



# Quality of Service

# [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



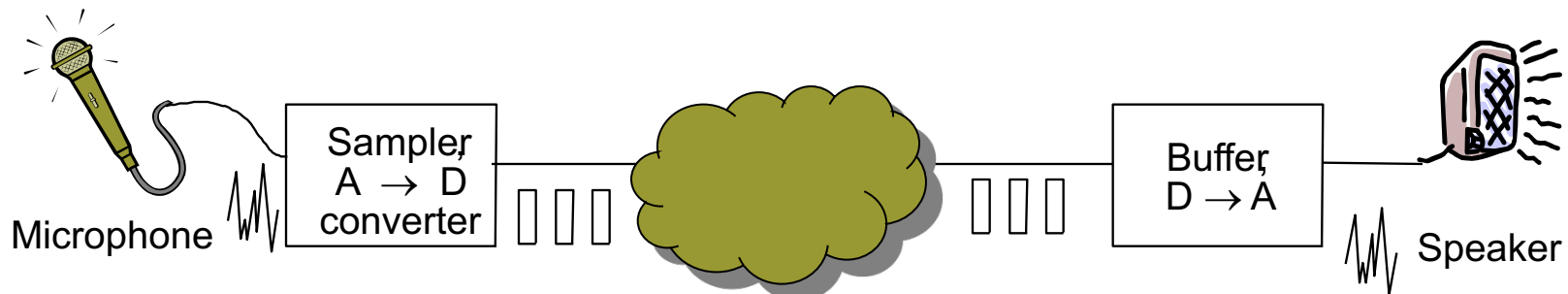
# [ Timely Delivery ]

- 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



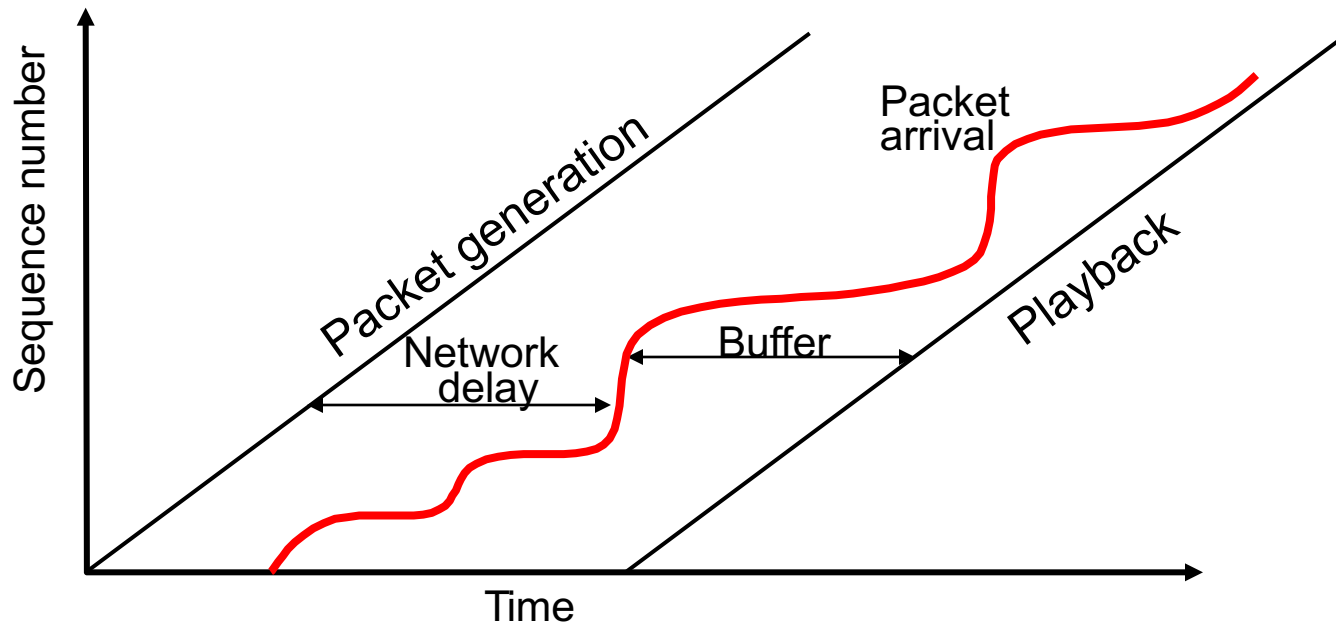
# Real-time Applications

- Two types of applications
  - Hard real-time
  - Elastic (soft real-time)
- Example real-time application requirements - audio
  - Sample voice once every  $125\mu\text{s}$
  - Each packet has a playback time
  - Packets experience variable delay in network
  - Add constant factor to playback time – playback point



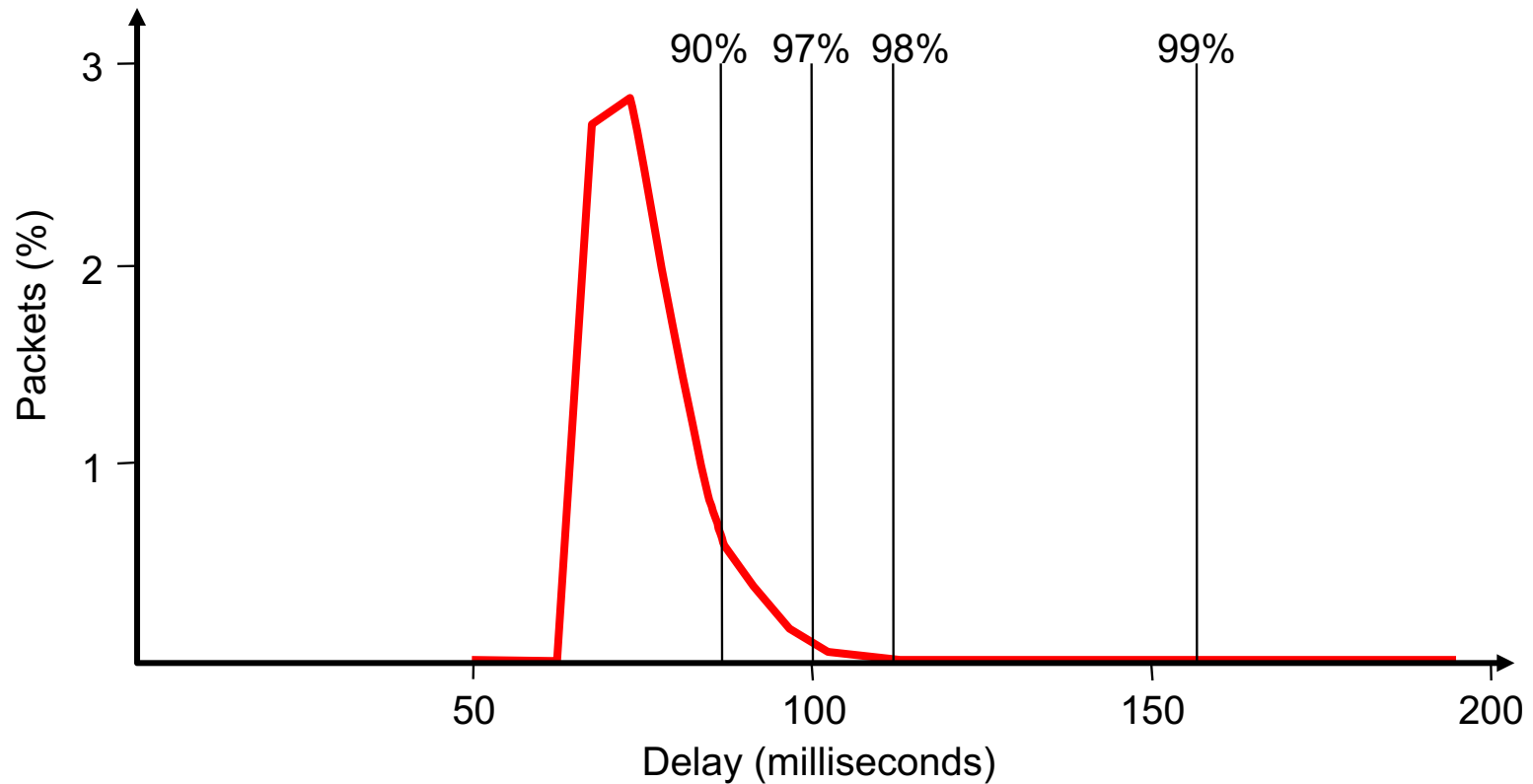
# [ Real-Time Applications ]

## ■ Playback Buffer



# Delay Distribution

What is a good delay?





# [ 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:  $B$

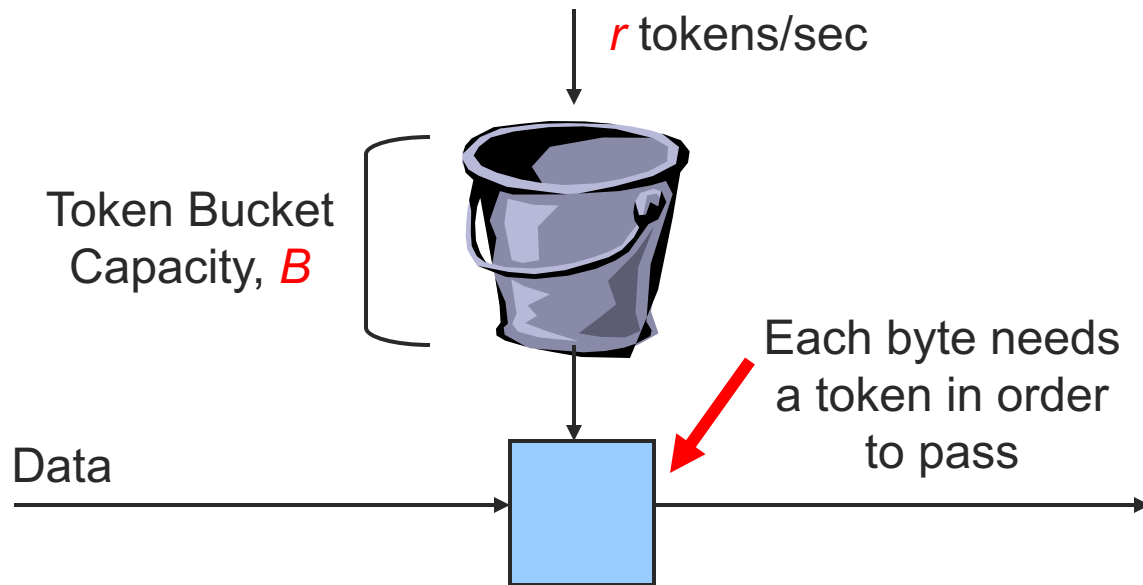
## ■ Use

- 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]



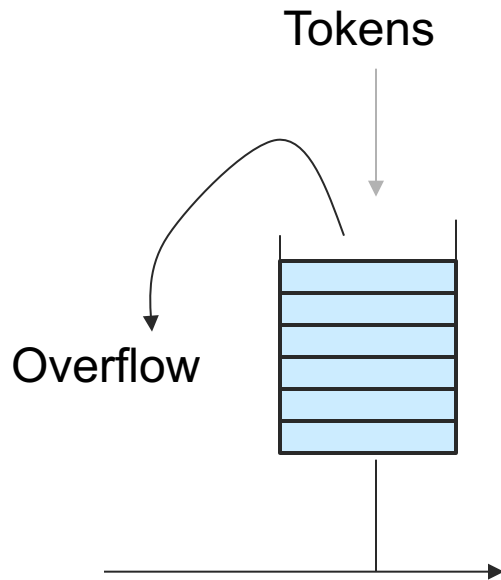
Dropping Filter: drops packets if token is not available

Buffered Filter: buffers data until tokens become available

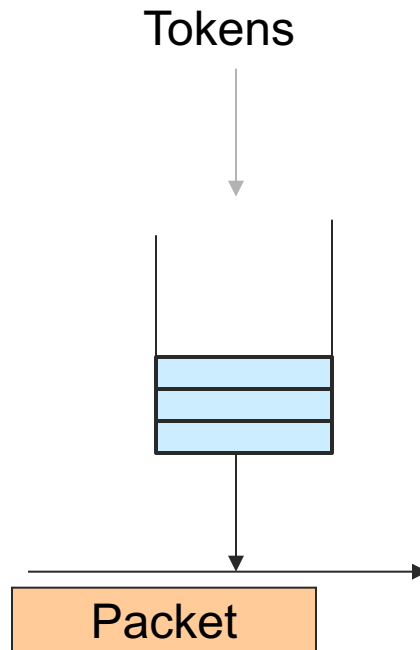




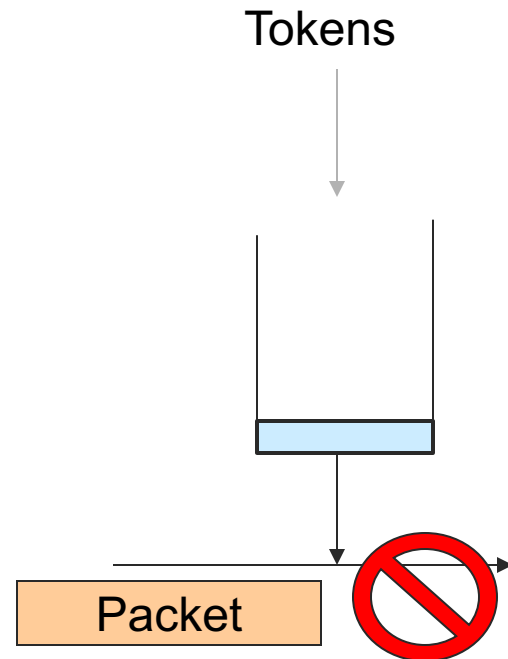
# [Token Bucket Operation]



Buffer tokens up to capacity of bucket



Enough tokens → packet goes through, tokens removed



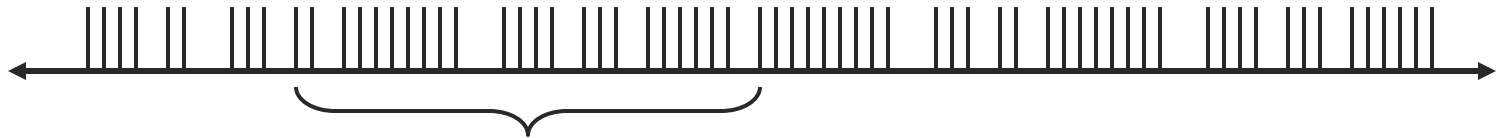
Not enough tokens → wait for tokens to accumulate



# [Token Bucket Filters]

## ■ Question

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



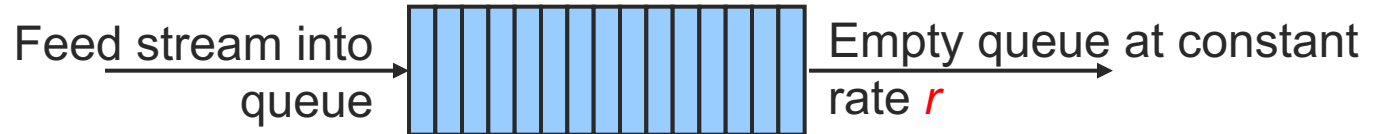
Not if during every time interval, the number of bytes is less than or equal to  $B + rt$ , where  $t$  is the length of the interval

- 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]

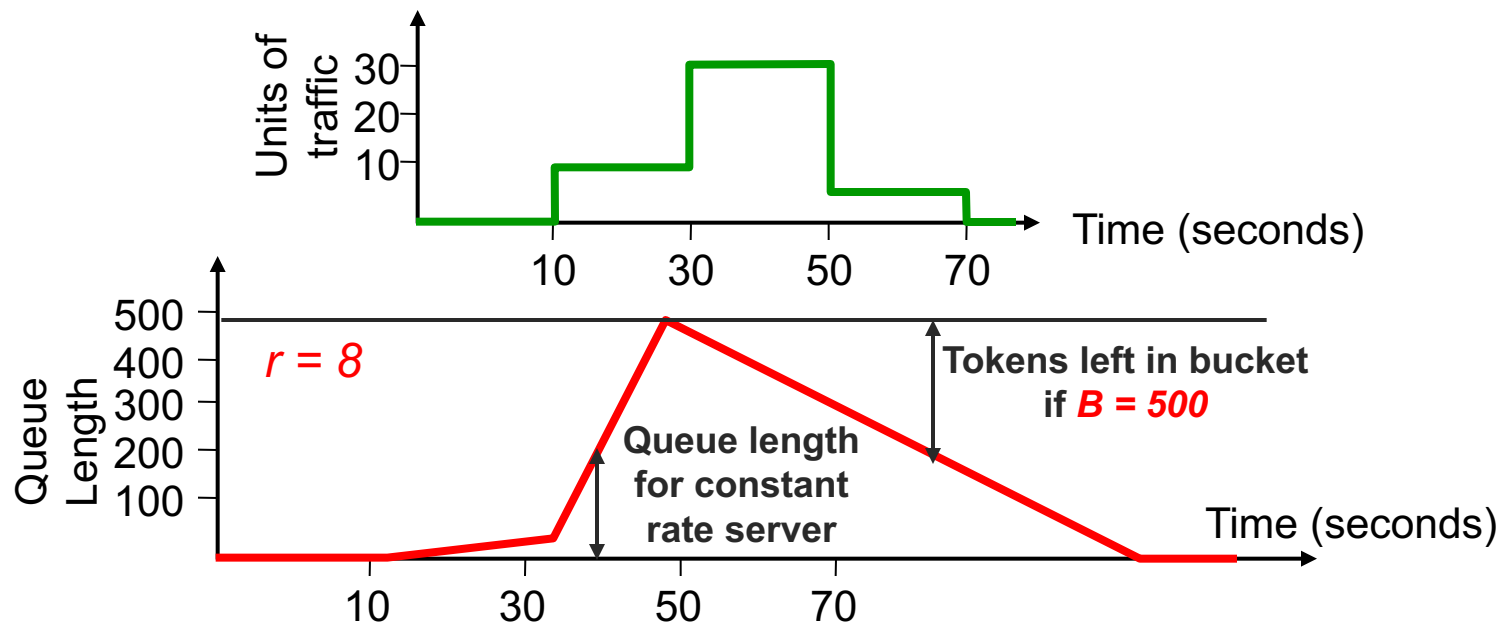
- Given a token rate  $r$  and a finite data trace, how can the minimum token bucket size  $B$  be found such that the filter has no effect?



- 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

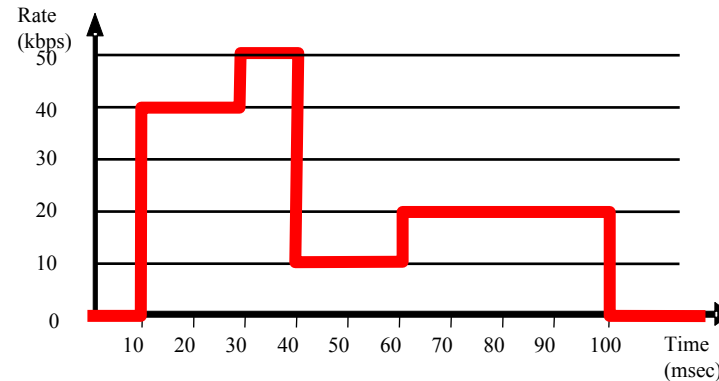






# [Token Bucket Filters]

- $r = 15$  kbps

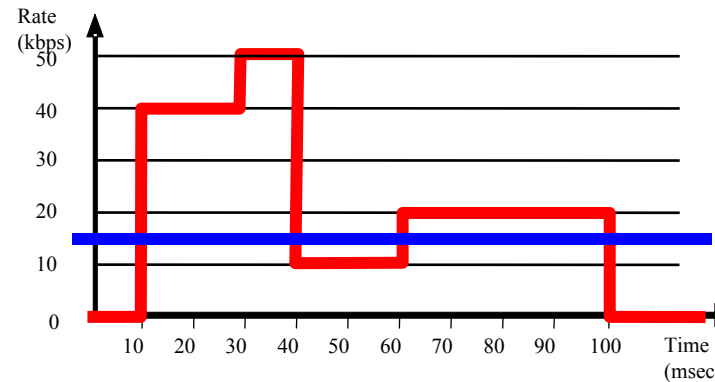


- What is the minimum size of  $B$  required so that the filter lets the stream pass with no loss or delay?



# [Token Bucket Filters]

- $r = 15$  kbps

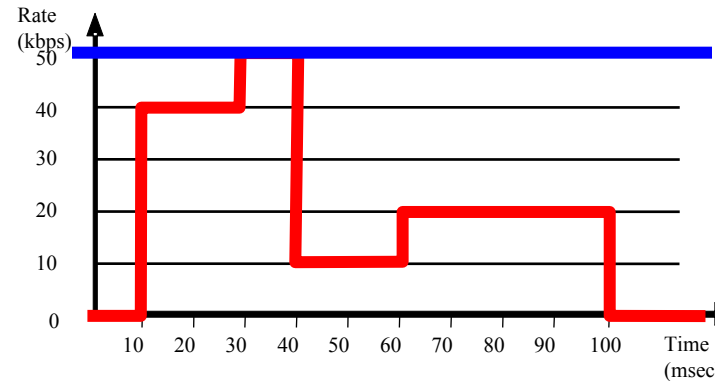


- Min  $B =$   
 $(40 - 15) * 20 +$   
 $(50 - 15) * 10 -$   
 $(15 - 10) * 20 +$   
 $(20 - 15) * 40$   
 $= 950$  bits



# Token Bucket Filters

- What is the minimum  $B$  needed for arbitrary  $r > 0$
- If  $r \geq 50$   
 $B = 0$
- If  $50 > r \geq 40$   
 $\text{Min } B = (50 - r) * 10$
- If  $40 > r \geq 20$   
 $\text{Min } B = (40 - r) * 20 + (50 - r) * 10$
- If  $20 > r \geq 10$   
 $\text{Min } B = (40 - r) * 20 + (50 - r) * 10 - (r - 10) * 20 + (20 - r) * 40$
- If  $10 > r \geq 0$   
 $\text{Min } B = (40 - r) * 20 + (50 - r) * 10 + (10 - r) * 20 + (20 - r) * 40$



# 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 ( $2^6 = 64$  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”

