Quality of Service

- How “good” are late data and low-throughput channels?
- It depends on the application. Do you care if...
  - Your e-mail takes 1/2 hour to reach your friend?
  - You have to spend 1/2 hour to make a cheaper plane reservation on the Web?
  - Your call to 911 takes 1/2 hour to go through your nifty new IP phone service?
Application Requirements

- Internet currently provides one single class of “best-effort” service
  - No assurances about delivery
- High speed networks have enabled new applications
  - Require “deliver on time” assurances from the network
  - Real-time applications
    - Sensitive to the timeliness of their data
    - Voice
    - Video
    - Industrial control
Timely Delivery

- How to achieve timely delivery
  - When actual RTT small (< 2/3) relative to acceptable delay
    - Retransmit
  - When base RTT (no queuing delay) large (> 2) relative to acceptable delay
    - Impossible
  - Otherwise possible, but not through retransmission
Timely Delivery

- Within the 48-state U.S
  - Base RTT (no queueing delay) peaks around 75 msec
  - Actual RTT is often 10-100 msec

- Humans notice about 50 msec delay for voice
  - Use erasure codes across packets, or
  - Support delay preferences in the network; called quality of service, or QoS
Real-time Applications

- Two types or applications
  - Hard real-time
  - Elastic (soft real-time)

- Example real-time application requirements - audio
  - Sample voice once every 125μs
  - Each packet has a playback time
  - Packets experience variable delay in network
  - Add constant factor to playback time – playback point
Real-Time Applications

- Playback Buffer

![Diagram showing playback buffer with timeline, sequence number, packet generation, network delay, buffer, packet arrival, and playback axes.](image-url)
Delay Distribution

What is a good delay?

Packets (%)

Delay (milliseconds)

90% 97% 98% 99%
Quality of Service Approaches

- Approach: Admission control
  - Flow tells the network what it wants
  - Network decides if flow can be admitted

- Fine-grained
  - Provide QoS to individual applications or flows
  - Example: Resource Reservation Protocol (RSVP)

- Coarse-grained
  - Provide QoS to large classes of data or aggregated flows
    - Example: Differentiated Services (DIFFSERV)
Mechanisms

- Flow specification
  - Tell the network what the flow wants

- Admission control
  - Network decides if it can handle flow

- Reservation
  - Enable admission control

- Packet classification
  - Map packets to flows

- Scheduling
  - Forwarding policy
Characterizing a Flow

- Describe flow’s traffic characterization
  - Average bandwidth + burstiness: token bucket filter
  - Token rate: \( r \)
  - Bucket depth: \( B \)

- Use
  - Must have a token to send a byte
  - Must have \( n \) tokens to send \( n \) bytes
  - Start with no tokens
  - Accumulate tokens at rate of \( r \) per second
  - Can accumulate no more than \( B \) tokens
Token Bucket Filters

Each byte needs a token in order to pass

- Dropping Filter: drops packets if token is not available
- Buffered Filter: buffers data until tokens become available
Token Bucket Operation

- **Tokens**:
  - **Overflow**: Buffer tokens up to capacity of bucket
  - **Packet**: Enough tokens → packet goes through, tokens removed
  - **Packet**: Not enough tokens → wait for tokens to accumulate

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Token Bucket Filters

Question

- Given a finite length data stream, will it be affected by a token bucket filter?

Not if during every time interval, the number of bytes is less than or equal to $B + rt$, where $t$ is the length of the interval.

- Given a token rate $r$ and a finite data trace, how can the minimum token bucket size $B$ be found such that the filter has no effect?
Token Bucket Filters

- Given a token rate $r$ and a finite data trace, how can the minimum token bucket size $B$ be found such that the filter has no effect?

  - Simply observe the maximum buffer size
    - Why?
    - If the buffer is truncated to size $B$, then the number of empty buffer positions is equivalent to the number of tokens in an $(r,B)$ token bucket filter
Token Bucket Filters

- The number of empty buffer positions for buffer size \( B \) and a constant rate server is equivalent to the number of tokens in an \((r, B)\) token bucket filter.
Token Bucket Filters

- $r = 15$ kbps

What is the minimum size of $B$ required so that the filter lets the stream pass with no loss or delay?
Token Bucket Filters

- $r = 15$ kbps

- $\text{Min B} = (40 - 15) \times 20 + (50 - 15) \times 10 - (15 - 10) \times 20 + (20 - 15) \times 40 = 950$ bits
Token Bucket Filters

What is the minimum $B$ needed for arbitrary $r > 0$

- If $r \geq 50$
  \[ B = 0 \]
- If $50 > r \geq 40$
  \[ \text{Min } B = (50 - r) \times 10 \]
- If $40 > r \geq 20$
  \[ \text{Min } B = (40 - r) \times 20 + (50 - r) \times 10 \]
- If $20 > r \geq 10$
  \[ \text{Min } B = (40 - r) \times 20 + (50 - r) \times 10 - (r - 10) \times 20 + (20 - r) \times 40 \]
- If $10 > r \geq 0$
  \[ \text{Min } B = (40 - r) \times 20 + (50 - r) \times 10 + (10 - r) \times 20 + (20 - r) \times 40 \]
Differentiated Services

- **Goal**
  - Scalability through the use of only a small number of service classes
    - Two classes
      - Regular and premium (i.e. first class and bulk mail)
    - Diffserv
      - Proposes 6 bits of IP ToS field (26 = 64 classes)

- **Questions**
  - Who is allowed to set the premium bit?
    - Typically an ISP
  - Should we allow an individual customer or application?
  - How do routers react to such a classification?
    - IETF has specified per-hop behavior
Differentiated Services

- Expedited forwarding
  - Per-hop behavior
  - Need to strictly limit the load of traffic receiving expedited forwarding
    - Give strict priority
    - Use weighted fair queueing (WFQ) and assign sufficiently large weights for traffic receiving expedited forwarding
Differentiated Services

- Assured forwarding
  - Per-hop behavior
  - Like RED but with “in” and “out” packets (RIO)
  - Does not reorder packets
  - For more than two classes of traffic, use weighted RED

- Profile meters at the edges of ISP networks could mark packets as “in” or “out”