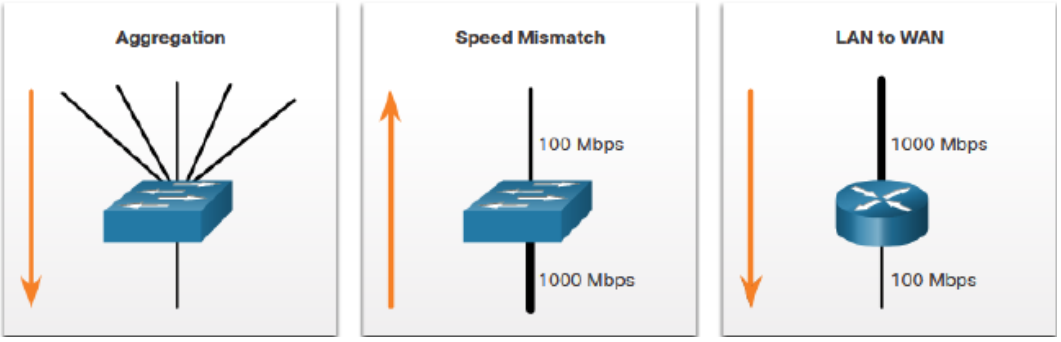
Quality of Service (QoS)

- **Recall concepts:**
  - **Throughput:** actual bit rate of the channel
  - **Bandwidth:** maximum throughput (max bit rate a data channel can handle)
  - **Latency:** delay the data experiences when it travels from one point to another.
    - **End-to-End delay:** results from the accumulation of individual delays (transmission, queuing, processing, and propagation)
    - **Round-Trip Time (RTT):** time taken for a data packet to travel from one host to another and back (ping).
  - **Jitter:** the variance (fluctuations) in end-to-end delay
- **Problem:**
  - When traffic volume is large (congestion), devices queue packets and this causes delay.
  - Packets are dropped (packet loss) as buffers fill up, causing reduced throughput, increased latency, and jitter.
  - Typical congestion points: aggregation, speed mismatch, and LAN to WAN links.

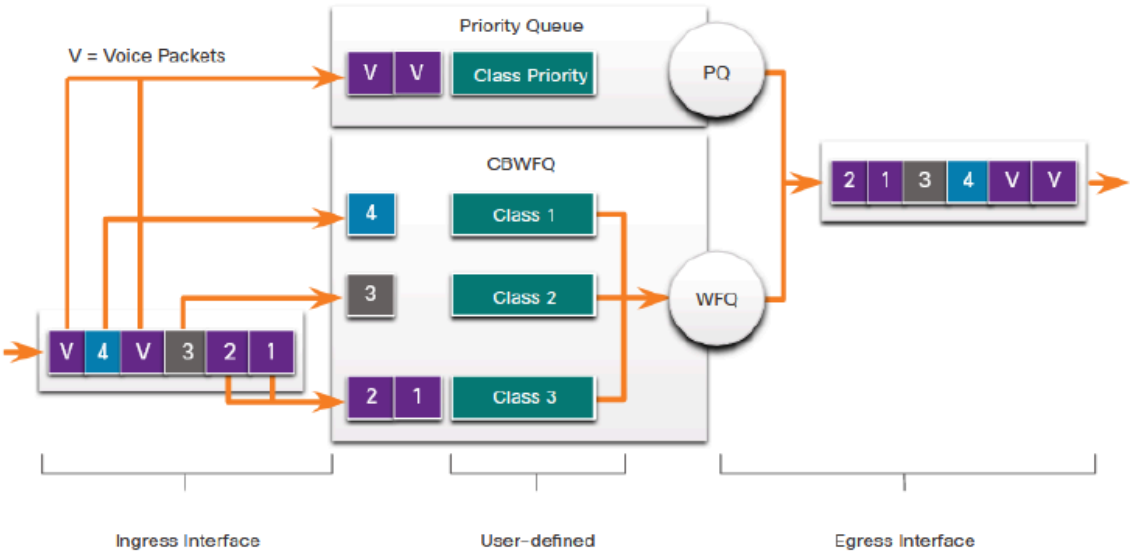


- **Quality of Service (QoS)**
  - Techniques to mitigate congestion by classifying traffic into multiple queues based on their criticality/importance.
  - By 2022, voice and video represented 82% of Internet traffic.
  - Real-Time Protocol (RTP) used for voice traffic and Real-Time Streaming Protocol (RSTP) used for video traffic.
  - Voice and Video traffic tolerate latency, loss, and jitter to some extent, unlike other data (e.g., files or emails).
  - QoS can buffer, prioritize, or reorder packets before transmission/forwarding.
- **Queuing algorithms**
  - **First-In First-Out (FIFO):** one queue that buffers packets in arrival order.
  - **Weighted Fair Queue (WFQ)**
    - Identifies traffic priority (e.g., high, med, low) and divide bandwidth based on weights

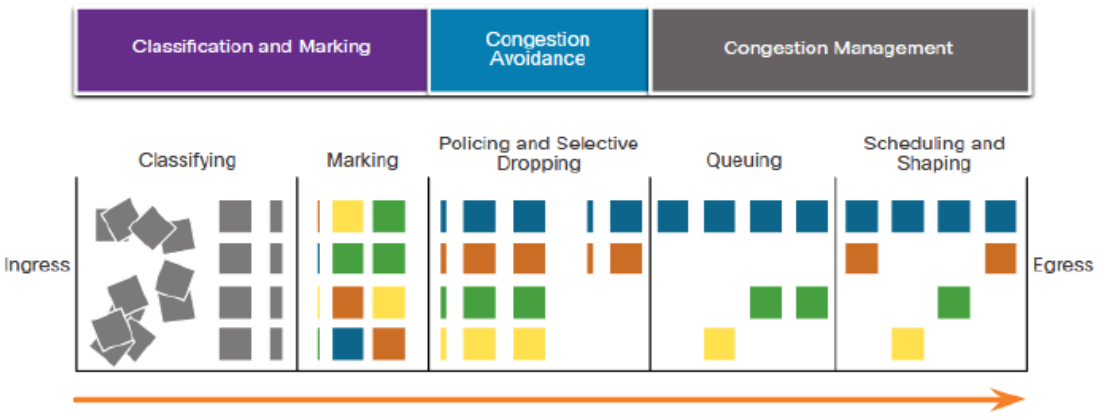
      In WFQ, a scheduler handling N flows is configured with one weight w_i for each flow. Then, the flow of number i will achieve an average data rate of $\frac{w_i}{(w_1 + w_2 + \ldots + w_N)} R$, where R is the link rate. A WFQ scheduler where all weights are equal is a FQ scheduler.

    - Not supported with tunneling and encryption

- **Class-Based Weighted Fair Queuing (CBWFQ)**
  - Extends WFQ with user-defined classes.
  - FIFO queue for each class
  - Defined parameters for each class (e.g., guaranteed bandwidth, packet limits)
- **Low Latency Queuing (LLQ)**
  - Extends CBWFQ with priority classes (e.g., special PQ for voice traffic)



- **QoS Policy Models**
  - **Best-Effort model:** no deliver guarantees, used when QoS is not configured.
  - **Integrated Services (IntServ):** highest QoS guarantee, very resource intensive, and not easily scalable.
    - App requests specific kind of service before sending data.
    - Uses Resource Reservation Protocol (RSVP) to signal the need for resources, if it cannot be reserved. The application does not send data.
    - End-to-end approach with stateful nature.
  - **Differentiated Service (DiffServ):** flexible, less resource-intensive and more scalable
    - Router classifies traffic and uses appropriate QoS mechanisms based on the class.
    - Hop-by-hop basis, stateless nature.
- **QoS Tools**



  - **Classification and Marking:**

        - Sessions or flows are analyzed to determine class and mark packets based on that.
        - Classifying and marking at layer 2-3 uses ACLs and Class Maps. At layer 4-7 use Network-Based Application Recognition (NBAR).
            - Marking at layer 2 through 802.1Q VLAN header priority bits (3-bit: 8 levels).
            - Marking at layer 3: IPv4 Type of Service (ToS) and IPv6 Traffic Class.
                - The IPv4 header contained an 8-bit field using for QoS
                    - Historically, it contained "IP precedence" value and related fields.
                    - Currently, it contains two (6+2 bit) fields: Differentiated Services Code Point (DSCP) and Explicit Congestion Notification (ECN).
                - DSCP: first 3 bits map directly to layer-2 priority field.
                    - Default Forwarding (DF): DSCP=0
                    - Expedited Forwarding (EF): recommended for voice. DSCP=46
                    - Assured Forwarding (AF): classes from 1 (worst) to 4 (best)

Assured Forwarding behavior group

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

    - **Congestion avoidance:**
        - Selectively choose traffic to be dropped, delayed, or re-marked to avoid congestion.
        - Primary tool is Weighted Random Early Detection (WRED) used to regulate traffic (e.g., by dropping low-priority packets) before queue buffer happens.
    - **Congestion management** use queuing and shaping mechanisms to handle the cases when congestion occur.
- **Traffic Shaping and Traffic Policing**
    - Two mechanisms provided by QoS software to prevent congestion
    - **Shaping** is applied to outbound traffic to queue excess packets for later controlled transmission, resulting in a smooth output rate.

    - **Policing** is applied to inbound traffic to enforce a certain traffic contract (e.g., max bandwidth limitation). Providers may allow bursting over limits if the network is not currently congested.

- **QoS Policy Guidelines:**
  - Enable queuing at every device in the path between source and destination.
  - Classify and mark traffic as close the source as possible.
  - Shape and police traffic flows as close to their sources as possible.