# show mls rate-limit usage
                          Rate-limiter Type     Packets/s   Burst
                        ---------------------   ---------   -----
Layer3 Rate-limiters:
        RL# 0: Used
                            MCAST IP OPTION           10        1
        RL# 1: Used
                            UCAST IP OPTION           10        1
        RL# 2: Used
                                TTL FAILURE          500       10
        RL# 3: Used
                             ACL BRIDGED IN          500       10
                             ACL BRIDGED OUT         500       10
        RL# 4: Used
                                   CEF GLEAN       10000       10
        RL# 5: Used
                              IP RPF FAILURE         500       10
                       ICMP UNREAC. NO-ROUTE         500       10
                       ICMP UNREAC. ACL-DROP         500       10
                                   IP ERRORS         500       10
        RL# 6: Used
                               ICMP REDIRECT         100       10
        RL# 7: Used
                              MCAST DFLT ADJ       10000       10
        RL# 8: Rsvd for capture           -            -        -
Layer2 Rate-limiters:
        RL# 9: Reserved
        RL#10: Reserved
        RL#11: Used
                                  MCAST IGMP        5000       10
        RL#12: Used
                                 LAYER_2 PDU        1000      100
```

The deployment of hardware-based rate-limiters requires detailed consideration of the types of rate-limiters to be deployed and the specific values to be set. The following guidelines provide best practice recommendations for their deployment.

- Special-cases hardware-based rate-limiters should be used in most environments. However, not all rate-limiters may be applicable. Configuring rate-limiters does take up resources on the platform and thus you should not configure rate-limiters that do not need to be applied in your environment. For example, if VACL logging is not used, do not enable the VACL log special-cases rate-limiter. Since this rate-limiter is enabled by default it must be disabled. To disable the VACL log rate-limiter, enter the following command:

  ```
  Switch(config)# no mls rate-limit unicast acl vacl-log
  ```

  Disabling certain Cisco IOS features can also eliminate the need to configure specific rate-limiters. For example, disabling IP-redirects eliminates the need for the **ip icmp redirect mls rate-limiter**.

- Eight registers are present in the Layer 3 forwarding engine and two registers are present in the Layer 2 forwarding engine. The registers are assigned on a first-come, first-serve basis. Some rate-limiters share one register. Should all registers be used, the only means to configure another special-case rate-limiter is to free one register. All ten special-case rate-limiter hardware resources available should be used.
  - Use all eight Layer 3 hardware registers (i.e., RL# 0 through RL# 7). Consider the most likely attack vectors given the network environment and enable the special-cases rate-limiters that will provide the most benefit.
  - Use the two Layer 2 hardware registers (i.e., RL#11 and RL#12) with care. When configuring the special-cases PDU rate-limiter, estimate the expected/possible number of valid PDUs, and double or triple that amount. Be sure to include BPDUs, DTP, VTP, PAgP/LACP, UDLD, etc. when estimating traffic rates.
- Special-case rate-limiters override the hardware CoPP policy for packets matching the rate-limiters criteria. That is, if traffic matches a special-case rate-limiter, it is never compared against the hardware CoPP policy. However, it will only be compared against the software CoPP policy. CoPP and special-case rate-limiters should be used in conjunction and it is strongly recommended that the "Cisco Express Forwarding (CEF) Receive" rate-limiter be disabled when using CoPP. The CEF Receive rate-limiter is disabled by default. If enable, it can be easily disabled by issuing the command:

  ```
  Switch(config)# no mls rate-limit unicast cef receive
  ```

- As a baseline for many environments, the following rate-limiter configurations are recommended:

```
Switch(config)#mls rate-limit unicast cef glean 1000 10
Switch(config)#mls rate-limit multicast ipv4 fib-miss 10000 10
Switch(config)#mls rate-limit unicast acl input 500 10
Switch(config)#mls rate-limit unicast acl output 500 10
Switch(config)#mls rate-limit all ttl-failure 500 10
Switch(config)#mls rate-limit unicast ip options 10 1
Switch(config)#mls rate-limit multicast ipv4 ip-option 10 1
! If you disable ip unreachables via Switch(config-if)#no ip unreachables
! that eliminates the need for the following two lines.
Switch(config)#mls rate-limit unicast ip icmp unreachable no-route 500 10
Switch(config)#mls rate-limit unicast ip icmp unreachable acl-drop 500 10
Switch(config)#mls rate-limit unicast ip errors 500 10
Switch(config)#mls rate-limit unicast rpf-failure 500 10
Switch(config)#mls rate-limit unicast ip icmp redirect 100 10
Switch(config)#mls rate-limit multicast ipv4 igmp 5000 10
Switch(config)# mls rate-limit layer2 pdu 1000 100
Switch(config)#mls rate-limit multicast ipv4 partial 10000 10
! If various interface MTUs re used, include the following line
Switch(config)#mls rate-limit all mtu-failure 500 10
```

The above guidelines provide operationally derived best practices for CoPP and special-cases hardware-based rate-limiter deployments within the context of achieving an overall level of infrastructure security. Other mechanisms are available and contribute to the full protection of the RP resources and overall infrastructure security of the 6500/7600 platform. Review the latest configuration and command reference guides, as well as applicable release notes, for the most up-to-date information.

Monitoring CoPP and Special-Cases Rate-Limiter Deployments for 6500/7600 Platforms

The procedures for monitoring CoPP for 6500/7600 platforms are identical to those described in the general CoPP section above. That is, this is mainly done via the use of show commands for the access-lists, class-maps, and policy-maps associated with CoPP, as well as through the use of the CISCO-CLASS-BASED-QOS-MIB. In addition, the 6500/7600 platforms support Embedded Event Manager (EEM) version 2.1 and later capabilities. EEMv2.1 added the ability for users to program their own policies using Tcl, as well as additional Event Detectors. EEM should be quite useful for automating CoPP monitoring tasks. Example EEM scripts are outside the scope of this white paper. A number of CoPP-related and other security-related scripts are available on the Cisco website and are referenced at the end of this paper.

There are no counters associated with the special-cases hardware-based rate-limiters, and these mechanisms cannot be monitored.

Cisco IOS XR

Cisco IOS XR Software is a real-time, distributed, modular microkernel-based operating system. It provides the foundation for self-healing and secure routing applications and services that demand high-scale, nonstop operations. Cisco IOS XR Software provides unprecedented routing system scalability, high availability, service isolation, and manageability to meet the mission-critical requirements of IP Next-Generation Networks (IP NGN). Currently, Cisco IOS XR Software is available for Cisco CRS-1 Carrier Routing System and Cisco XR12000 Series routers.

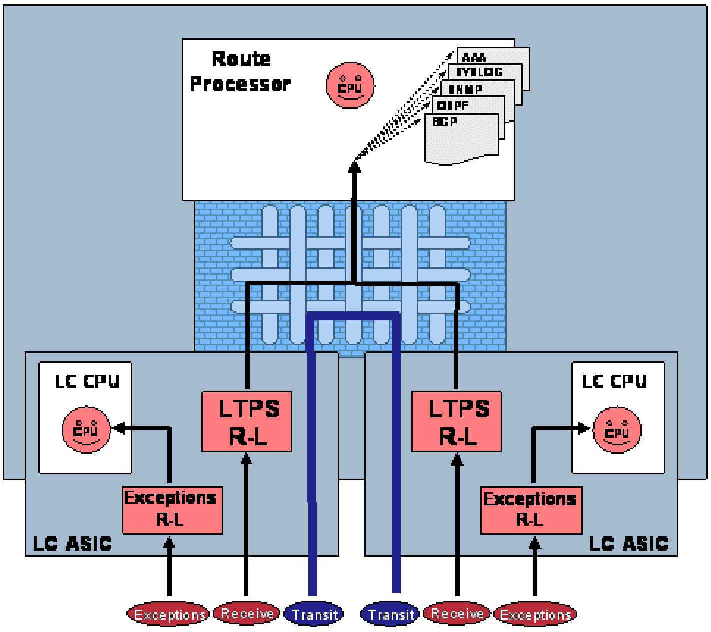
As routers handle greater traffic loads and network architectures become larger and more complex, it is increasingly difficult for network engineers to manually configure all of the controls necessary to protect the router and core network infrastructure. Cisco IOS XR takes router self-protection beyond requiring manual configuration and mere detection and reporting on security violations. It provides intelligence that automatically provisions many aspects of router self-protection functions, including differentiating between unidentified and trusted control plane sessions. In Cisco IOS XR, this functionality is provided by hardware rate-limiters associated with the Local Packet Transport Services (LPTS) to control packet flows for all internal applications that receive packets from outside the router. In addition, exceptions packet rate-limiters control all other packets that require punting for CPU support. LPTS and exceptions packet rate-limiters are preconfigured to use default values and thus are capable of functioning without the need for any user-configuration. However, LPTS does provide the capabilities for users to configure customized rate-limits in the event that the default policer settings are inadequate for the specific deployment model.

A detailed review of Cisco IOS XR and LPTS are outside the scope of this white paper. Both represent significant departures from traditional Cisco IOS-based methods and both are covered in great depth in other documents, some of which are included in the References section. However, a brief introduction into the LPTS features and functionality is useful for comparative purposes and completeness.

LPTS Deployment

In Cisco IOS XR, two groups of hardware-based rate-limiters control the flow of all traffic that punts to any CPU within the device. One group of hardware-based rate-limiters utilized by LPTS controls the flow of all packets destined to all internal applications such as control plane and management plane functions that receive packets from outside the router. A separate group is used to control exceptions and transit packets that require punting for CPU support. The relationship between these two mechanisms is illustrated in Figure 7.

Figure 7. Relationship between IOS XR Local Packet Transport Services Rate-Limiters and Exceptions Packet Rate-Limiters



LPTS groups receive packets by flow, based on various parameters like L3 protocol, L3 address, L4 port, interface, and other information that is used to classify, rate-limit, and deliver packets to the proper internal applications. LPTS maintains tables that describe packet flows for each application. In this way, for example, explicitly configured BGP peering sessions are automatically allocated adequate resources, whereas non-configured sessions are rejected or given minimum treatment. For example, BGP peering sessions are based on the association of statically configured IP addresses and dynamic Layer 4 port numbers. Prior to authentication and establishment for maximum admission control, different resource policies exist for initial connections. Here, BGP packets initially go through different polices until they are authorized and allocated greater resources. In a similar fashion, every control and management plane packet is rate-limited in hardware to protect each application and the RP.

In Cisco IOS XR, LPTS policers are programmed statically during bootup. The policers are automatically applied based on the flow type of the incoming traffic. This automation frees time spent by network administrators on manual configuration for use on other mission-critical tasks. However, beginning with Cisco IOS XR version 3.6, you can configure the rate per policer per node (locally) or globally from CLI; therefore, overwriting the static policer values.

The general form for modifying LPTS hardware policer values is as follows:

```
RP/0/RP0/CPU0:RTR(config)# config term
RP/0/RP0/CPU0:RTR(config)# lpts pifib hardware police ?
 flow  lpts flow type
 location Location Specification
 <cr>
```

In the above CLI, selecting location enters the pifib policer per-node configuration mode, while selecting flow (or <cr>) enters pifib policer global configuration mode. In global configuration mode, LPTS hardware policer values can be modified on a per-flow basis. This example illustrates modifying LPTS hardware policers:

```
configure
 lpts pifib hardware police
 flow ospf unicast default rate 200
 flow bgp configured rate 200
 flow bgp default rate 100
 !
 lpts pifib hardware police location 0/2/CPU0
 flow ospf unicast default rate 100
 flow bgp configured rate 300
 !
```

Arguments are available for all applicable flow types and the rate keyword specifies the rate in packets per seconds (PPS). Consult the LPTS configuration guide for a listing of all flow types.

The current status of the LPTS policer configuration values can be displayed using various show commands. The following example illustrates this:

```
RP/0/RP0/CPU0:RTR#show lpts pifib hardware police location 0/2/CPU0
FT - Flow type ID; PPS - Packets per second configured rate
FT Flow type                  Rate (PPS) Accept/Drop
-- -------------------------- ---------- ----------------
0  unconfigured-default       101        0/0
1  Fragment                   1000       0/0
2  OSPF-mc-known              1500       0/0
3  OSPF-mc-default            250        0/0
4  OSPF-uc-known              2000       0/0
5  OSPF-uc-default            250        267352/0
6  ISIS-known                 1500       1192706/0
7  ISIS-default               250        532158/0
8  BGP-known                  2000       839904/0
9  BGP-cfg-peer               1500       90/0
10 BGP-default                500        107387/0
11 PIM-mcast                  1500       875476/0
12 PIM-ucast                  1500       7/0
13 IGMP                       1500       77305/0
14 ICMP-local                 1046       35/0
15 ICMP-app                   1046       4/0
16 ICMP-control               1000       73604/0
17 ICMP-default               1046       4/0
18 LDP-TCP-known              1500       0/0
---<output truncated>---
```

As illustrated, the output of this command not only provides the currently configured rate-limit values, but also the number of packets accepted or dropped by LPTS.

In addition to LPTS, which controls the flow of all receive packets, a separate group of hardware-based rate-limiters automatically control exceptions and transit packets that require punting for CPU support. Examples of packets of this type include various Layer 2 packets, CDP, IPv4 TTL errors, IPv4 options, ARP/RARP, and many others. Because these packet types do not represent traffic flows that the router wishes to keep track of, there is no need to provide per-flow control as is the case with LPTS and receive packets. Therefore, these exceptions rate-limiters are simply programmed statically and are not user-configurable.

Summary and Conclusions

The route processor (RP) of any network device must handle certain types of data directly to perform tasks critical to the operation and maintenance of the network. Most notably, these include routing protocols such as BGP, OSPF, and ISIS, remote access protocols such as telnet and SSH, and network management traffic such as SNMP, Syslog, NTP, FTP, and others. This also includes other Layer 2 traffic such as Layer 2 keepalives, Cisco Discovery Protocol (CDP) packets, and PPP Link Control Protocol (LCP) packets. High packet rates, whether due to malicious and non-malicious events, can overwhelm the route processor and reduce the availability of resources for critical tasks.

The Cisco IOS-wide feature Control Plane Policing (CoPP) is designed to manage the flow of traffic handled by the route processor to prevent it being overwhelmed by unnecessary traffic. CoPP protects the route processor on network devices by treating the route processor resources as a separate entity with its own ingress interface. Because of this, a CoPP policy can be developed for this control plane interface and this policy is applied only to those packets within the control plane and not have any effect on data plane (user) traffic. CoPP is user-configured using the Modular QoS CLI (MQC). Using MQC allows CoPP to define classification and policing policies that are not limited to the permit and deny actions associated with simple ACLs, but rather also provide for rate-limiting of permitted flows. This adds tremendously to the capabilities and flexibility of developing and deploying a useable CoPP policy.

Cisco IOS XR takes router self-protection a step beyond manual configuration by providing intelligence that automatically provisions hardware rate-limiters to control packet flows for all internal applications that receive packets, as well as for exceptions packets that require punting for CPU support. The Cisco IOS XR feature LPTS and separate exceptions packet rate-limiters provide this functionality to automatically provide many aspects of router self-protection functions.

To meet business needs such as network availability and rapid deployment of IP services, it is critical to utilize these security features and services. Security best practices help secure the network foundation by protecting network elements and their interactions, ensuring the availability of the network elements under all circumstances.

Acknowledgments

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References

Router Security Strategies: Securing IP Network Traffic Planes. Gregg Schudel and Smith, David J. Cisco Press, ISBN:1587053365. January 2008.
http://www.ciscopress.com/bookstore/product.asp?isbn=1587053365

LAN Switch Security: What Hackers Know About Your Switches. Eric Vyncke and Paggen, Christopher. Cisco Press, ISBN:1587052563. September 2007.
http://www.ciscopress.com/store/lan-switch-security-what-hackers-know-about-your-switches-9781587052569

Cisco IOS Network Foundation Protection (NFP) - Deploying Control Plane Policing.
http://www.cisco.com/c/en/us/products/security/ios-network-foundation-protection-nfp/index.html

Control Plane Policing, Cisco
//www.cisco.com/c/en/us/td/docs/switches/lan/catalyst6500/ios/15-1SY/config_guide/sup2T/15_1_sy_swcg_2T/control_plane_policing_copp.html

Infrastructure Protection on Cisco IOS Software-Based Platforms
//www.cisco.com/en/US/prod/collateral/iosswrel/ps8802/ps6970/ps1838/prod_white_paper0900aecd804ac831.pdf

Control Plane Protection Feature Guide
//www.cisco.com/c/en/us/td/docs/ios/12_4t/12_4t4/htcpp.html

Embedded Event Manager in a Security Context
//www.cisco.com/c/en/us/about/security-center/embedded-event-manager-security-context.html

GSR: Receive Access Control Lists
http://www.cisco.com/en/US/tech/tk648/tk361/technologies_white_paper09186a00801a0a5e.shtml

Understanding Selective Packet Discard (SPD)
http://www.cisco.com/en/US/products/hw/routers/ps167/products_tech_note09186a008012fb87.shtml

Catalyst 6500 Release 12.2SX Software Configuration Guide, Configuring Denial of Service Protection.
//www.cisco.com/en/US/partner/docs/switches/lan/catalyst6500/ios/12.2SX/configuration/guide/dos.html

Catalyst 6500 Release 12.2SX Software Configuration Guide, Configuring Control Plane Policing (CoPP)
//www.cisco.com/en/US/partner/docs/switches/lan/catalyst6500/ios/12.2SX/configuration/guide/copp.html

Implementing LPTS on Cisco IOS XR Software
//www.cisco.com/c/en/us/td/docs/routers/crs/software/crs_r3-9/addr_serv/configuration/guide/ic39crs1book/ic39lpts.pdf

LPTS Commands on Cisco IOS XR Software
//www.cisco.com/c/en/us/td/docs/ios_xr_sw/iosxr_r3-2/addr_serv/command/reference/ad_r32/ir32lpts.pdf

LPTS Debug Commands on Cisco IOS XR
//www.cisco.com/c/en/us/td/docs/ios_xr_sw/iosxr_r3-8/addr_serv/debug/command/reference/irdb38_book/ir38lpdb.pdf

CRS-1 and IOS XR Operational Best Practices
http://www.cisco.com/en/US/products/ps5763/products_tech_note09186a0080772675.shtml

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