Understanding QoS as Implemented in the Solution

This chapter presents a more detailed understanding of Quality of Service (QoS) as it is implemented in the solution, and presents the following topics:

- Introduction, page C-1
- DiffServ Classification, page C-3
- Class Selector Values, page C-3F
- Assured Forwarding, page C-4
- Express Forwarding, page C-4
- Default Class, page C-5
- DSCP-to-CoS Mapping, page C-5
- Queueing and Thresholds, page C-6
- 1-GE Asymmetric and 10-GE Symmetric Topologies: Known Threshold Parameters, page C-9

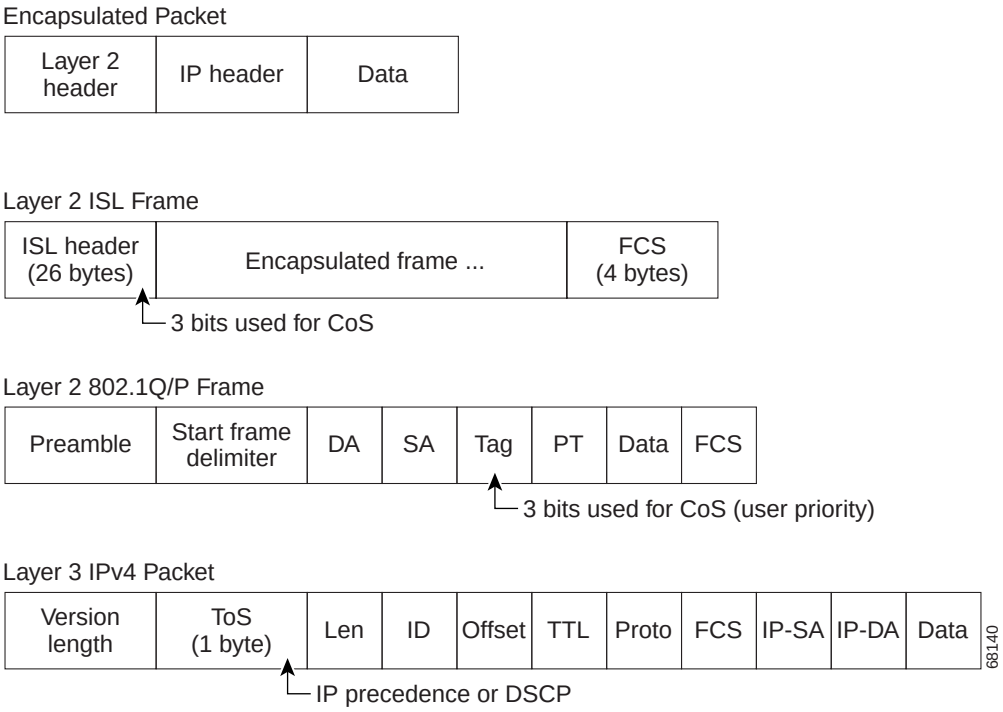
Note For the architectural design aspects of QoS, refer to QoS Architecture, page 3-46.

Introduction

Each packet that enters the network at the DER or AR is classified according to the service type. Classification is done through extended ACLs and a policy map that specifies the Differentiated Services Code Point (DSCP) value (0–63) to assign to the incoming packet. The noningress ports of the network are configured to trust the incoming Differentiated Services Code Point (DSCP) values.

On interfaces configured as Layer-2 IEEE 802.1q trunks, all traffic is encapsulated in 802.1q frames except for traffic that is in the native VLAN. The IEEE 802.1q frame headers have a 2-byte Tag Control Information field that carries the Class of Service (CoS) value (0–7) in the three most-significant bits, which are called the User Priority bits. Figure C-1 on page C-2 illustrates the Layer 2 and Layer 3 QoS fields.

Figure C-1 Layer 2 and Layer 3 QoS Fields



Different switch models handle DSCP differently In the Cisco 7600 series and Cisco Catalyst 6500 series switches, the DSCP values are mapped to CoS values. The CoS values are in turn mapped to different transmit queues in the egress interface, and thresholds are used for buffer management. In the Cisco Catalyst 4000, DSCP values are mapped to transmit queues in the egress interface. Weighted Round Robin (WRR) and Strict Priority (SP) is used to service the transmit queues.

Table C-1 summarizes the service types and their corresponding DSCP, Ethernet CoS, and ATM Class values as used in the solution.

Table C-1 Solution Service Types and Values

Service	DSCP	Ethernet CoS	ATM Class
Multicast video	AF41	4	VBR-rt (variable bit rate, real time)
Unicast video (50%)	AF42	2	
	AF43	1	
VoIP	EF	5	CBR (constant bit rate)
Signaling	CS3	3	VBR-rt
HSD	Default	0	UBR (unspecified bit rate)

DiffServ Classification

The six most-significant bits of the DiffServ field are the DSCP values. [The last two bits in the DiffServ field were not defined within the DiffServ field architecture, but were later specified as Explicit Congestion Notification (ECN) bits.] As illustrated in Table C-2, the DiffServ standard uses the three most-significant bits (DS5, DS4, DS3) for precedence bits, and offers finer granularity through the use of the next three bits.

Table C-2 DiffServ Bits and Values

Bit	0	1	2	3	4	5	6	7
Value	DS5	DS4	DS3	DS2	DS1	DS0	ECN	ECN

Four types of forwarding behavior are used: Class Selector (CS), Assured Forwarding (AF), Express Forwarding (EF), and Default.

Class Selector Values

Class Selector values have the format *xxx*000, where *x* is 0 or 1. These values enable backward compatibility with the older IP-Precedence scheme. For this solution, we recommend that VoIP or video signaling be marked with a Class of Service (CS) of 3. This class guarantees a minimum rate and has a DSCP value of 24 (0x011000). Table C-3 shows the class selector values for the DiffServ precedence levels.

Table C-3 Class Selector Values for DiffServ Precedence Levels

Class Selector Value	DiffServ Precedence Level and Description
0x111000 CS7 DSCP 56	Link layer and routing protocol keepalive
0x110000 CS6 DSCP 48	IP routing protocols
0x101000 CS5 DSCP 40	Express forwarding
0x100000 CS4 DSCP 32	Class 4
0x011000 CS3 DSCP 24	Class 3
0x010000 CS2 DSCP 16	Class 2

Table C-3 Class Selector Values for DiffServ Precedence Levels (continued)

Class Selector Value	DiffServ Precedence Level and Description
0x001000 CS1 DSCP 8	Class 1
0x000000 CS0 DSCP 0	Best effort

Assured Forwarding

Assured Forwarding (AF) provides for the delivery of IP packets in four independently forwarded AF classes. Within each AF class, an IP packet can be assigned one of three different levels of drop precedence. This class is used when a service (application) requires a high probability of packets being forwarded, so long as the aggregate traffic from each site does not exceed the subscribed information rate (profile). Each of the four AF classes allocates a certain amount of forwarding resources, such as buffer space and bandwidth in each network node. When congestion occurs, the drop precedence of a packet determines the relative importance of the packet within the AF class.

For this solution, we recommend that all video be marked as with Precedence Level 4 (known as the Assured Forwarding class), with three levels of granularity. Therefore, multicast video has the lowest allowed drops (AF41), and unicast video has the second lowest (AF42). Table C-4 illustrates the drop thresholds and values for the Assured Forwarding classes.

Table C-4 Drop Thresholds and Values for the Assured Forwarding Classes

Drop Threshold	Class 1	Class 2	Class 3	Class 4
Low	001010 AF11 DSCP 10	010010 AF21 DSCP 18	011010 AF31 DSCP 26	100010 AF41 DSCP 34
Medium	001100 AF12 DSCP 12	010100 AF22 DSCP 20	011100 AF32 DSCP 28	100100 AF42 DSCP 36
High	001110 AF13 DSCP 14	010110 AF23 DSCP 22	011110 AF33 DSCP 30	100110 AF43 DSCP 38

Express Forwarding

Express forwarding is a low-loss, low-latency, low-jitter, assured-bandwidth, end-to-end service. Expedited Forwarding (EF) is defined as within the range for express forwarding. The DSCP value for EF is 46 (0x101110). For this solution, we recommend that VoIP traffic be marked as EF.

Default Class

The Default class is a best-effort class with no guaranteed rates. The DSCP value for Default is 0 (0x000000). For this solution, we recommend that high-speed data (HSD) be marked as Default. Table C-5 summarizes the recommended DSCP markings for the various services.

Table C-5 Recommended DSCP Markings

Service	DSCP
Multicast video	AF41
Unicast video 1 (50%)	AF42
Unicast video 2 (50%)	AF43
VoIP	EF
Signaling	CS3
HSD	Default

DSCP-to-CoS Mapping

The DSCP values in the IP packets are mapped to a CoS field in the Ethernet frame. These tags form part of the IEEE 802.1q header. On the DSL links, the ATM classes and CoS values are associated with the different services. The different services should have the CoS values shown in Table C-6.

Table C-6 Solution DSCP-to-CoS Mappings

Service	DSCP	Ethernet CoS	ATM Class	ATM Priority
Multicast video	AF41 (34)	4	VBR-rt (variable bit rate, real time)	5
Unicast video (50%)	AF42 (36)	2		5
	AF43 (38)	1		5
VoIP	EF (46)	5	CBR (constant bit rate)	6
Signaling	CS3 (24)	3	VBR-rt	5
HSD	Default (0)	0	UBR (unspecified bit rate)	0

For Ethernet interfaces, the default DSCP-to-CoS mapping is used, as shown in Table C-7 on page C-6.

Table C-7 Default Ethernet DSCP-to-CoS Mappings

DSCP	Ethernet CoS
0–7	0
8–15	1
16–23	2
24–31	3
32–39	4
40–47	5
48–55	6
56–63	7

Queueing and Thresholds

Each port in the switch has a series of input and output queues that are used as temporary storage areas for data. The queues are implemented in hardware ASICs for each port by means of two types of queues: a special strict-priority (SP) queue, and weighted queues. The SP queues are used for latency-sensitive traffic such as VoIP and are serviced until they are empty. The weighted queues are serviced only when the SP queue is empty. If a weighted queue is being serviced and a frame arrives in the SP queue, the scheduling of frames from the lower queues stops in order to process the frame in the SP queue. Only when the SP queue is empty does the scheduling of packets from the lower queue(s) recommence. Frames are placed in the different queues according to the CoS field in the frame.

Weighted Round Robin (WRR) is the scheduling algorithm used to empty the transmit queues. For each queue a weighting is used to dictate how much data is emptied from the queue before moving onto the next queue.

The Cisco 7600 series and Cisco Catalyst 6000 series also have a means of ensuring that buffers do not overflow. Thresholds are defined in the queues at which the congestion management algorithm can start dropping data. Different CoS values in the same queue can be mapped to different thresholds. Once the buffers have been fully utilized, tail-drop buffer management is used to drop newly arriving frames.

Queueing Structures on Cisco 7600 Series and Cisco Catalyst 6000 Series Line Cards

Each line card on the Cisco 7600 series and the Cisco Catalyst 6000 series has a unique queuing structure, as discussed below.

- 1-GE Line Card (WS-X6816)

  This line card uses the queue structure 1P1Q4T on the receive side and 1P2Q2T on the transmit side. Each GE ASIC on the line card supports a total of 2 Mbytes of buffer space, which is equally divided among each of the four GE ports under the control of that ASIC. This means that each GE port supports 512 kbytes of buffering for both receive and transmit. The receive-side buffer holds 73 kbytes, and the transmit-side buffer holds 439 kbytes.

- 1-GE Line Cards (WS-X6724, WS-X6748)

These line cards use the queue structure 1Q8T on the receive side and 1P3Q8T on the transmit side. When a DFC3a is used, two receive queues are available, the new one being a SP queue. Each GE port supports 1.3 Mbytes of buffer space. The receive-side buffer holds 166 kbytes, and the transmit-side buffer holds 1.2 Mbytes.

- 10-GE Line Card (WS-X6704-10GE)

  This line card uses the queue structure 8Q8T on the receive side and 1P7Q8T on the transmit side. An SP queue is supported on the transmit side only. Each 10-GE port supports 16 Mbytes. The receive-side buffer holds 2 Mbytes, and the transmit-side buffer holds 14 Mbytes.

Queueing Structures on Cisco Catalyst 4000 Series Line Cards and Ports

Unlike the Cisco 7600 series and the Cisco Catalyst 6500 series, the Cisco Catalyst 4000 series line cards share the same queuing structure. The only difference is in the queue sizes for the 1-GE and 10-GE ports.

- 1-GE Line Card (WS-X4306-GB)

  This line card has one receive queue and four transmit queues. One transmit queue can be configured as an SP queue. Each transmit queues holds 1920 packets.

- 10-GE Ports (WS-X4315-GB)

This SupV with 10-GE ports has one receive queue and four transmit queues. One transmit queue can be configured as an SP queue. Each transmit queue holds 2080 packets.

We recommend using three transmit queues for the six types of traffic on the network. In the lowest-priority queue, HSD should be carried. In the middle priority queue, VoD signaling, VoD high priority, VoD low priority, broadcast video, and network signaling should be carried. In the strict priority queue, VoIP should be carried. For more information about the DSCP and CoS values used in the solution, see DSCP-to-CoS Mapping, page C-5.

The amount of buffering the network queuing provides for average video traffic is calculated below.

10-GE Symmetric Topology: Known and Unknown Queue Parameters

For the symmetric topology, 10-GE links are used in the transport. The amount of video traffic in the 10-GE transport approaches 7 Gbps. On the Cisco 7600 series and the Cisco Catalyst 6500 series, the transmit queue (TxQueue) for video is configured for 7 Mbytes. On the Cisco Catalyst 4500 series, the transmit queue for video is configured for approximately 3.2 Mbytes. Known and unknown queue parameters for the 10-GE symmetric topology are listed below.

Known Parameters	Value
link_speed	10,000,000,000 bits/sec
video_queue_size_Cat6k	7,000,000 bytes
	(56,000,000 bits)
video_queue_size_Cat4k	3,200,000 bytes
	(25,600,000 bits)
video_link_utilization	70%

Unknown Parameters	Value
avg_buffering	? sec
video_queue_size_Cat6k	*link_speed * avg_buffering * video_link_utilization*
avg_buffering_Cat6k	*(link_speed * video_link_utilization)/ video_queue_size_Cat6k*
	(10,000,000,000 bits/sec * 0.70)/56,000,000 bits
	= 1/125 sec
	= **8 msec**
avg_buffering_Cat4k	*(link_speed * video_link_utilization)/ video_queue_size_Cat4k*
	(10,000,000,000 bits/sec * 0.70)/25,600,000 bits
	= 1/274 sec
	= **~4 msec** (3.65)

1-GE Asymmetric Topology: Known and Unknown Queue Parameters

For the asymmetric topology, 1-GE links are used in the transport. The maximum amount of video traffic on any of the bidirectional links is approximately 700 Mbps. The amount of video traffic on the unidirectional links approaches 700 Mbps. Known and unknown queue parameters for the 1-GE asymmetric topology are listed below.

Known Parameters	Value
link_speed	1,000,000,000 bits/sec
video_queue_size_Cat6k	256,000 bytes
	(2,048,000 bits)
video_queue_size_Cat4k	2,972,160 bytes
	(~24,000,000 bits)
video_link_utilization	70%

Unknown Parameters	Value
avg_buffering	? sec
video_queue_size_1GE	*link_speed * avg_buffering * video_link_utilization*
avg_buffering_Cat6k	*(link_speed * video_link_utilization)/ video_queue_size_Cat6k*
	(1,000,000,000 bits/sec * 0.70)/2,048,000 bits
	= 1/342 sec
	= ~**3 msec**

Unknown Parameters	Value
avg_buffering_Cat4k	*(link_speed * video_link_utilization)/ video_queue_size_Cat4k*
	(1,000,000,000 bits/sec * 0.70)/24,000,000 bits
	= 1/3428 sec
	= **~30 msec**

1-GE Asymmetric and 10-GE Symmetric Topologies: Known Threshold Parameters

For the 10-GE links, the following thresholds should be configured on the transmit queue that holds broadcast video, VoD, VoD signaling, and network signaling. These thresholds should be configured for tail drop.

For the Cisco 7600 series and Cisco Catalyst 6500 series that have thresholds in the queues, we recommend that two thresholds be used in the middle-priority queue to drop VoD low-priority and VoD high-priority traffic before dropping broadcast video traffic. For the 10-GE links, the following two thresholds should be configured on the transmit queue that holds broadcast video, VoD low, VoD high, VoD signaling, and network signaling. These thresholds should be configured for tail drop.

Known Parameters (10 GE)

Parameter	Value
link_speed	10,000,000,000 bits/sec
avg_buffering	8 msec
VoD_low_link_utilization	45%
VoD_high_link_utilization	85%
VoD_low_threshold	*link_speed * avg_buffer * VoD_low_link_utilization*
	= 10,000,000,000 bits/sec * 0.008 sec * 45%
	= 36,000,000 bits
	= **4,500,000 bytes**
VoD_high_threshold	*link_speed * avg_buffer * (VoD_low_link_utilization + VoD_high_link_utilization)*
	= 10,000,000,000 bits/sec * 0.008 sec * 85%
	= 68,000,000 bits
	= **8,500,000 bytes**

For the 1-GE links, broadcast video is separated from the VoD traffic, so two thresholds should be configured on the transmit queue of the unidirectional links that hold VoD low, VoD high, VoD signaling, and network signaling.

VoD_low_threshold = **50%**

VoD_high_threshold = **100%**

These thresholds should be configured for tail drop.

Two types of queue management are used for HSD. On the Cisco 7600 series and the Cisco Catalyst 6500 series, Weighted Random Early Drop (WRED) should be configured between 75% and 100% queue utilization. On the Catalyst 4500 series, tail drop should be configured at 100%.

For VoIP, tail drop at 100% utilization should be configured on all three types of switches.

The following figures show the queue size, CoS-to-TxQueue mapping, queue thresholds, and WRR for the 10-GE symmetric and 1-GE asymmetric topologies with the following line cards:

- WS-X6704-10GE (Figure C-2 on page C-10)
- WS-X4513-10GE (Figure C-3 on page C-10)
- WS-X6816 (Figure C-4 on page C-11)
- WS-X4306-GB (Figure C-5 on page C-11)

Figure C-2 WS-X6704-10GE Queueing Structure (10-GE Symmetric)

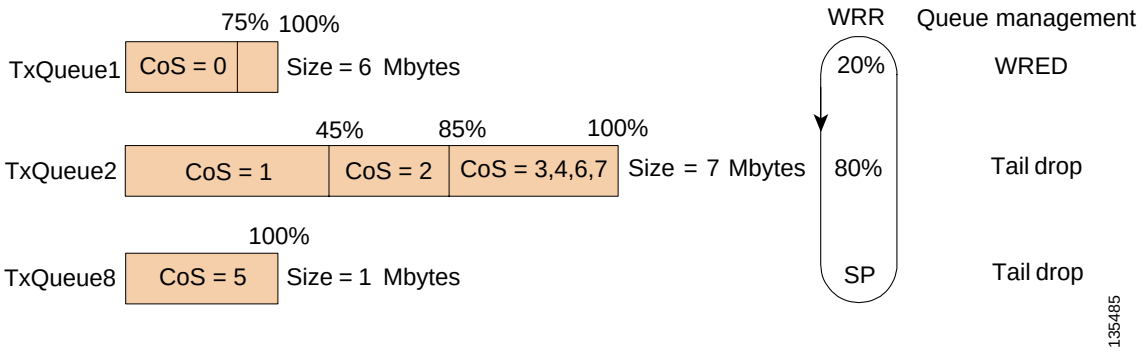


Figure C-3 WS-X4513-10GE Queueing Structure (10-GE Symmetric)

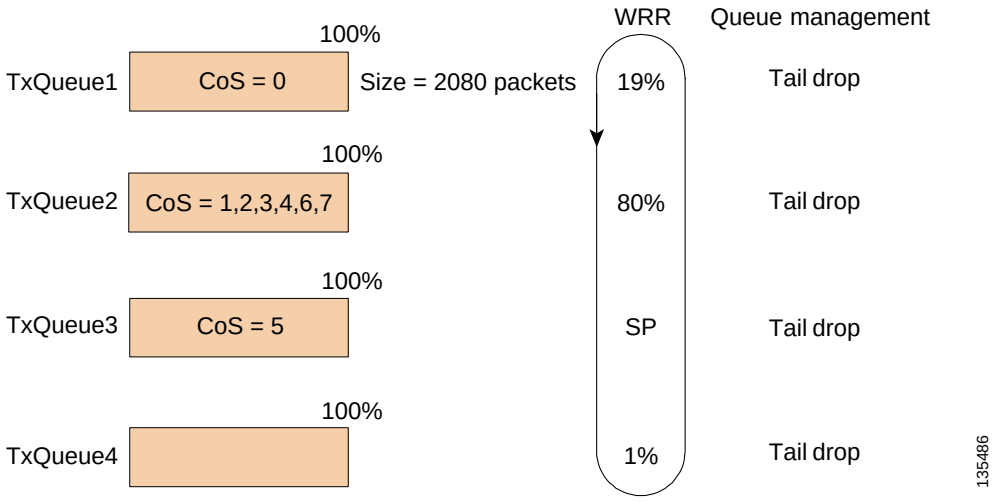
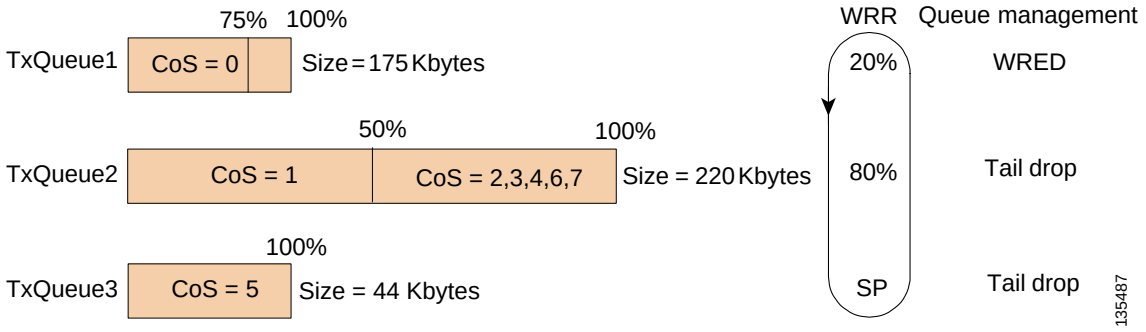


Figure C-4 WS-X6816 Queueing Structure (1-GE Asymmetric)



Note Because VoIP, HSD, broadcast video, and VoD signaling are carried on bidirectional links only, no VoD traffic populates TxQueue 2 on the bidirectional links. Because VoD traffic is carried on the unidirectional links only, no VoIP or HSD traffic populates TxQueue 2 on the unidirectional links.

Figure C-5 WS-X4306-GB Queueing Structure (1-GE Asymmetric)

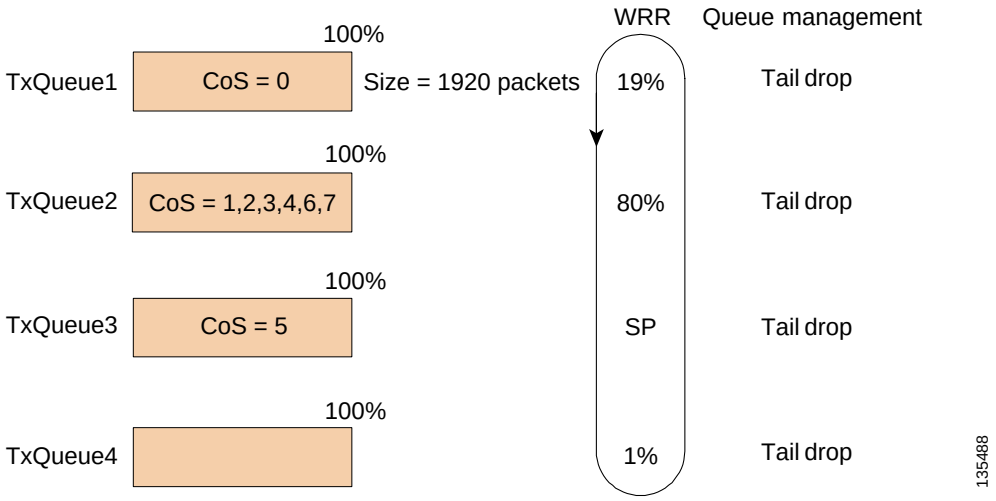


Table C-8 on page C-11 shows the queueing and thresholds used in the solution for a Cisco Catalyst 6000 series. The thresholds for the Cisco Catalyst 4000 series are the same as the queue length.

Table C-8 Solution Queueing and Thresholds for a Cisco Catalyst 6000 Series

Service	Transmit Queue/Percent	Threshold for 1 GE, kB	Threshold for 10 GE, MB
HSD	TxQueue 1/20	~132	4.5

Table C-8 Solution Queueing and Thresholds for a Cisco Catalyst 6000 Series

Service	Transmit Queue/Percent	Threshold for 1 GE, kB	Threshold for 10 GE, MB
Multicast video	TxQueue 2/80	220	7
VoD high		220	~6
VoD low		110	3.15
Signaling		220	7
VoIP	TxQueue 3/SP[1]	44	1

1. Strict priority