White Paper

Cisco Catalyst 3750 Metro Series Switch Enhanced Services Ports Deliver Advanced QoS Features for Metro Ethernet Service Providers

Overview

Today’s enterprise customers are demanding a higher level quality of service (QoS) from service providers. The ability to apply QoS criteria to network traffic is essential for service provider networks. As enterprises and service providers continue the shift to a single converged network carrying mission-critical applications over a unified multiservice (data, voice, and video) architecture, the ability to manage traffic flows and delivery terms becomes increasingly critical.

Enterprises that outsource their network services to service providers will turn to providers who can supply QoS features to ensure that on-demand, bandwidth-intensive applications and time-sensitive, information-delivery applications receive the bandwidth necessary to maintain performance. The ability to apply QoS to customer traffic will become vital to meeting service-level agreements (SLAs) and maintaining network performance. Support for advanced QoS features will also allow service providers to create premium products and service bundles.

Cisco® Catalyst® 3750 Metro Series switches meet the demand for a high level of QoS. The series’ QoS technology facilitates the management of network performance with respect to bandwidth, delay, jitter, and packet loss, which are critical to optimizing application performance and meeting SLAs. The switch supports the Cisco Hierarchical Queuing Framework (HQF), which includes traffic classification; two-rate, three-color policing; Class-Based Weighted Fair Queuing (CBWFQ); Low-Latency Queueing (LLQ); and traffic shaping on the output of the Enhanced Services ports.

The hierarchical implementation of this framework enables service providers to manage their QoS at three different levels—at the physical interface level (Enhanced Services ports), the VLAN level (VLANs within each port), and marked class level (classes with within each VLAN), providing the most granular and flexible architecture to fulfill SLAs. In addition, congestion-avoidance techniques such as Weighted Random Early Detection (WRED) and tail drop are supported to better regulate network traffic and prevent congestion.

Product Overview

The Cisco Catalyst 3750 Metro Series is a new premier multilayer switch that brings greater intelligence to the metro Ethernet edge, enabling the delivery of more differentiated metro Ethernet services. The switch features a hierarchical QoS framework and traffic shaping, intelligent 802.1Q tunneling, VLAN mapping, Multiprotocol Label Switching (MPLS)
and Ethernet over MPLS (EoMPLS) support, and redundant AC or DC power. The switch is ideal for service providers seeking to deliver profitable business services, such as Layer 2, Layer 3, and MPLS VPNs, in several bandwidths and with different SLAs. Moreover, with flexible software options, the Cisco Catalyst 3750 Metro Series offers service providers a cost-effective path for meeting current and future service requirements from enterprises and commercial businesses.

Cisco Catalyst 3750 Metro Series switches are built with two types of ports—customer ports and Enhanced Services ports. Customer ports connect to end customers and have the same features as Cisco Catalyst 3750 Series switches. The main QoS features available on customer ports include single-rate ingress policer, egress queue shapers, and weighted tail drop.

Enhanced services ports connect to the network. These ports have all the advanced QoS features on hardware and software that service provider customers demand. For example, in today’s Ethernet access switches, the egress port usually has only four or eight queues. This is not a problem if each switch is only servicing a single customer, but when the second customer is added to the switch, service providers will have to mix all customer traffic together and provide similar QoS profiles. This limits the different QoS profiles demanded by each customer.

The solution is to increase the number of queues supported on the network port. Cisco Catalyst 3750 Metro Series switches use Cisco HQF technology. The Catalyst 3750 Metro Series hardware supports 4000 queues on each of its Enhanced Services ports. Numerous egress queues allow service providers to configure a set of queues for each customer. This removes the constraint of sharing multiple customers’ traffic in the same queues and provides a custom QoS profile for each customer.

This white paper discusses Hierarchical Queuing Framework features only on egress of enhanced services ports.

**Cisco HQF Overview**

Cisco HQF provides hierarchical queuing management. Unlike traditional multilayer switches, which support a flat level of queues, the Cisco Catalyst 3750 Metro Series switch’s enhanced services ports provide three levels of packet queues—physical, logical, and class level. The physical level of hierarchy is used for policing or shaping the physical interface. It can only be identified by class default.

The logical level of hierarchy is classified by VLAN ID. At this level, the classification can match on VLAN tag (802.1Q or Inter-Switch Link [ISL]) or 802.1Q tunnel tags (Q-in-Q).

Traffic at the class level is classified by class of service (CoS), IP Precedence, IP differentiated services code point (DSCP), and MPLS EXP bits. The three levels of queues include 4096 class level queues, 1024 logical level queues, and 1 physical level queue available on each Enhanced Services port. For each logical level queue, there can be 1 to 8 class level queues. These queues can also be serviced by multiple QoS functions such as policing, shaping, and sharing.
Cisco Catalyst 3750 Metro Series switches perform the following functions within Cisco HQF:

- Queue scheduling
  - CBWFQ
  - Strict priority
- Traffic shaping
- Policing—Two-rate, three-color policer
- WRED

**Queue Scheduling—CBWFQ and LLQ**

Cisco Catalyst 3750 Metro Series switches support two types of queue scheduling—CBWFQ and LLQ. CBWFQ is used for bandwidth allocation. It allows users to allocate minimum bandwidth to each class of traffic. In addition, it allows queues to share bandwidth when one class is not using all its allocated bandwidth.

LLQ requires the configured queue to have strict priority. As long as there is traffic in this queue, it will always be serviced first. Due to the behavior, LLQ has very low latency, which is good for voice or video traffic.
CBWFQ
CBWFQ extends standard WFQ to provide support for user-defined traffic classes. For CBWFQ, users define traffic classes based on match criteria, including CoS, IP Precedence, IP DSCP, and MPLS EXP bits. Packets satisfying the match criteria for a class constitute the traffic for that class. A queue is reserved for each class, and traffic belonging to a class is directed to the queue for that class. After a class has been defined according to its match criteria, users can assign it bandwidth to guarantee a minimum amount of bandwidth that is available to it during times of congestion.

LLQ
LLQ brings strict priority queuing to CBWFQ. Strict priority queuing allows delay-sensitive data such as voice to be dequeued and sent first (before packets in other queues are dequeued), giving delay-sensitive data preferential treatment over other traffic. This feature reduces latency and jitter in configured queues.

Traffic Shaping
Traffic shaping buffers the data frames from a particular traffic flow. The data frames are then sent into the network in regulated amounts to ensure that the traffic fits within the promised traffic envelope for the particular connection. Traffic shaping decreases the “burstiness” of User Datagram Protocol (UDP) and TCP traffic, decreasing the load on network elements. The traffic shaping function on the Cisco Catalyst 3750 Metro Series allows for the configuration of the average rate at which the traffic is sent out of each queue. In addition to providing a smoother traffic flow, traffic shaping can also be used to control the maximum amount of bandwidth allowed for that queue.

Policing
Cisco Catalyst 3750 Metro Series switches support a two-rate, three color policer, providing advanced bandwidth management through rate limiting. The Cisco Catalyst 3750 Metro Series' policing function allows users to control the maximum rate of traffic received on each Enhanced Services port queue. This rate-limiting function is based on user-defined criteria; it marks packets by setting the CoS value, IP Precedence value, IP DSCP value, and MPLS experimental value.

With the two-rate policer, users can enforce traffic policing according to two separate rates—Committed Information Rate (CIR) and Peak Information Rate (PIR). The two-rate policer manages the maximum rate of traffic through the dual-token bucket algorithm, which uses user-configured values to determine the maximum rate of traffic allowed on a queue at a given moment.

The dual-token bucket algorithm provides users with three actions for each packet—a conform action, an exceed action, and an optional violate action. Traffic entering the queue with the two-rate policer configured is placed into one of these categories. Within these three categories, users can decide packet treatments. For instance, packets that conform can be configured to be sent, packets that exceed can be configured to be sent with a decreased priority, and packets that violate can be configured to be dropped.

In addition to rate limiting, the two-rate policer allows users to independently mark a packet according to whether the packet conforms, exceeds, or violates a specified rate. Networking devices within the network can then use this setting to determine how the traffic should be treated. For example, the WRED feature uses the IP Precedence value to determine the probability that a packet will be dropped.
**WRED**

RED is a congestion avoidance mechanism that takes advantage of TCP’s congestion control mechanism. By randomly dropping packets prior to periods of high congestion, RED tells the packet source to decrease its transmission rate. Assuming the packet source is using TCP, it will decrease its transmission rate until all the packets reach their destination, indicating that the congestion is cleared.

WRED on Cisco Catalyst 3750 Metro Series provides the ability to configure RED features selectively, based on IP Precedence or IP DSCP. Based on these two traffic markings, the user has the options to configure minimum threshold, maximum threshold, and mark probability.

When the average queue depth is above the minimum threshold, RED starts dropping packets. The rate of packet drop increases linearly as the average queue size increases, until the average queue size reaches the maximum threshold. When the average queue size is above the maximum threshold, all packets are dropped.

The mark probability denominator is the fraction of packets dropped when the average queue depth is at the maximum threshold. For example, if the denominator is 512, one out of every 512 packets is dropped when the average queue is at the maximum threshold.

**Order of Operation**

On Cisco Catalyst 3750 Metro Series Enhanced Services ports, all QoS functions can be enabled at the same time. This provides the flexibility to configure many types of QoS profiles. Depending on the order of the functions, the resulting profiles can be very different—it is important to understand the order of processing as the frames enter and leave the queues. The order of the main QoS functions is first—policing, then CBWFQ, then shaping. Figure 3 briefly describes the QoS stages that an Enhanced Services port goes through for each frame it receives from customer ports.
Cisco HQF Configuration

Cisco HQF is configured on the Cisco Catalyst 3750 Metro Series using Cisco Modular QoS CLI (MQC). Cisco MQC standardizes the command-line interface (CLI) and semantics for configuring QoS features. It provides standardized QoS provisioning across all Cisco IOS® Software platforms, and hides the underlying hardware architecture. Customers can thus upgrade to the next-generation Cisco platform and copy existing Cisco MQC QoS configurations, regardless of the deployment platforms. Cisco MQC also supports the concept of hierarchical policies to deliver an extremely powerful QoS solution.

Cisco MQC allows the configuration of QoS functions in the Cisco Catalyst 3750 Metro Series for traffic classification, modification, policing, queuing, and scheduling, which can be used at various levels in the hierarchy. The available commands under Cisco MQC are as follows:

- **Bandwidth**—Specify a minimum bandwidth allocation to a traffic class
- **Priority**—Specify that a traffic class requires low latency
- **Shape**—Specify a maximum rate for a traffic class
- **Police**—Specify a policer for the traffic class
- **Queue-Limit**—Tune the limit on queue depth for a traffic class
- **Random-Detect**—Enable WRED drop policy on a traffic class
- **Set**—Set CoS, DSCP, IP Precedence, and MPLS EXP bits in a traffic class
- **Match**—Match any, VLAN, inner VLAN, CoS, DSCP, IP Precedence, and MPLS EXP bits to classify traffic
- **Service-Policy**—Attach a service policy to either the physical interface or logical level
Not all these commands can be configured at all hierarchy levels. On the physical level, the commands available are **Police** and **Shape**. On the logical level, the commands available include **Bandwidth**, **Shape**, **Police**, and **Match** (any, VLAN, and inner VLAN). On the class level, the commands available are **Bandwidth**, **Priority**, **Shape**, **Police**, **Queue-Limit**, **Random-Detect**, **Match** (any, CoS, DSCP, IP Precedence, MPLS EXP), and **Set** (CoS, DSCP, IP Precedence, MPLS EXP). Modular QoS CLI configuration includes the following steps:

**Step 1.** Define a traffic class with the **class-map** command

**Step 2.** Create a traffic policy by associating the traffic class with one or more QoS features (using the **policy-map** command)

**Step 3.** Attach the traffic policy to the interface with the **service-policy** command

The **class-map** command is used to define a traffic class, which classifies traffic. A traffic class contains three major elements—a name, a series of **match** commands, and, if more than one **match** command exists in the traffic class, an instruction on how these **match** commands should be evaluated. The traffic class is named in the **class-map** command line; for example, if you enter the **class-map cisco** command while configuring the traffic class in the CLI, the traffic class would be named cisco.

The **match** commands are used to specify various criteria for classifying packets. Packets are checked to determine 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 forwarded according to the QoS specifications set in the traffic policy. Packets that fail to meet any of the matching criteria are classified as members of the default traffic class.

```c3750m(config)# class-map cisco
C3750M(config-cmap)# match ip precedence 1
```

The **policy-map** command is used to create a traffic policy, which configures the QoS features that should be associated with the traffic that has been classified in a user-specified traffic class or classes. A traffic policy contains three elements—a name, a traffic class (specified with the **class** command), and the QoS policies.

The name of a traffic policy is specified in the **policy-map** CLI (for example, issuing the **policy-map class1** command would create a traffic policy named class1). The traffic class that is used to classify traffic to the specified traffic policy is defined in policy map configuration mode, which is the automatic mode after naming the traffic policy. After choosing the traffic class that is used to classify traffic to the traffic policy, the user can enter the QoS features to apply to the classified traffic. This is done in policy-map class configuration mode.

```c3750m(config)# policy-map shape
C3750M(config-pmap)# class cisco
C3750M(config-pmap)# shape average 64000
```

Cisco MQC does not require that users associate only one traffic class to one traffic policy. When packets match to more than one match criterion, multiple traffic classes can be associated with a single traffic policy. The **service-policy** command is used to attach the traffic policy, as specified with the **policy-map** command, to an interface or a class to create hierarchy.

```c3750m(config)# policy-map parent
C3750M(config-pmap)# class cisco
C3750M(config-pmap)# service-policy child
```
On Cisco Catalyst 3750 Metro Series switches, the Cisco HQF can only be attached to the egress of ES ports. The `service-policy output class1` command would attach all the characteristics of the traffic policy named class1 to the specified interface. All packets leaving the specified interface are evaluated according to the criteria specified in the traffic policy named class1.

```
Router(config)# interface gi1/1/1
Router(config-if)# service-policy output class1
```

**Cisco HQF Configuration Guidelines**

**Bandwidth**

The following rules and methods are used while allocating bandwidth for the logical and class level classes.

- The shaper at the physical level restricts the bandwidth visible to the logical level classes; the shaper rate configured at the physical interface becomes the total bandwidth available to all the logical level classes.
- At all logical level classes, the shaper rate also becomes the visible bandwidth if the user for that class does not specify the bandwidth.
- At all logical and class level classes, the shaper rate must be greater than or equal to the bandwidth allocated at that level.
- The total bandwidth at the logical level classes, including the default class, cannot exceed the visible bandwidth at the physical level.
- The total bandwidth at the class level classes, including the default class, cannot exceed the visible bandwidth at the parent logical level.
- At the logical and class levels, the user-configured bandwidth is summed for all siblings. If the summed-up bandwidth is less than the parent visible bandwidth, remaining bandwidth is distributed equally among all the siblings.

**Priority**

- Priority queuing can only be configured at the class level
- For each logical level queue, one class priority queue can be configured
- Priority queuing on the Cisco Catalyst 3750 Metro Series is strict priority; no bandwidth or percent command is allowed

**Cisco HQF Application Examples**

**Ethernet to the Business—TLS with Differentiated Services**

Metro Ethernet Provider A is providing Transparent LAN Service (TLS) to two customers in a building. Both customers are connected to a Cisco Catalyst 3750 Metro Series switch in the basement. The provider wants to limit the uplink to 500 MB but to also provide both customers with their own QoS profiles.

**Customer A**

- SP ID = 10
- TLS bandwidth = 150 MB shaped, must be accessible by all classes
• Three levels of class:
  – Priority class: For voice, identified by IP Precedence = 5
  – VPN class: Regular data traffic, identified by IP Precedence = 3; 60 percent of bandwidth
  – Internet class: Internet traffic, identified by IP Precedence = 0; 20 percent of bandwidth

Customer B
• SP ID = 15
• TLS bandwidth = CIR: 75 MB, PIR: 100 MB; must be accessible by all classes
• Two VLANs:
  – VLAN 2
    – VPN class: IP DSCP = 32 in case of congestion; 70 percent of available bandwidth should be guaranteed for this class
    – Data class: IP DSCP = 8; 20 percent of available bandwidth should be guaranteed for this class
  – VLAN 100
    – Internet class: Should never exceed 10 MB
Configuration

class-map match-all custAvlan10
match vlan 10
---◊ identify Customer A

class-map match-all custAipprec5
match ip precedence 5
--◊ Customer A's priority traffic

class-map match-all custAipprec0
match ip precedence 0
--◊ Customer A's Internet traffic

class-map match-all custAipprec3
match ip precedence 3
--◊ Customer A's VPN traffic

class-map match-all custBvlan15
match vlan 15
match vlan inner 2
match vlan inner 100
--◊ identify Customer B

class-map match-all custBipdscp32
match ip dscp 32
---◊ Customer B's VPN traffic

class-map match-all custBipdscp8
match ip dscp 8
--◊ Customer B's data traffic

policy-map custAclasspolicy
class custAipprec5
priority
--◊ policy for Customer A's class queues

class custAipprec3
bandwidth percent 60
--◊ assign strict priority to this queue
random-detect
random-detect precedence 3 200 400 3000
class custAipprec0
  bandwidth percent 20
policy-map custBclasspolicy
  class custBipdscp32
    bandwidth percent 70
  class custBipdscp8
    bandwidth percent 20
  class class-default
    shape average 10000000
policy-map vlanpolicy
  class custAvlan10
    shape average 150000000
  service-policy custAclasspolicy
  class custBvlan15
  police cir 75000000 bc 8192 pir 100000000 be 8192
  service-policy custBclasspolicy
policy-map ES1
  class class-default
    shape average 500000000
  service-policy vlanpolicy
  interfaces gi1/1/1
  service-policy output ES1

--- policy for Customer B's class queues
--- logical level policy attaching class level policies
--- physical level policy attaching logical level policy
--- attach the HQF policy to the interface
Scalability Numbers

Table 1  Scalability Numbers

<table>
<thead>
<tr>
<th>Queues</th>
<th>8000</th>
</tr>
</thead>
<tbody>
<tr>
<td>Traffic shapers</td>
<td>8000</td>
</tr>
<tr>
<td>Policers</td>
<td>2000</td>
</tr>
<tr>
<td>Class-map</td>
<td>4000</td>
</tr>
<tr>
<td>Policy-map</td>
<td>2000</td>
</tr>
<tr>
<td>WRED</td>
<td>1000</td>
</tr>
</tbody>
</table>

Supported MIB

The Class-Based QoS MIB provides read access to QoS configurations. This MIB also provides QoS statistics information based on Cisco MQC, including information regarding class map and policy map parameters.

Summary

Cisco® Catalyst® 3750 Metro Series switches with the Hierarchical Queuing Framework features on the Enhanced Service ports is able to deliver traffic shaping, 2 rates 3 colors policers, and other advance QoS features on its 8000 queues. With the set of rich features and flexibility, the Service Providers will be able to offers differentiated services to multiple customers serviced by a Catalyst 3750 Metro Series switch. This will help Service Provider increase the revenues and receive higher profit margin from the Metro Ethernet Services.