Quality of Service • Part 1

Quality of Service Models

**Best Effort**
- No QoS policies are implemented

**Integrated Services (IntServ)**
- Resource Reservation Protocol (RSVP) is used to reserve bandwidth per-flow across all nodes in a path

**Differentiated Services (DiffServ)**
- Packets are individually classified and marked; policy decisions are made independently by each node in a path

Layer 2 QoS Markings

<table>
<thead>
<tr>
<th>Medium</th>
<th>Name</th>
<th>Type</th>
</tr>
</thead>
<tbody>
<tr>
<td>Ethernet</td>
<td>Class of Service (CoS)</td>
<td>3-bit 802.1p field in 802.1Q header</td>
</tr>
<tr>
<td>Frame Relay</td>
<td>Discard Eligibility (DE)</td>
<td>1-bit drop eligibility flag</td>
</tr>
<tr>
<td>ATM</td>
<td>Cell Loss Priority (CLP)</td>
<td>1-bit drop eligibility flag</td>
</tr>
<tr>
<td>MPLS</td>
<td>Traffic Class (TC)</td>
<td>3-bit field compatible with 802.1p</td>
</tr>
</tbody>
</table>

IP QoS Markings

**IP Precedence**
- The first three bits of the IP TOS field; limited to 8 traffic classes

**Differentiated Services Code Point (DSCP)**
- The first six bits of the IP TOS are evaluated to provide more granular classification; backward-compatible with IP Precedence

QoS Flowchart

<table>
<thead>
<tr>
<th>DSCP Per-Hop Behaviors</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Class Selector (CS)</strong></td>
</tr>
<tr>
<td>Backward-compatible with IP Precedence values</td>
</tr>
<tr>
<td><strong>Assured Forwarding (AF)</strong></td>
</tr>
<tr>
<td>Four classes with variable drop preferences</td>
</tr>
<tr>
<td><strong>Expedited Forwarding (EF)</strong></td>
</tr>
<tr>
<td>Priority queuing for delay-sensitive traffic</td>
</tr>
</tbody>
</table>

Terminology

**Per-Hop Behavior (PHB)**
- The individual QoS action performed at each independent DiffServ node

**Trust Boundary**
- Beyond this, inbound QoS markings are not trusted

**Tail Drop**
- Occurs when a packet is dropped because a queue is full

**Policing**
- Imposes an artificial ceiling on the amount of bandwidth that may be consumed; traffic exceeding the policer rate is reclassified or dropped

**Shaping**
- Similar to policing but buffers excess traffic for delayed transmission; makes more efficient use of bandwidth but introduces a delay

**TCP Synchronization**
- Flows adjust TCP window sizes in synch, making inefficient use of a link

**DSCP Per-Hop Behaviors**
- **Class Selector (CS)**
  - Backward-compatible with IP Precedence values
- **Assured Forwarding (AF)**
  - Four classes with variable drop preferences
- **Expedited Forwarding (EF)**
  - Priority queuing for delay-sensitive traffic

**Congestion Avoidance**

**Random Early Detection (RED)**
- Packets are randomly dropped before a queue is full to prevent tail drop; mitigates TCP synchronization

**Weighted RED (WRED)**
- RED with the added capability of recognizing prioritized traffic based on its marking

**Class-Based WRED (CBWRED)**
- WRED employed inside a class-based WFQ (CBWFQ) queue
# Quality of Service · Part 2

## Queuing Comparison

<table>
<thead>
<tr>
<th></th>
<th>FIFO</th>
<th>PQ</th>
<th>CQ</th>
<th>WFQ</th>
<th>CBWFQ</th>
<th>LLQ</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Default on Interfaces</strong></td>
<td>&gt;2 Mbps</td>
<td>No</td>
<td>No</td>
<td>&lt;=2 Mbps</td>
<td>No</td>
<td>No</td>
</tr>
<tr>
<td><strong>Number of Queues</strong></td>
<td>1</td>
<td>4</td>
<td>Configured</td>
<td>Dynamic</td>
<td>Configured</td>
<td>Configured</td>
</tr>
<tr>
<td><strong>Configurable Classes</strong></td>
<td>No</td>
<td>Yes</td>
<td>Yes</td>
<td>No</td>
<td>Yes</td>
<td>Yes</td>
</tr>
<tr>
<td><strong>Bandwidth Allocation</strong></td>
<td>Automatic</td>
<td>Automatic</td>
<td>Configured</td>
<td>Automatic</td>
<td>Configured</td>
<td>Configured</td>
</tr>
<tr>
<td><strong>Provides for Minimal Delay</strong></td>
<td>No</td>
<td>Yes</td>
<td>No</td>
<td>No</td>
<td>No</td>
<td>Yes</td>
</tr>
<tr>
<td><strong>Modern Implementation</strong></td>
<td>Yes</td>
<td>No</td>
<td>No</td>
<td>No</td>
<td>No</td>
<td>Yes</td>
</tr>
</tbody>
</table>

### First In First Out (FIFO)

- Packets are transmitted in the order they are processed
- No prioritization is provided
- Default queuing method on high-speed (>2 Mbps) interfaces
- Configurable with the `tx-ring-limit` interface config command

### Custom Queuing (CQ)

<table>
<thead>
<tr>
<th>Queue</th>
<th>Rate</th>
</tr>
</thead>
<tbody>
<tr>
<td>A</td>
<td>500 B/cycle</td>
</tr>
<tr>
<td>B</td>
<td>4500 B/cycle</td>
</tr>
<tr>
<td>C</td>
<td>1500 B/cycle</td>
</tr>
</tbody>
</table>

- Rotates through queues using Weighted Round Robin (WRR)
- Processes a configurable number of bytes from each queue per turn
- Prevents queue starvation but does not provide for delay-sensitive traffic

### Class-Based WFQ (CBWFQ)

<table>
<thead>
<tr>
<th>Queue</th>
<th>Min Rate</th>
<th>Max Rate</th>
</tr>
</thead>
<tbody>
<tr>
<td>A</td>
<td>512 Kbps</td>
<td>512 Kbps</td>
</tr>
<tr>
<td>B</td>
<td>1024 Kbps</td>
<td>1024 Kbps</td>
</tr>
<tr>
<td>Default</td>
<td>Remainder</td>
<td>Remainder</td>
</tr>
</tbody>
</table>

- WFQ with administratively configured queues
- Each queue is allocated an amount/percentage of bandwidth
- No support for delay-sensitive traffic

### Priority Queuing (PQ)

- Provides four static queues which cannot be reconfigured
- Higher-priority queues are always emptied before lower-priority queues
- Lower-priority queues are at risk of bandwidth starvation

### Weighted Fair Queuing (WFQ)

- Queues are dynamically created per flow to ensure fair processing
- Statistically drops packets from aggressive flows more often
- No support for delay-sensitive traffic

### Low Latency Queuing (LLQ)

- CBWFQ with the addition of a policed strict-priority queue
- Highly configurable while still supporting delay-sensitive traffic

### LLQ Config Example

```plaintext
Class Definitions
! Match packets by DSCP value
class-map match-all Voice
match dscp ef
! class-map match-all Call-Signaling
match dscp cs3
! class-map match-any Critical-Apps
match dscp af21 af22
! Match packets by access list
class-map match-match Scavenger
match access-group name Other

Policy Creation
! Priority queue policed to 33% priority percent 33
class Voice
! Allocate 5% of bandwidth
class Call-Signaling
bandwidth percent 5
! Extend queue size to 96 packets
class Critical-Apps
queue-limit 96
class Scavenger
! Police to 64 kbps
police cir 64000
! Enable WFQ
fair-queue
! Enable WRED
random-detector

Policy Application
! Apply the policy in or out
service-policy output Foo

LLQ Config Example
show policy-map [interface]
show interface
show queue <interface>
Show mls qos
```