CISC 7332X T6
Congestion Control and Quality of Service

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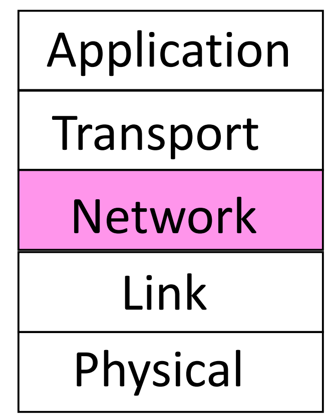
The Network Layer

- Responsible for delivering packets between endpoints over multiple links

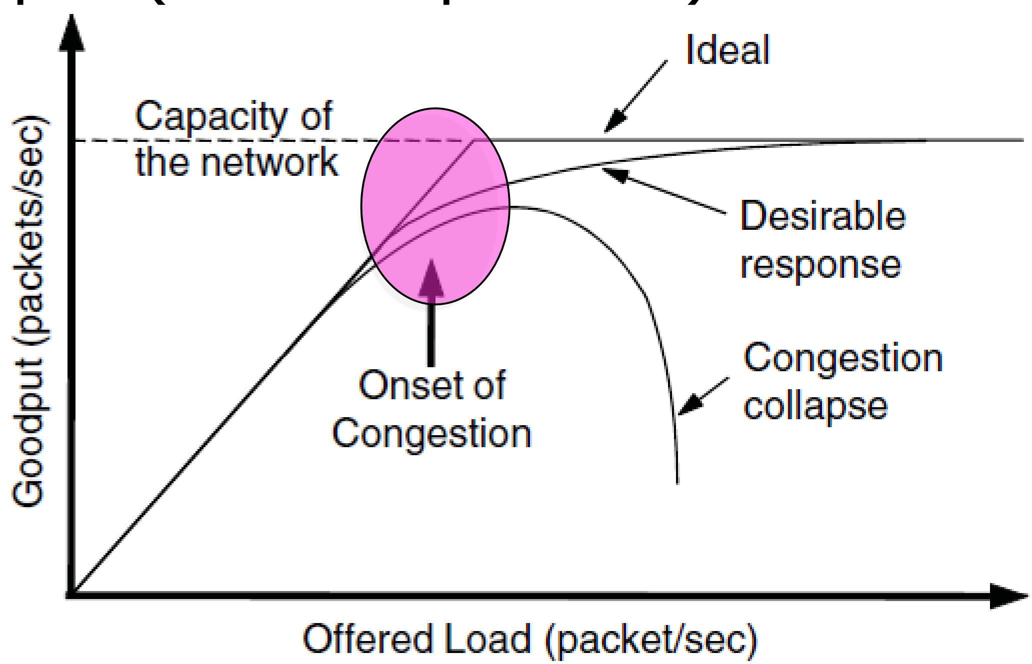


Congestion

- Overloading of network (when too much traffic is offered)
  - Packet switching: store-and-forward
    - Need memory to store packets
    - Need processing power to forward packets
  - e.g., too many packets arriving at a router, exceed its capacity, result in lost of packets (no memory to store the packets) or packet delay

Performance Degradation

- Performance degrades due to loss or retransmissions
  - Goodput (=useful packets) trails offered load

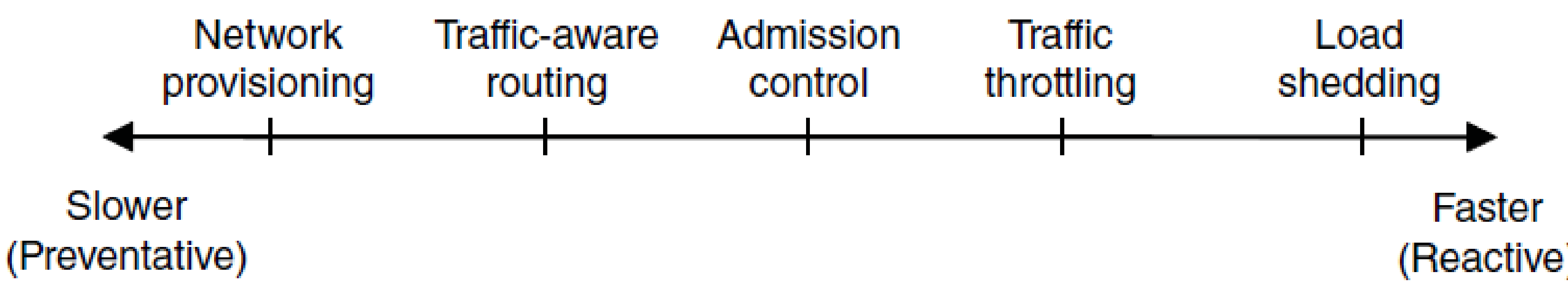


Handling Congestion: Layered Approach

- Effectively handling congestion requires that the Network and upper (e.g., Transport) layers work together
- Congestion control approaches in Network Layer
  - Traffic-aware routing
  - Admission control
  - Traffic throttling
  - Load shedding

Congestion Control Approaches

- Network must do its best with the offered load
  - Different approaches at different timescales
  - Nodes should also reduce offered load (Transport)

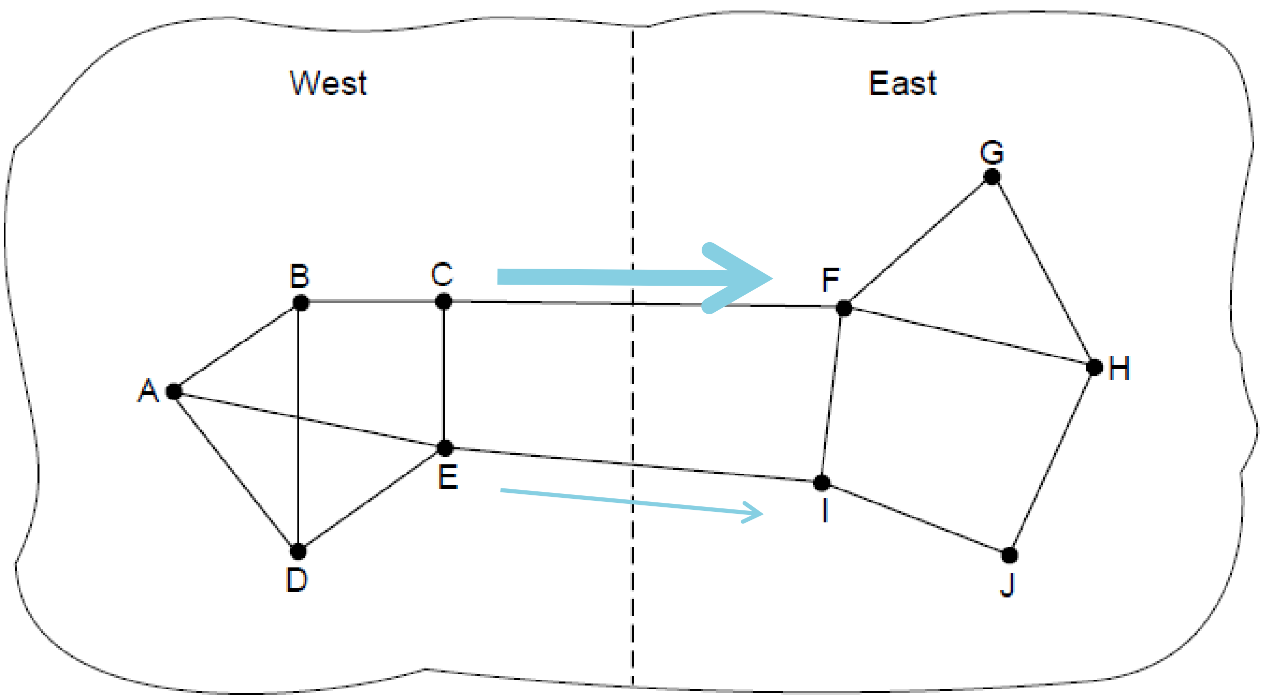


Traffic-Aware Routing

- Choose routes depending on traffic, not just topology

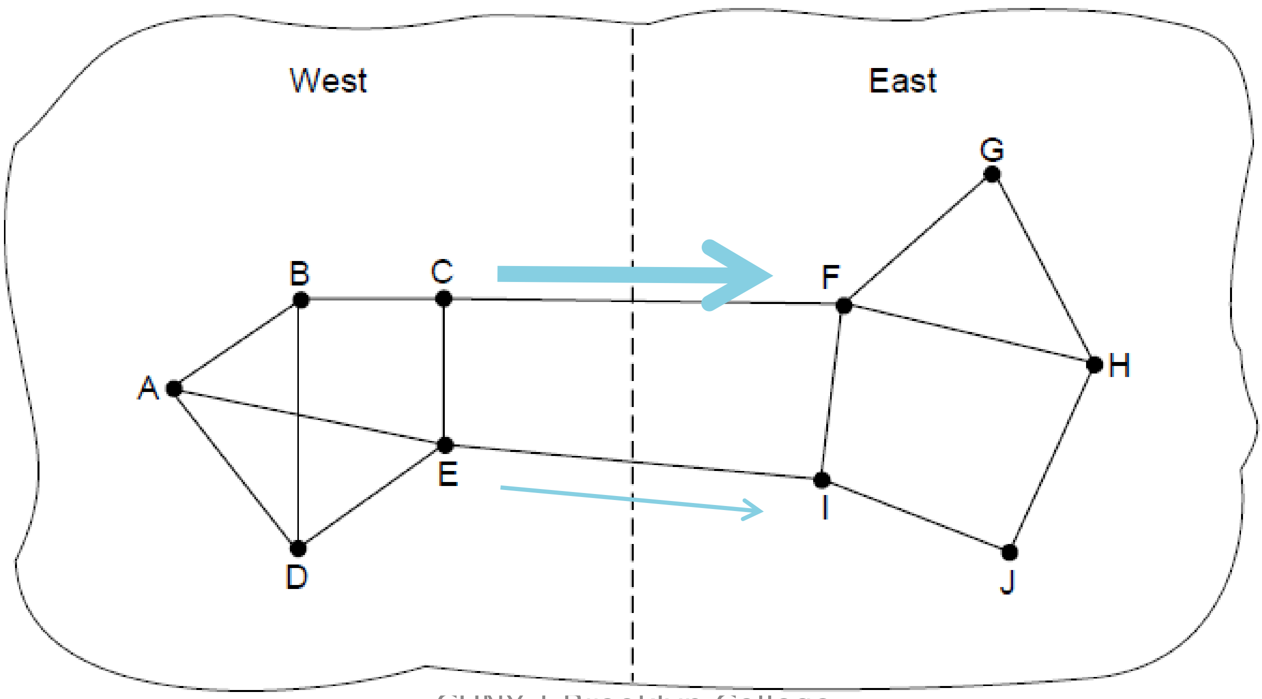
Traffic-Aware Routing: Example

- e.g., use *EI* for West-to-East traffic if *CF* is loaded



Traffic-Aware Routing: Challenges

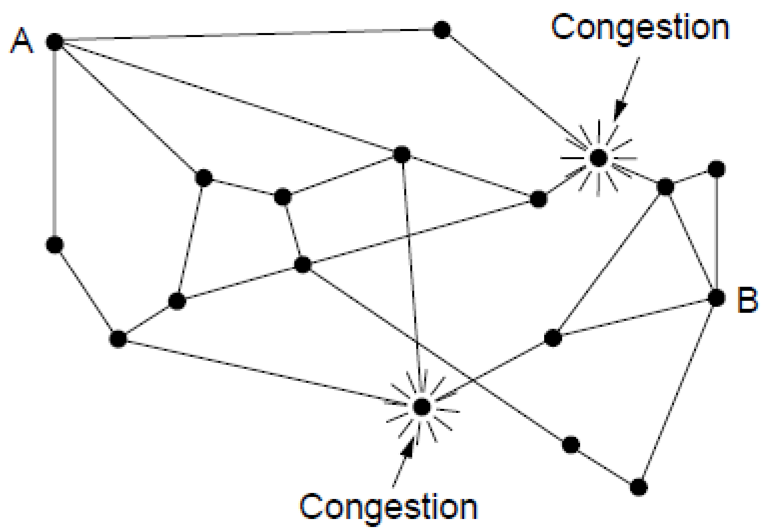
- Favorable routes changing quickly, results in wild oscillation in routing tables.



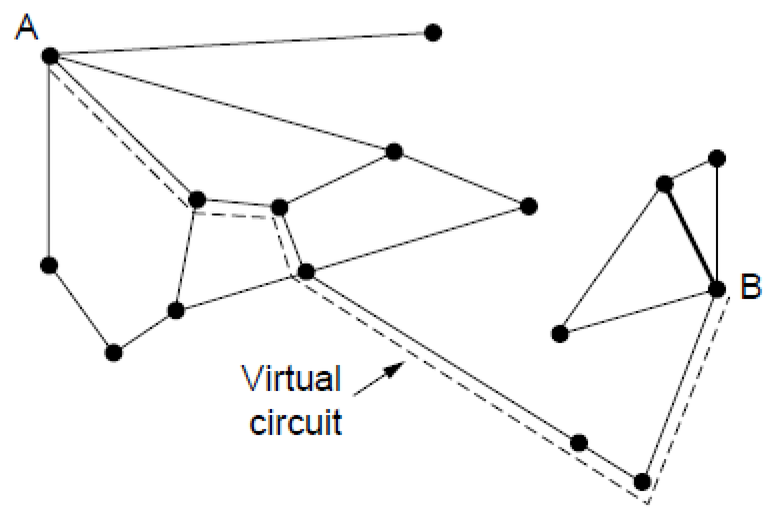
Admission Control

- Admission control allows a new traffic load only if the network has sufficient capacity, e.g., with virtual circuits
  - Can combine with looking for an uncongested route

Admission Control: Example



Network with some congested nodes



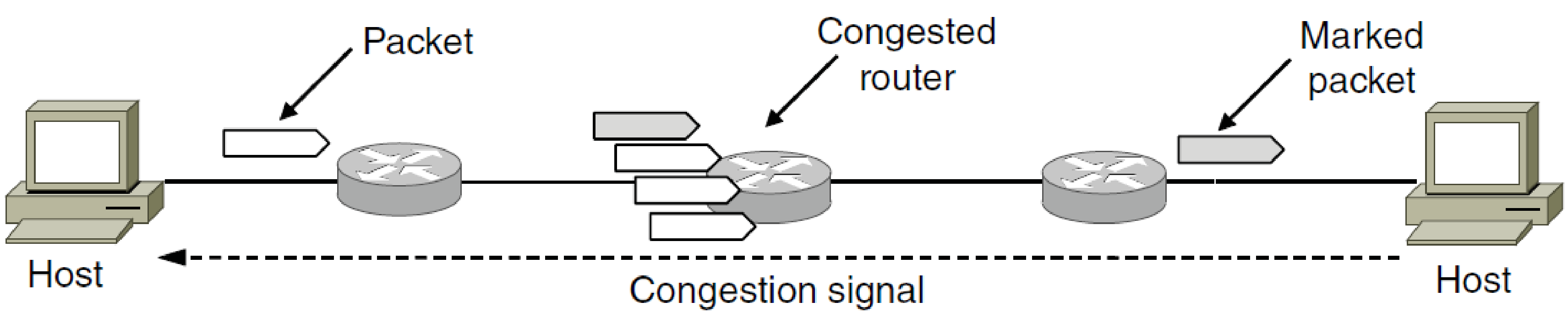
Unconggested portion and route *AB* around congestion

Traffic Throttling

- Congested routers signal hosts to slow down traffic
  - ECN (Explicit Congestion Notification) marks packets and receiver returns signal to sender

Traffic Throttling

- Example: using the Exponentially Weighted Moving Average on queuing delay inside routers
  - $d_{new} = \alpha \, d_{old} + (1 - \alpha) \, s$
  - where d is delay and s is queue length

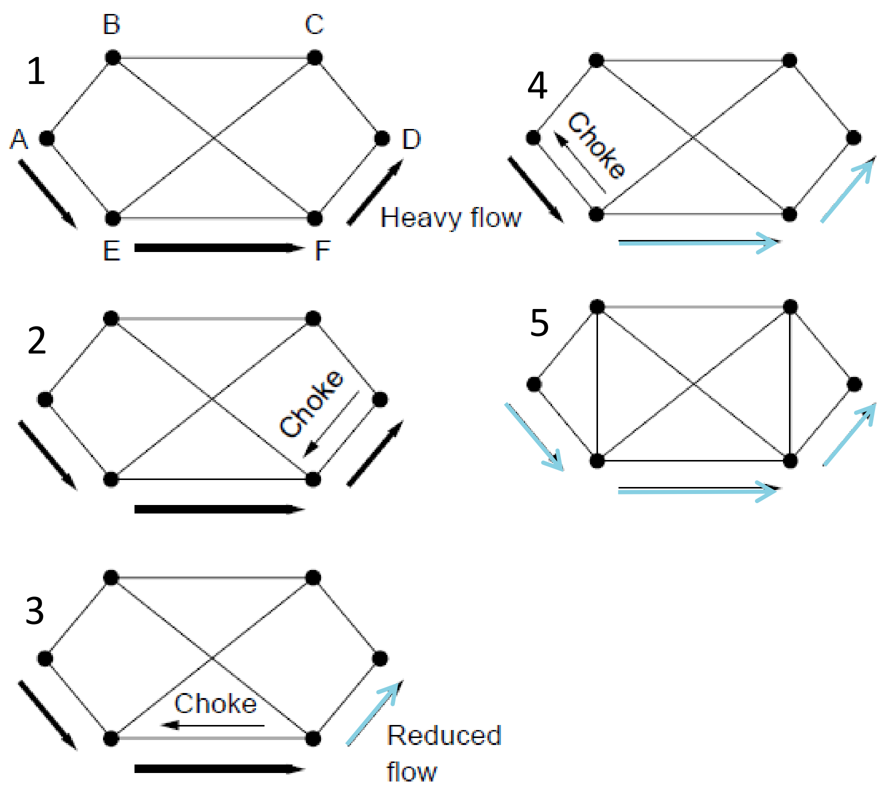


Load Shedding

- When all else fails, network will drop packets (shed load)
- Can be done end-to-end or link-by-link
- But which packet to drop?

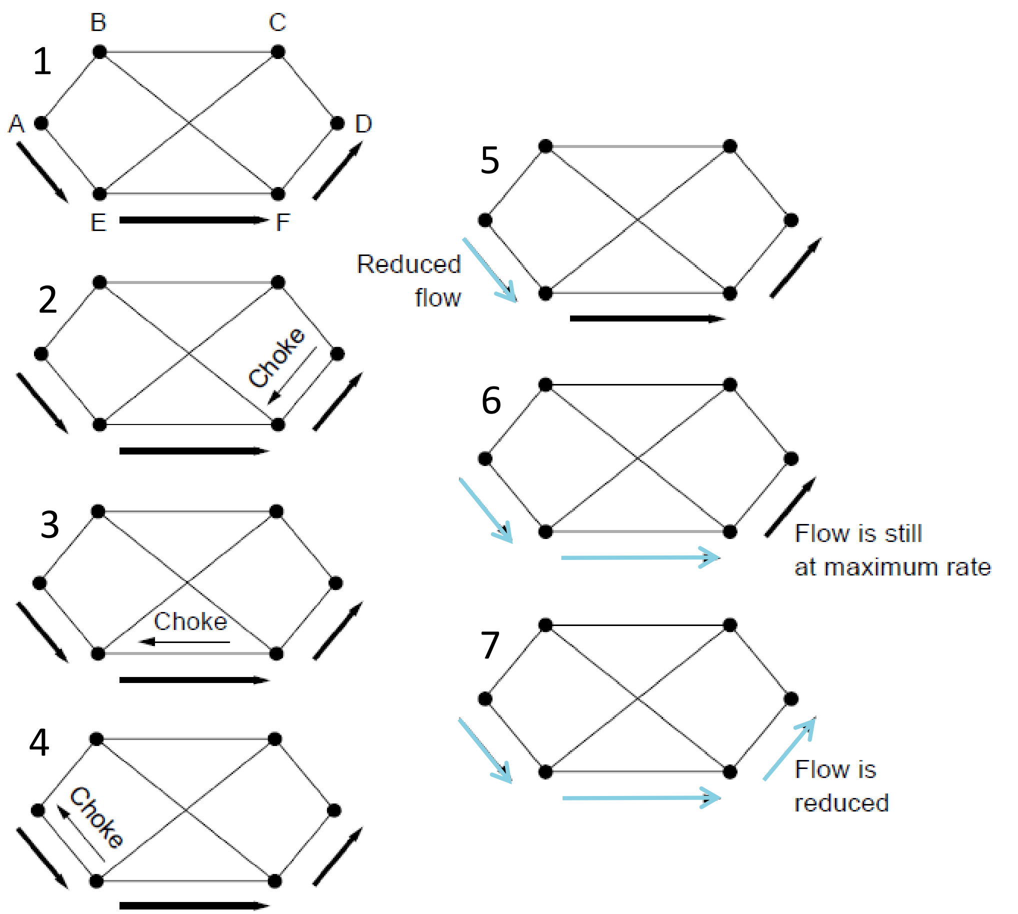
Link-by-Link Load Shedding

- Link-by-link produces rapid relief



End-to-end Load Shedding

- End-to-end takes longer to have an effect, but can better target the cause of congestion



Questions?

- Concept of congestion and congestion control
- Network layer approaches
  - Traffic-aware routing
  - Admission control
  - Traffic throttling
  - Load shedding

Quality of Service

- Application requirements
- Traffic shaping
- Packet scheduling
- Admission control
- Integrated services
- Differentiated services

Application Requirements

- Different applications care about different properties

Application	Bandwidth	Delay	Jitter	Loss
Email	Low	Low	Low	Medium
File sharing	High	Low	Low	Medium
Web access	Medium	Medium	Low	Medium
Remote login	Low	Medium	Medium	Medium
Audio on demand	Low	Low	High	Low
Video on demand	High	Low	High	Low
Telephony	Low	High	High	Low
Videoconferencing	High	High	High	Low

"High" means a demanding requirement, e.g., low delay

QoS on Network Layer

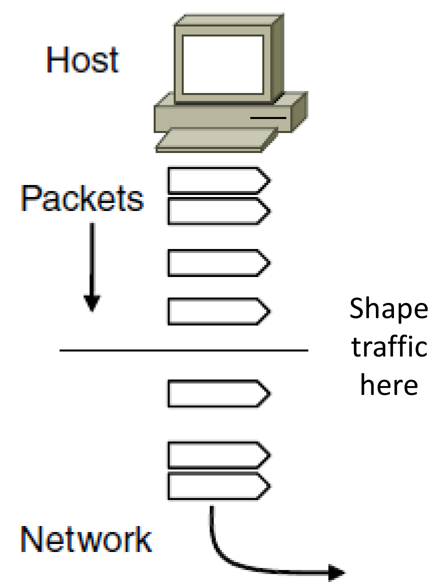
- Network provides service with different kinds of QoS (Quality of Service) to meet application requirements

Network Service	**Application**
Constant bit rate	Telephony
Real-time variable bit rate	Videoconferencing
Non-real-time variable bit rate	Streaming a movie
Available bit rate	File transfer

Example of QoS categories from ATM networks

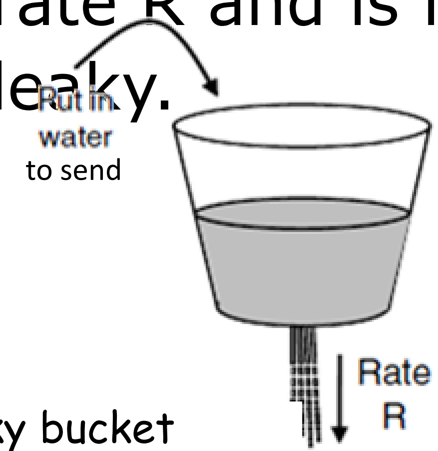
Traffic Shaping

- Traffic shaping regulates the average rate and burstiness of data entering the network
  - Lets users make guarantees: “my transmission pattern will look you handle it?”

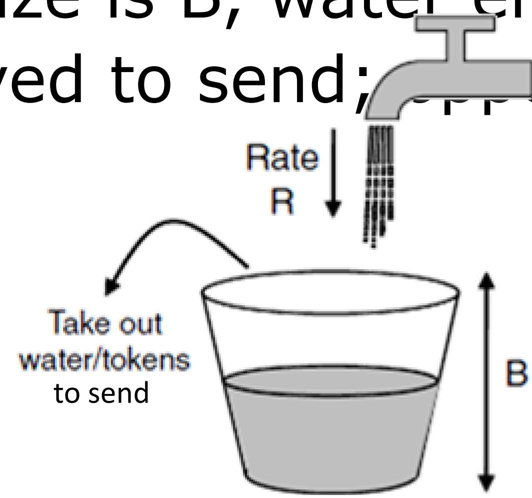


Token/Leaky Bucket

- Token/Leaky bucket limits both the average rate (R) and short-term burst (B) of traffic
  - For token, bucket size is B, water enters at rate R and is removed to send; opposite for leaky.



Leaky bucket
(need not full to send)



Token bucket
(need some water to send)

Effect of Token Bucket

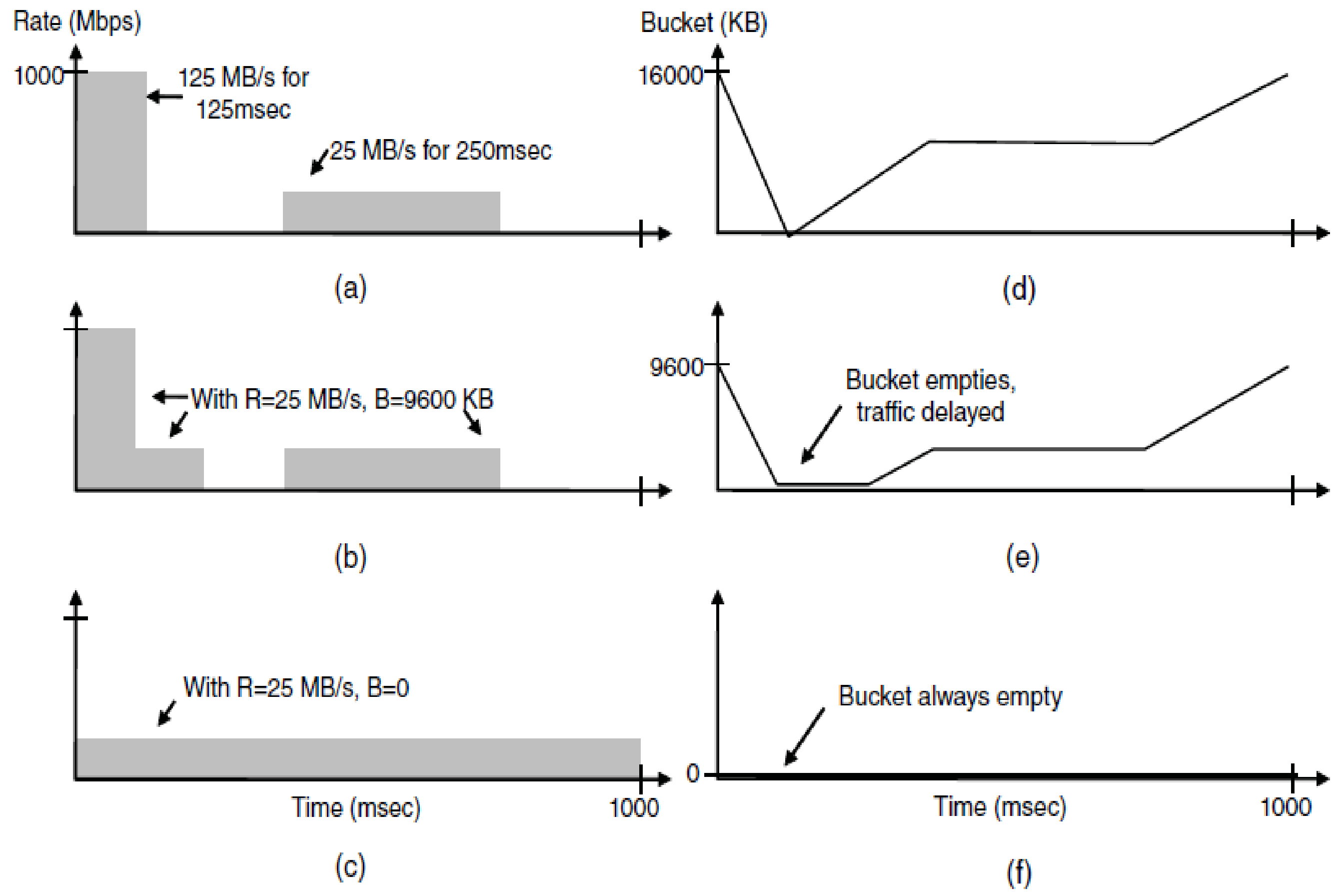
Host traffic
R=200 Mbps
B=16000 KB

↓

Shaped by
R=200 Mbps
B=9600 KB

↓

Shaped by
R=200 Mbps
B=0 KB

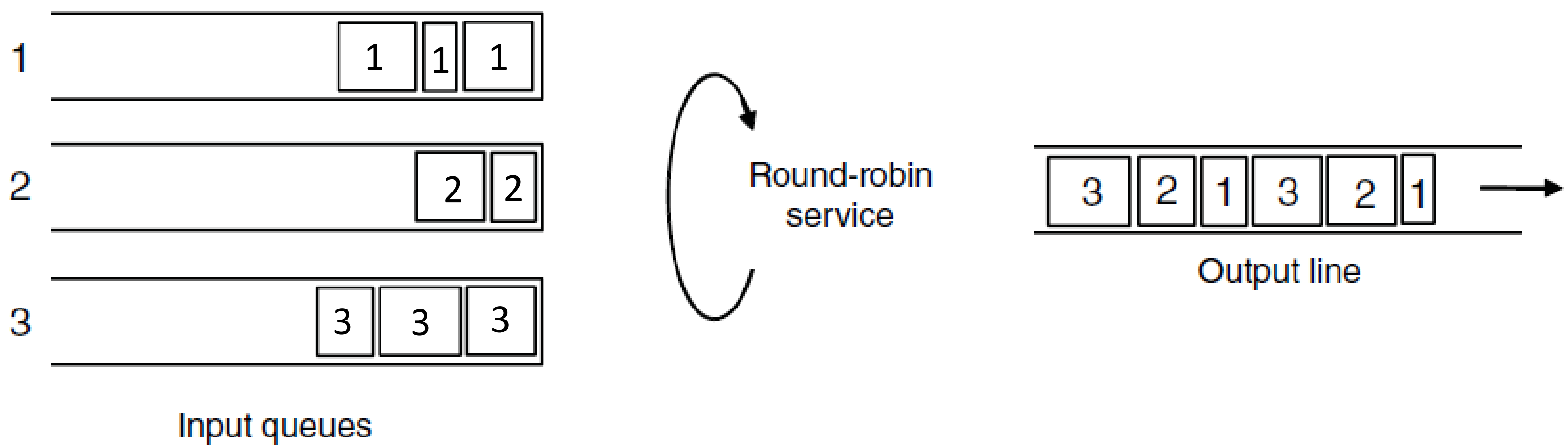


Smaller bucket size delays traffic and reduces burstiness

Packet Scheduling

- Without packet scheduling, packets are handled in the FIFO (first in first out) manner
- Packet scheduling divides router/link resources among traffic flows other than FIFO
    - Different queueing discipline

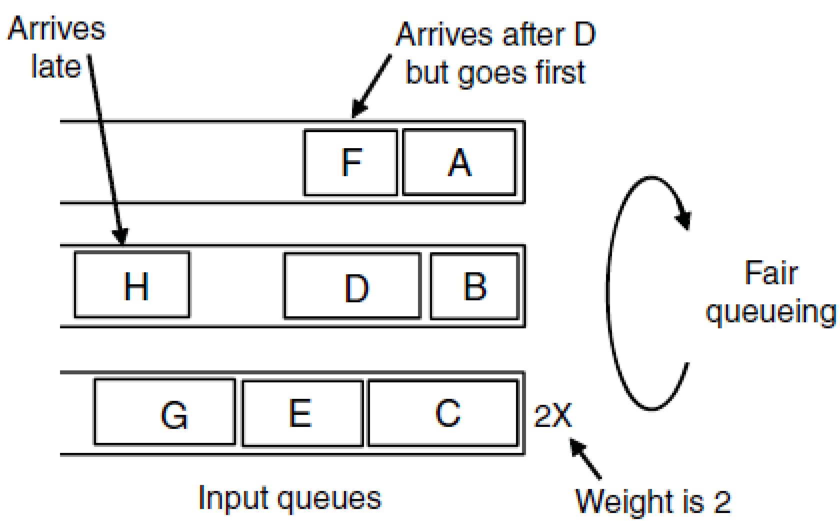
Round-Robin Fair Queueing



Weighted-Fair Queueing

- Fair Queueing approximates bit-level fairness with different packet sizes; weights change target levels

Weighted-Fair Queueing: Example



Packets may be sent out of arrival order

Packet	Arrival time	Length	Finish time	Output order
A	0	8	8	1
B	5	6	11	3
C	5	10	10	2
D	8	9	20	7
E	8	8	14	4
F	10	6	16	5
G	11	10	19	6
H	20	8	28	8

$F_i = \max(A_i, F_{i-1}) + L_i/W$

Finish virtual times determine transmission order

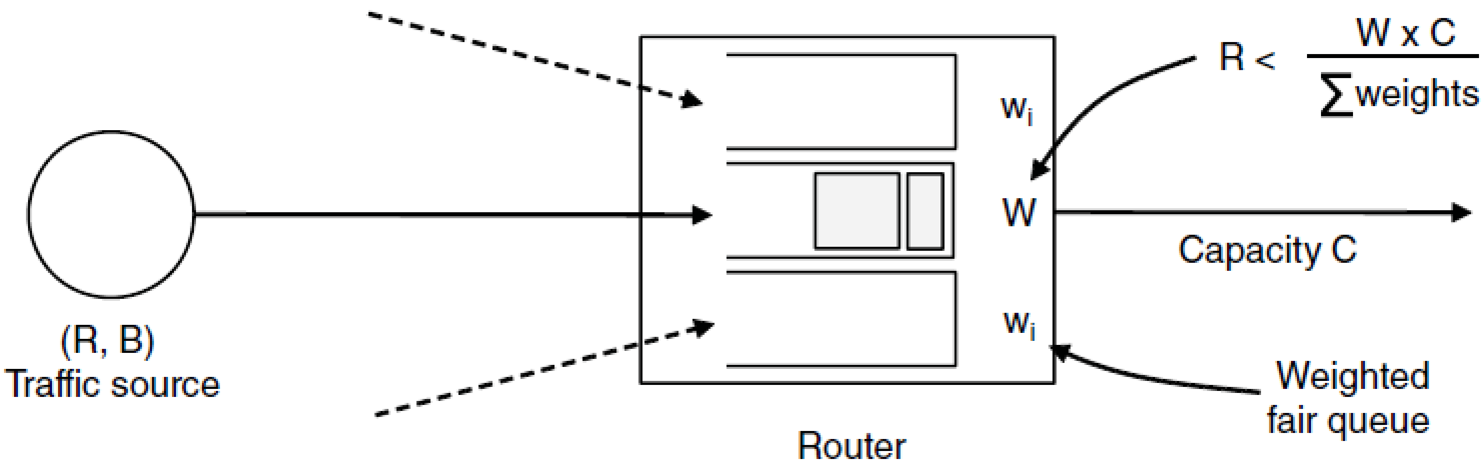
Admission Control

- Admission control takes a traffic flow specification and decides whether the network can carry it
  - Sets up packet scheduling to meet QoS

Parameter	Unit
Token bucket rate	Bytes/sec
Token bucket size	Bytes
Peak data rate	Bytes/sec
Minimum packet size	Bytes
Maximum packet size	Bytes

Example flow specification

Admission Control: Example



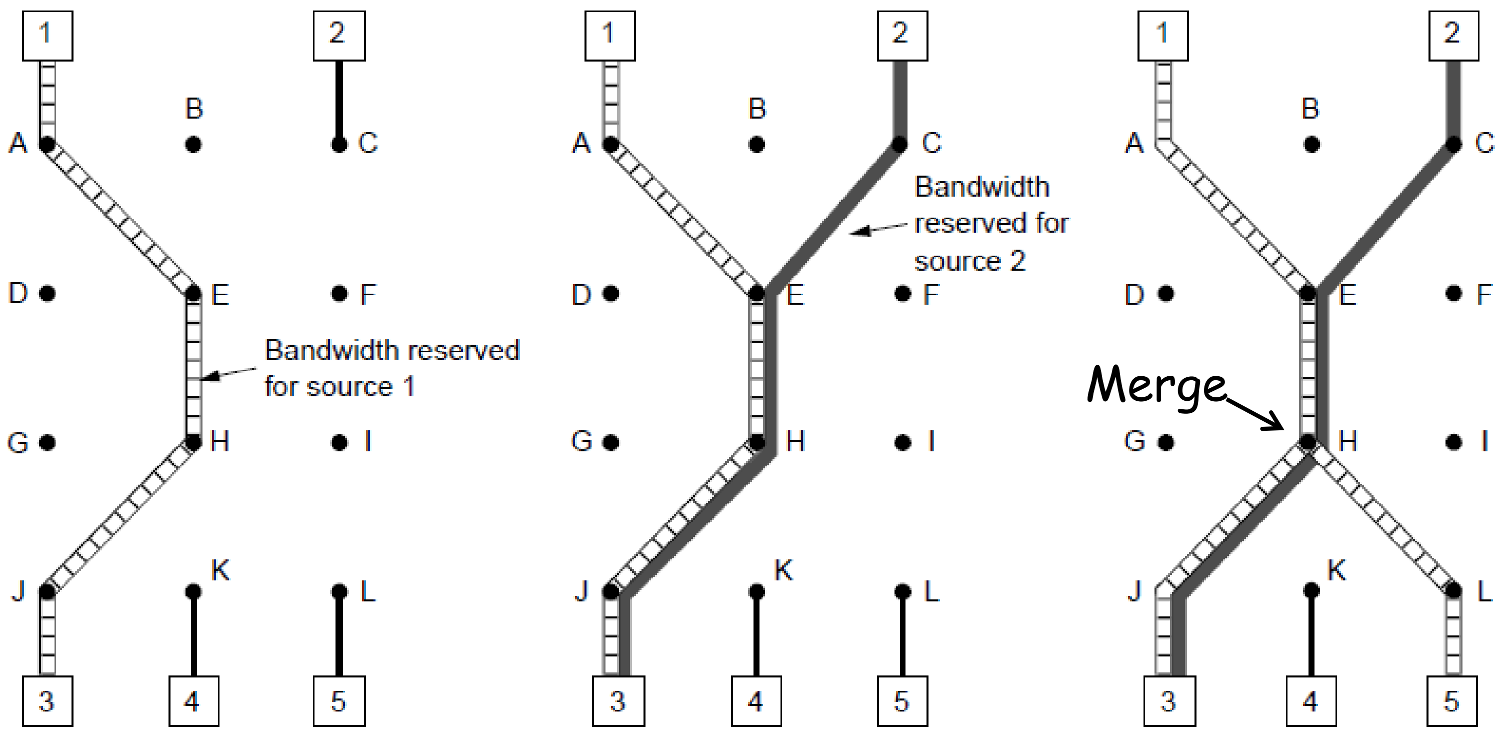
Admission Control: Example

- Construction to guarantee bandwidth B and delay D:
  - Shape traffic source to a (R, B) token bucket
  - Run WFQ with weight W / all weights > R/capacity
  - Holds for all traffic patterns, all topologies

Integrated Services

- Design with QoS for each flow
- Handle multicast traffic.
- Admission with RSVP (Resource reSerVation Protocol):
  - Receiver sends a request back to the sender
  - Each router along the way reserves resources
  - Routers merge multiple requests for same flow
  - Entire path is set up, or reservation not made
- Require advanced setup to establish each flow

Integrated Services: Example



R3 reserves flow from S1

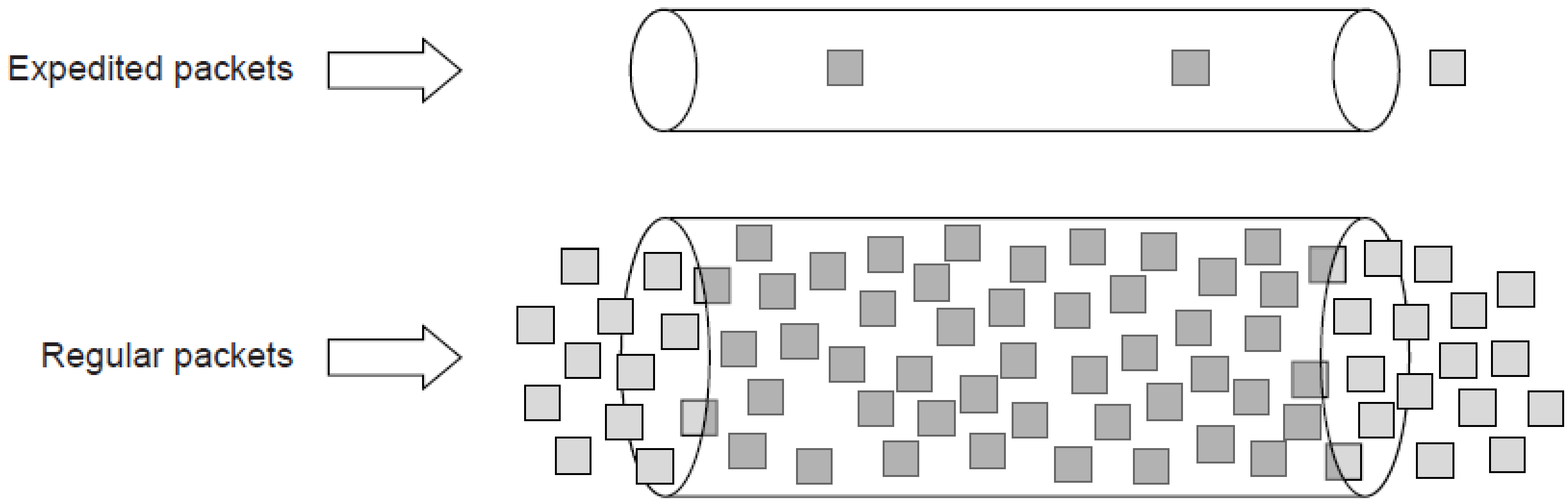
R3 reserves flow from S2

R5 reserves flow from S1; merged with R3 at H

Differentiated Services

- Design with classes of QoS
- Customers buy what they want
  - Expedited class is sent in preference to regular class
  - Less expedited traffic but better quality for applications
- No requirement on setting up path. Each router implements it indepedently

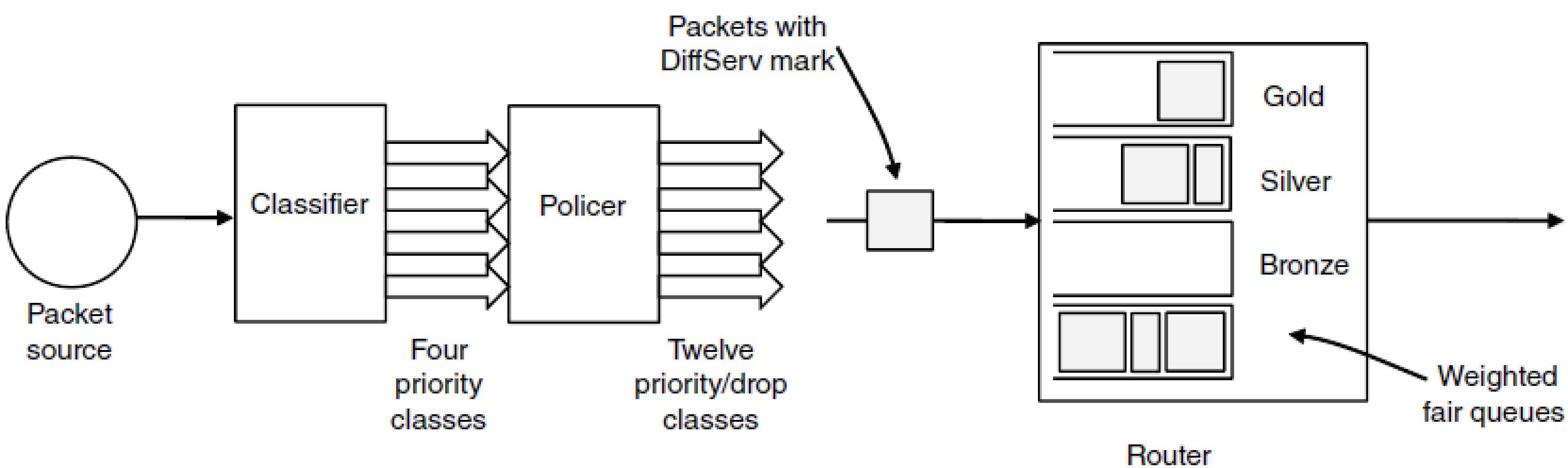
Differentiated Services: Example



Differentiated Services: Implementation

- Customers mark desired class on packet
- ISP shapes traffic to ensure markings are paid for
- Routers use WFQ to give different service levels

Differentiated Services: Implementation



Questions?

- Application requirements
- Quality of Services (QoS) provisioning
  - Traffic shaping
  - Packet scheduling
  - Admission control
  - Integrated services
  - Differentiated services