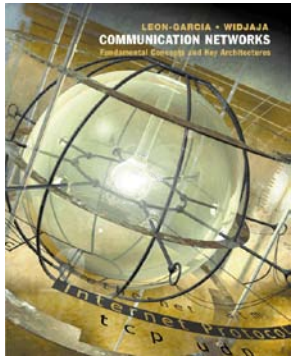
Communication Networks and Services



Quality of Service (QoS)

- *Identify traffic flows*
- *Mark traffic flows*
- *Police and shape traffic*
- *Apply priority (managed scheduling)*

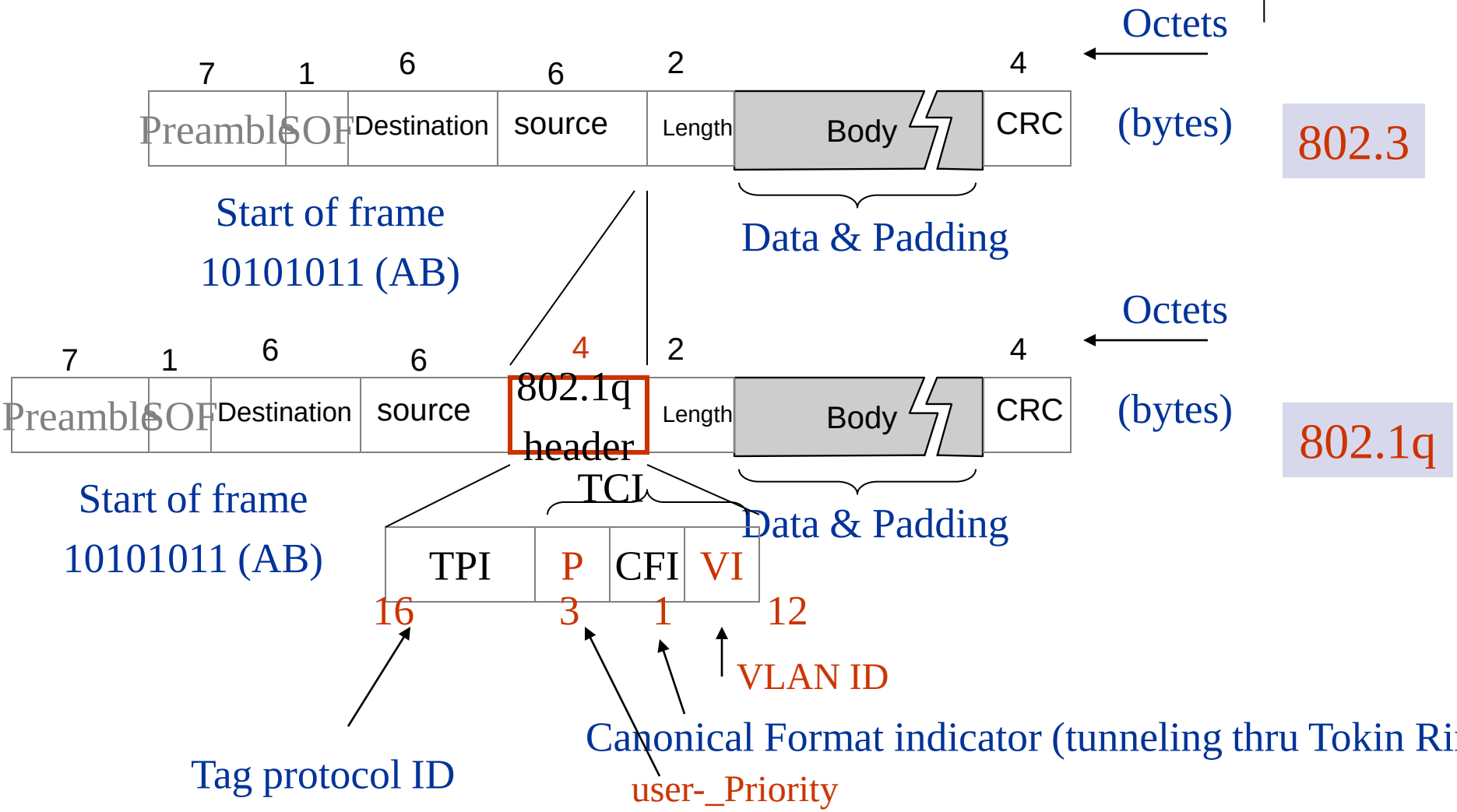
Open-Loop Control / QoS Model

- Network performance is guaranteed to all traffic flows that have been admitted into the network
- Initially for connection-oriented networks
- Key Mechanisms
  - Admission Control
  - Marking
  - Policing
  - Traffic Shaping
  - Traffic Scheduling

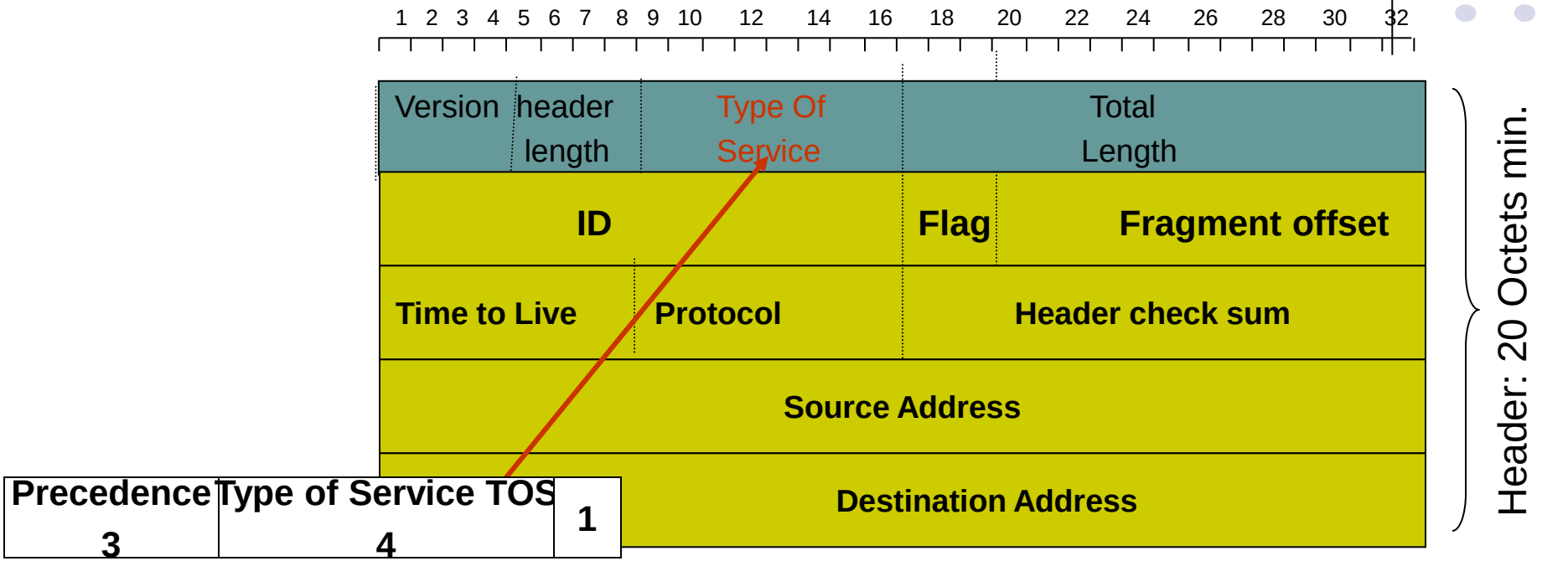
QoS Identification (marking)

- Frame Relay
  - DLCI Virtual circuit identifier & DE bit in the FR header
- ATM
  - VPI/VCI Virtual circuit identifier & CLP bit in the ATM header
- Ethernet (VLAN)
  - VLAN marking & VLAN priority
- IP
  - IPv4: Precedence bit, TOS
  - IPv6: traffic class
  - Diff Serv
- MPLS
  - E-LSP and L-LSP

IEEE 802.1q Frame format



IP Frame (RFC: 791)



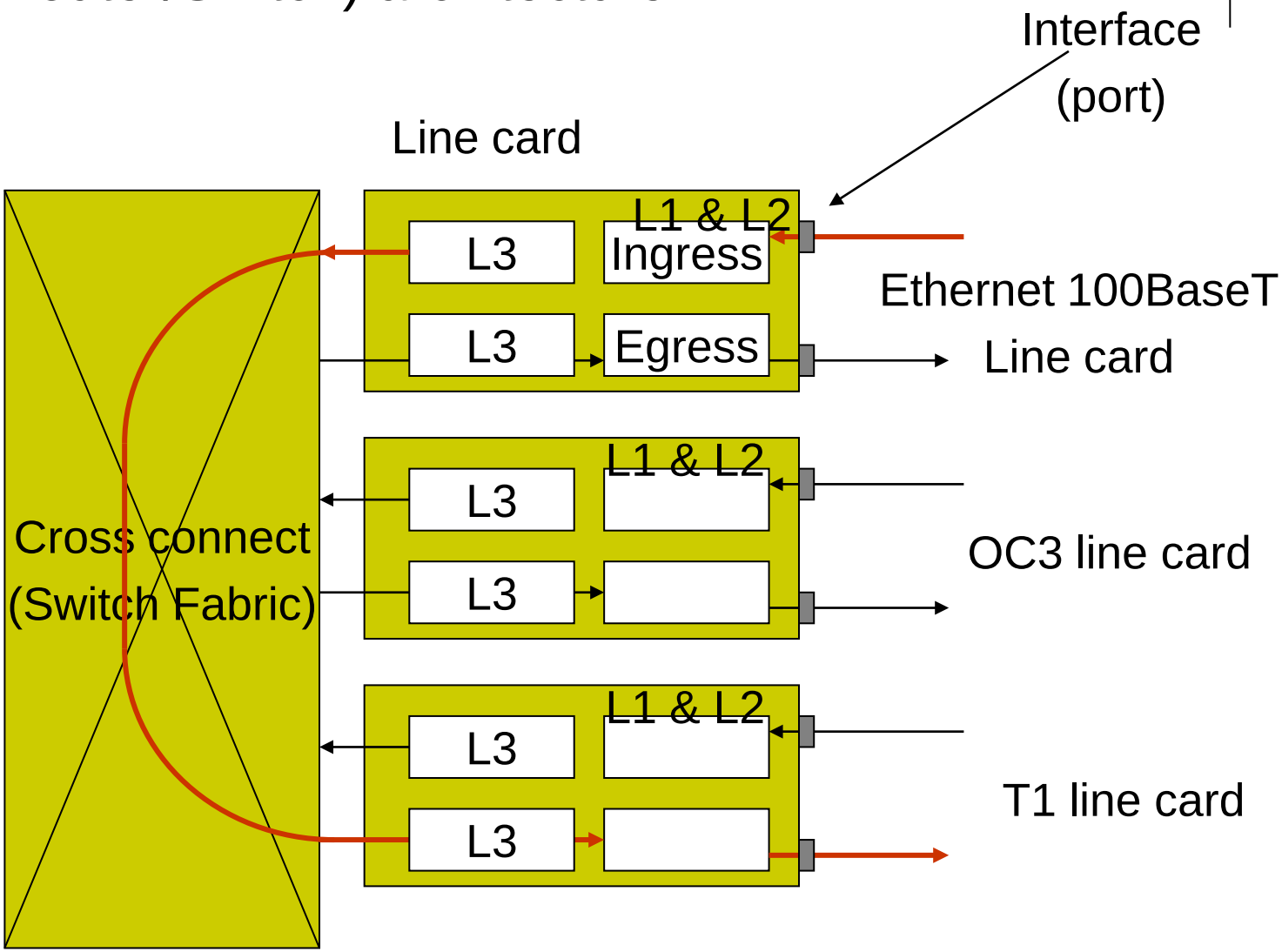
Diff Serv “QoS” marking

Diff Serv Class Field 6	Unused 2

The same DS header is used for IPv6

Generic Node Architecture

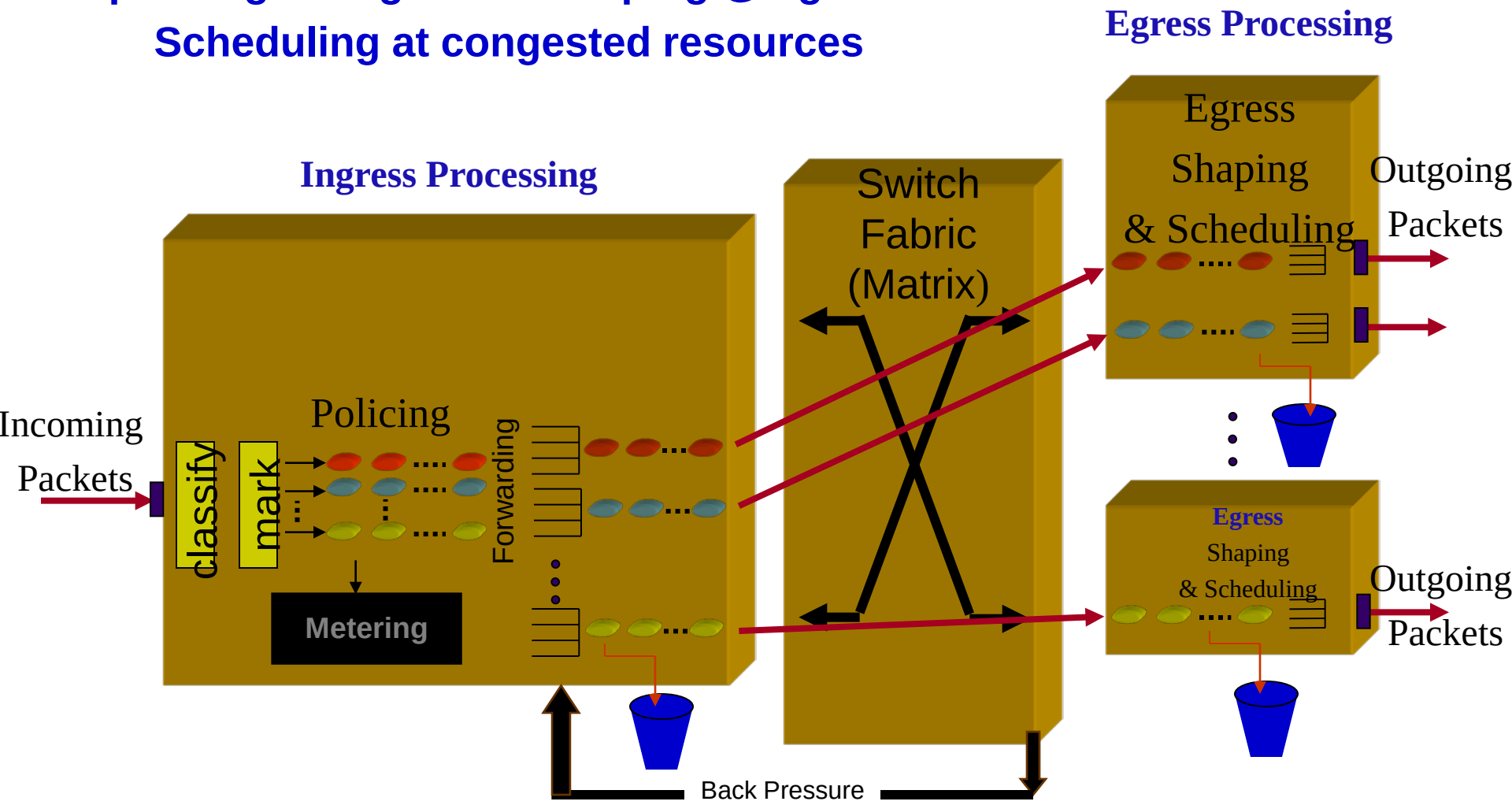
Nodal (Router/Switch) architecture



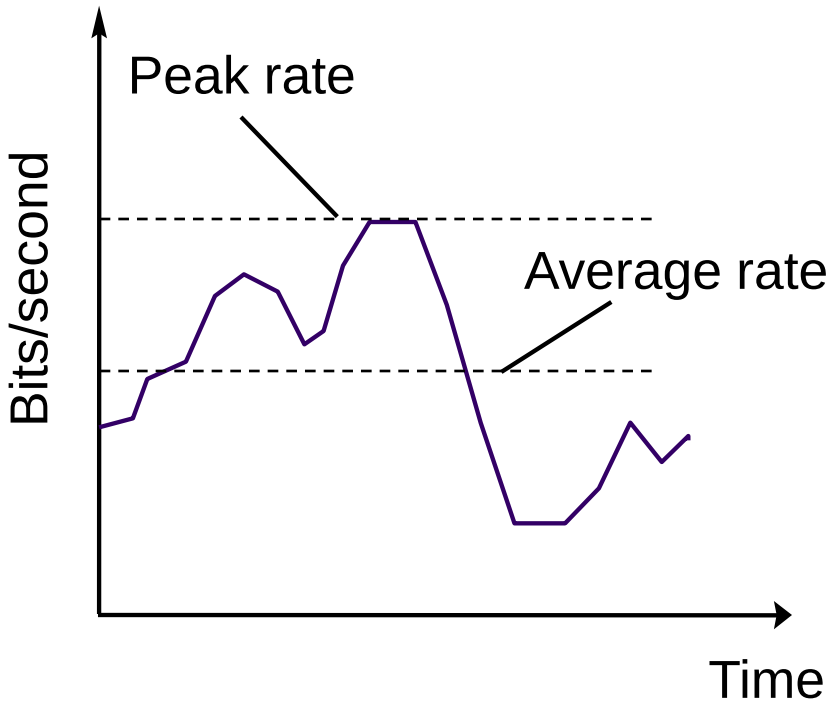
Nodal TM Generic Model

policing at ingress & Shaping @ egress

Scheduling at congested resources



Admission Control



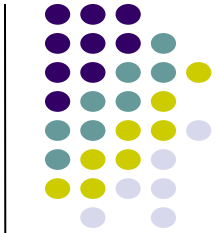
Typical bit rate demanded by a variable bit rate information source

- Flows negotiate contract with network
- Specify requirements:
  - Peak, Avg., Min Bit rate
  - Maximum burst size
  - Delay, Loss requirement
- Network computes resources needed
  - “Effective” bandwidth
- If flow accepted, network allocates resources to ensure QoS delivered as long as source conforms to contract

Marking (QoS identification)

- IP
  - IPv4: Precedence bit, TOS
  - IPv6: traffic class
  - Diff Serv

Policing & Shaping



- Network monitors traffic flows continuously to ensure they meet their traffic contract
- When a packet violates the contract, network can discard or tag the packet giving it lower priority
- If congestion occurs, tagged packets are discarded first
- ***Leaky Bucket Algorithm*** is the most commonly used policing mechanism
  - Bucket has specified leak rate for average contracted rate
  - Bucket has specified depth to accommodate variations in arrival rate
  - Arriving packet is *conforming* if it does not result in overflow

Leaky Bucket

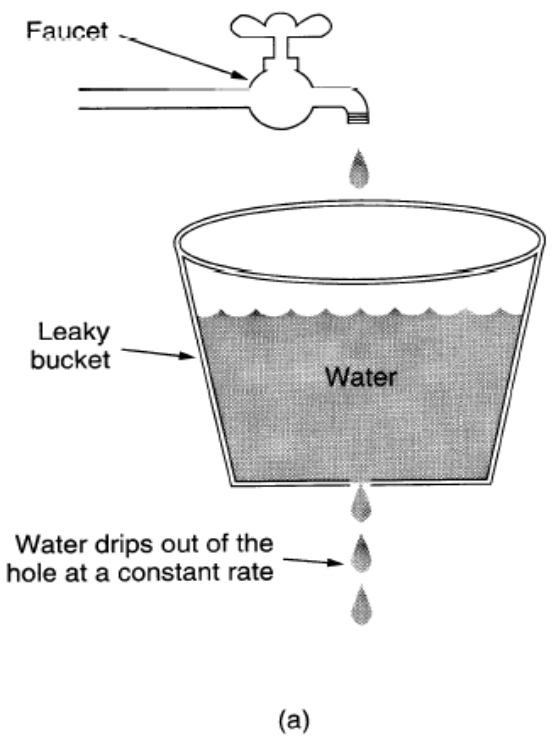
- Means to **smooth traffic** blasts & bumps
- Control egress rate (leak) & drop rate (bucket size)
- Smoothing packet rate or byte rate

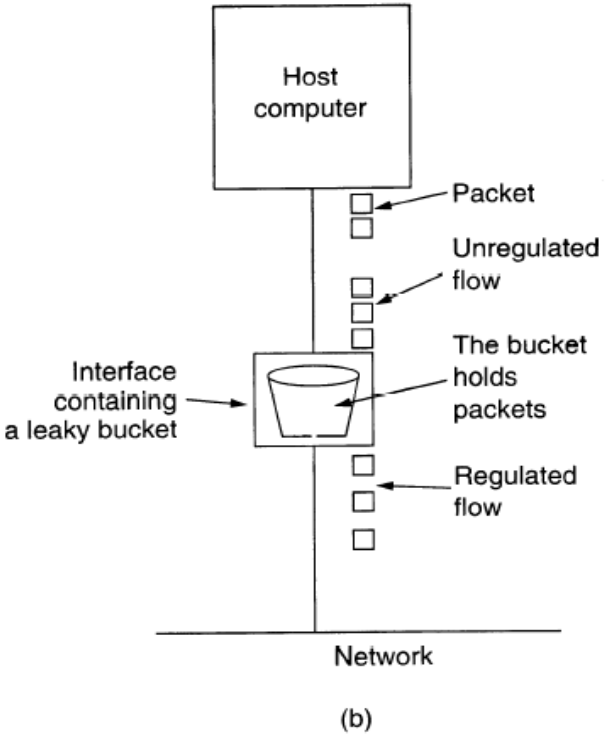
Queue servicing

- Every ΔT a packet is out
- Queue has a fixed size
- Bucket full➔drop packet

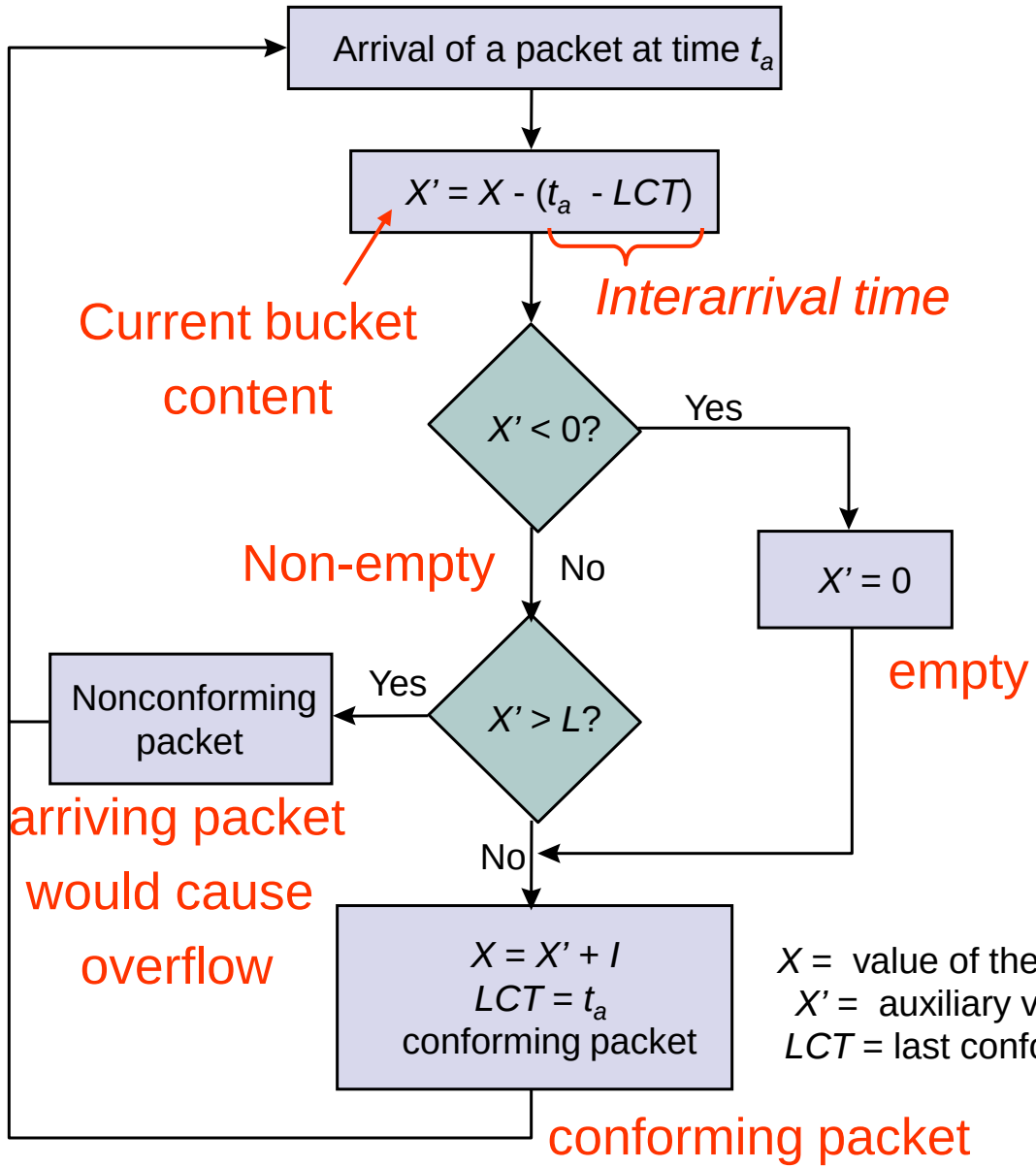
- Throughput determined by ΔT
- Loss (Drop preference) determined by queue length

- Packet delay = function of
  - Packets' size distribution
  - Packets' interarrival time distribution
  - ΔT





Leaky Bucket Algorithm



Depletion rate:
1 packet per unit time

$L+I$ = Bucket Depth

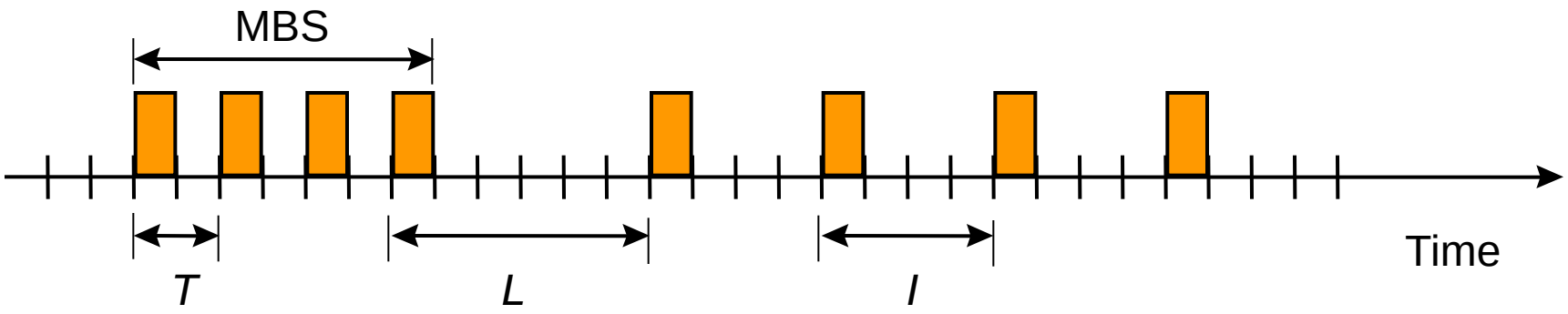
I = increment per arrival, nominal interarrival time

X = value of the leaky bucket counter
X' = auxiliary variable
LCT = last conformance time

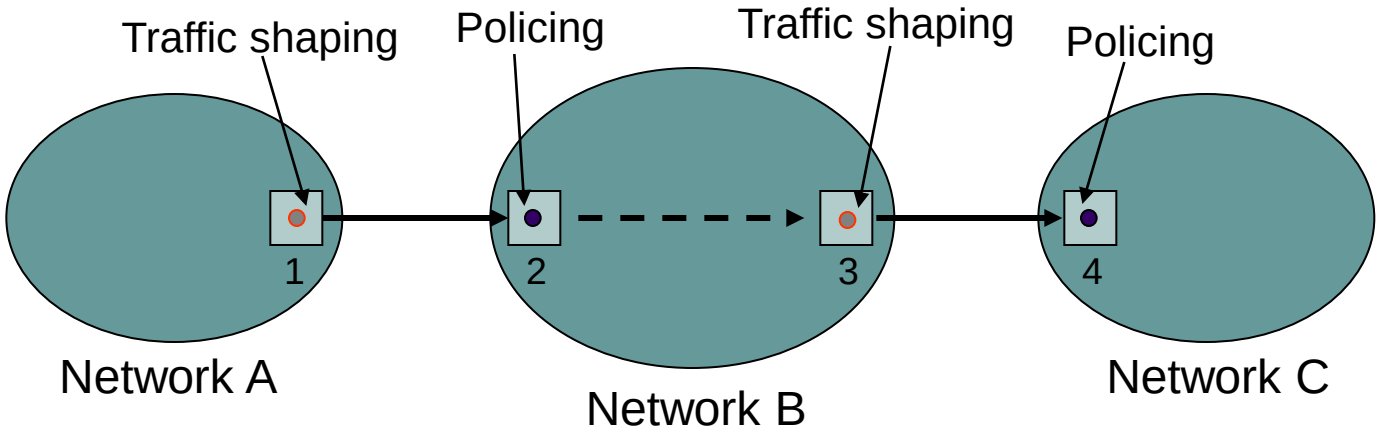
Policing Parameters

T = 1 / peak rate
MBS = maximum burst size
I = nominal interarrival time = 1 / sustainable rate

$$MBS = 1 + \left\lceil \frac{L}{I - T} \right\rceil$$

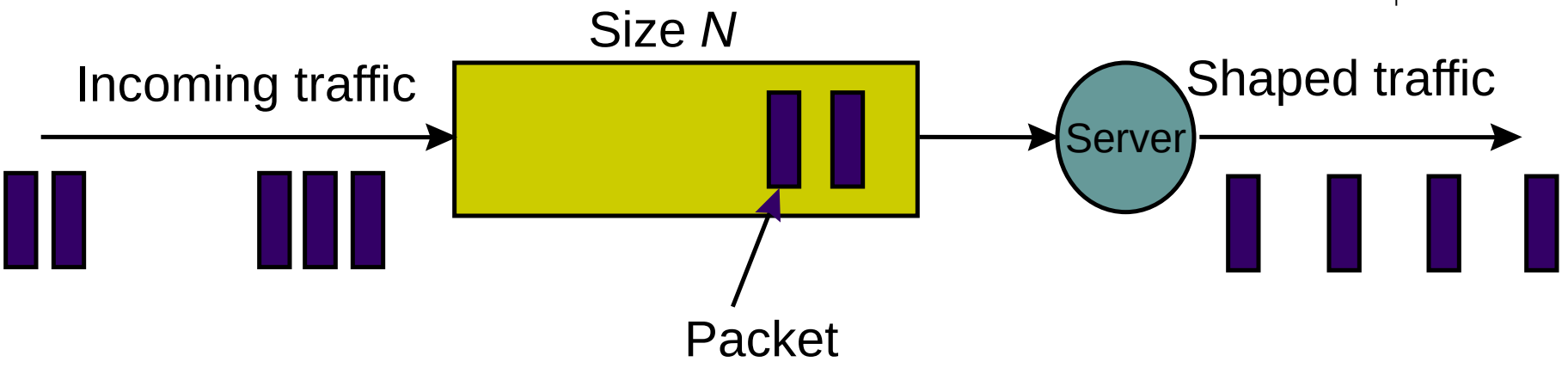


Traffic Shaping



- Networks police the incoming traffic flow
- *Traffic shaping* is used to ensure that a packet stream conforms to specific parameters
- Networks can shape their traffic prior to passing it to another network

Leaky Bucket Traffic Shaper

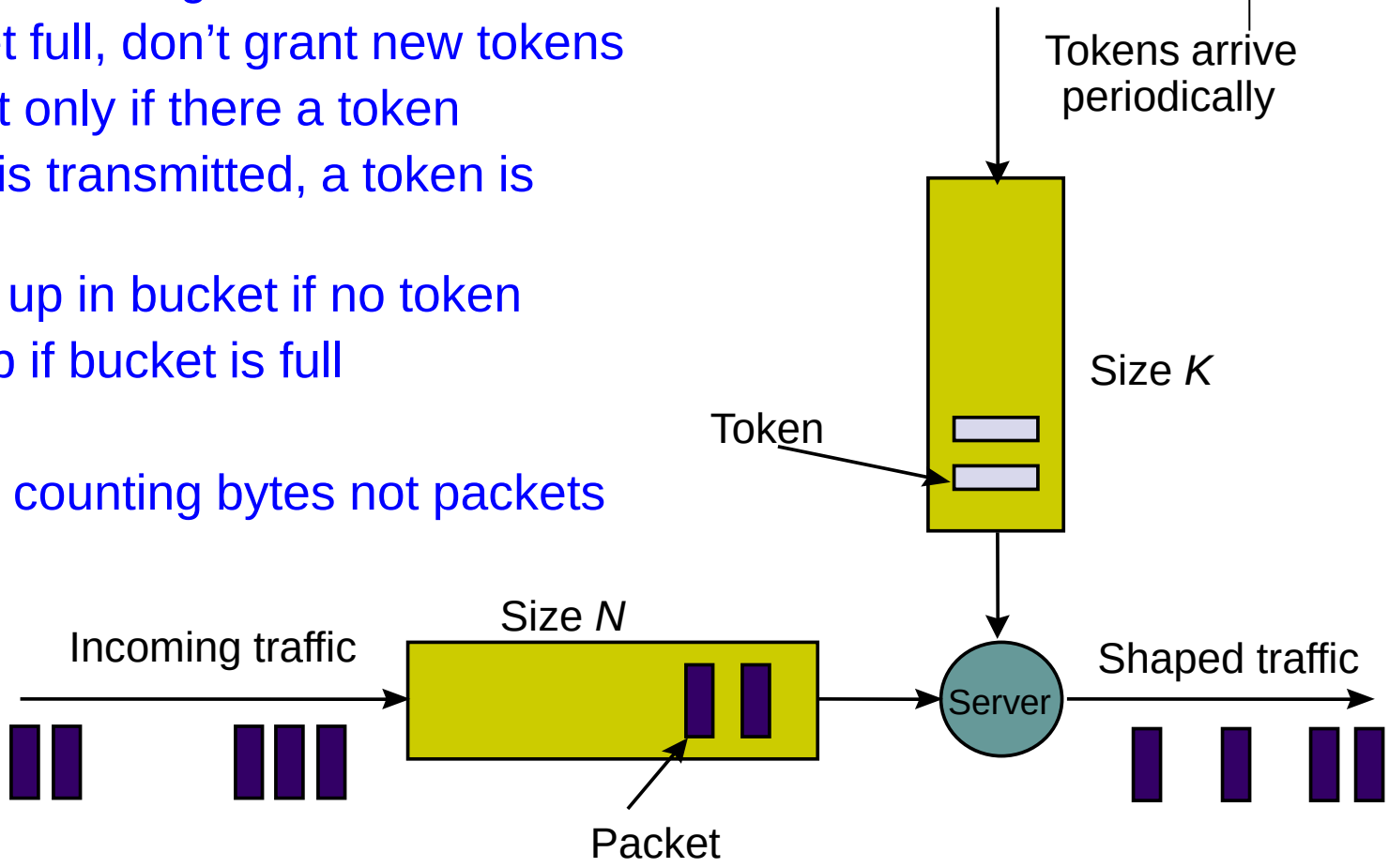


- Buffer incoming packets
- Play out periodically to conform to parameters
- Surges in arrivals are buffered & smoothed out
- Possible packet loss due to buffer overflow
- Too restrictive, since conforming traffic does not need to be completely smooth

Token Bucket Traffic Shaper

- Every ΔT, a token is granted and added
- When bucket full, don't grant new tokens
- Packet is out only if there a token
- As a packet is transmitted, a token is deleted
- Packet piles up in bucket if no token
- Packets drop if bucket is full

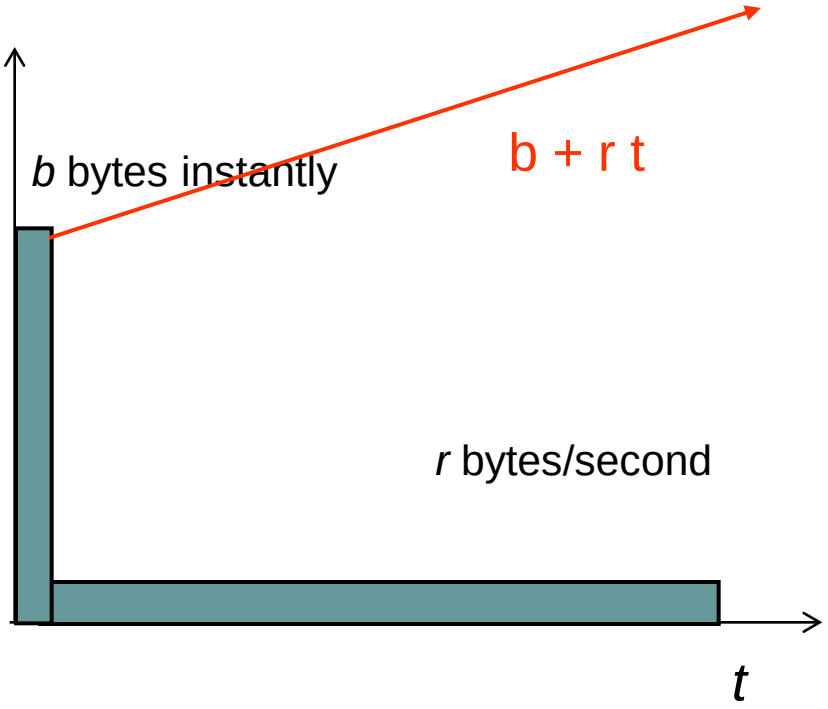
- Useful when counting bytes not packets



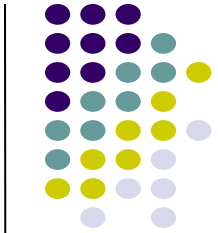
- Token rate regulates transfer of packets
- If sufficient tokens available, packets enter network without delay
- **K determines how much burstiness allowed into the network**

Token Bucket Shaping Effect

The token bucket constrains the traffic from a source to be limited to *b* + *r t* bits in an interval of length *t*

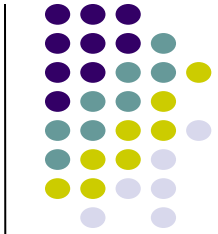


Scheduling for Guaranteed Service



- Suppose guaranteed bounds on end-to-end delay across the network are to be provided
- A call admission control procedure is required to allocate resources & set schedulers
- Traffic flows from sources must be shaped/regulated so that they do not exceed their allocated resources
- Strict delay bounds can be met

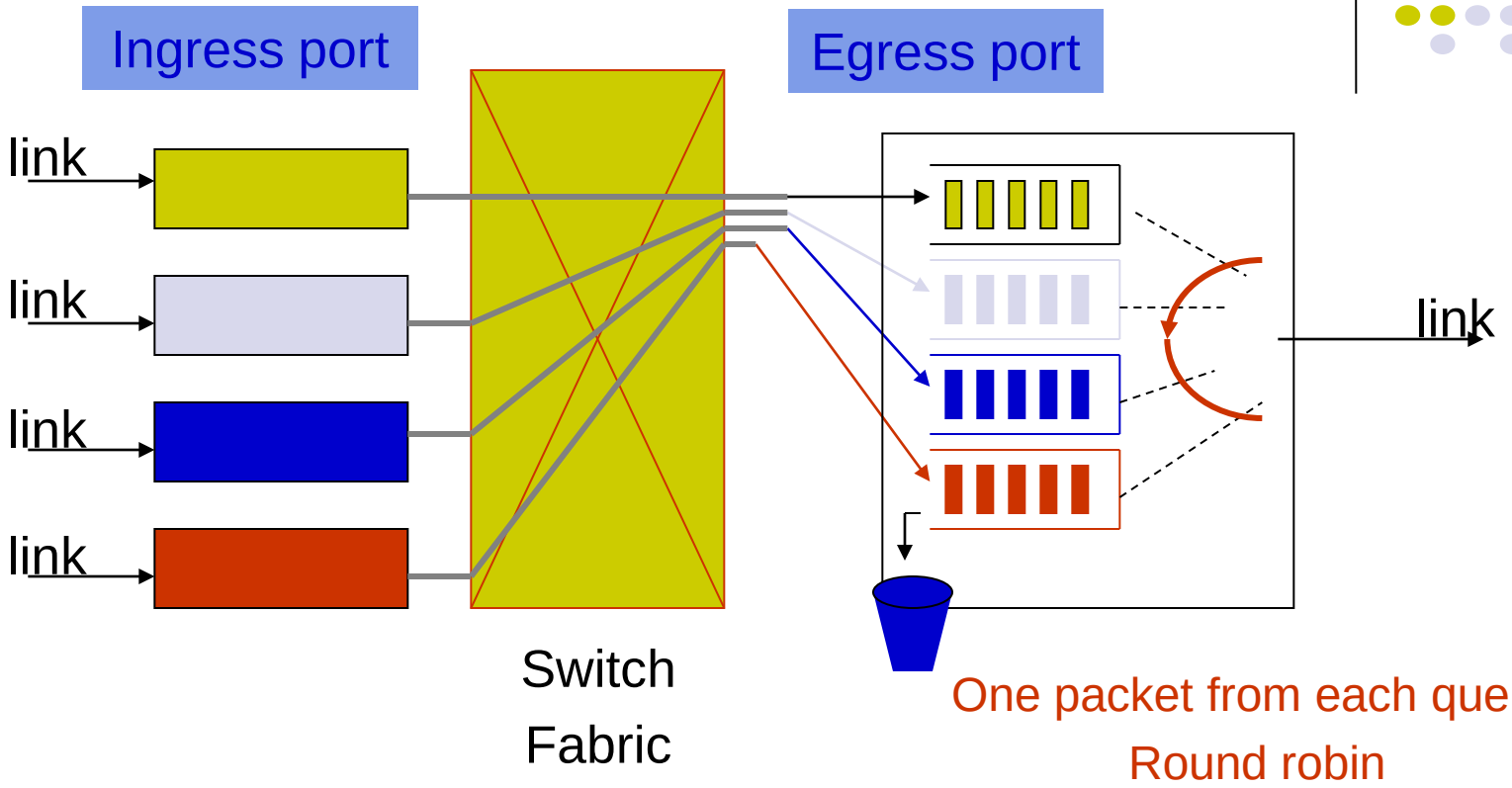
Scheduling



- Traffic is split into flows
  - End-2-end flows based on packet marking

- Differentiated queue treatment (depth, scheduling)
- Queue Scheduling algorithms
  - FIFO
  - Fair Queuing
  - Weighted Fair Queuing (many variations)
  - Priority Queuing / Low Latency Queuing (LLQ)
  - Deadline First Queuing
  - ……

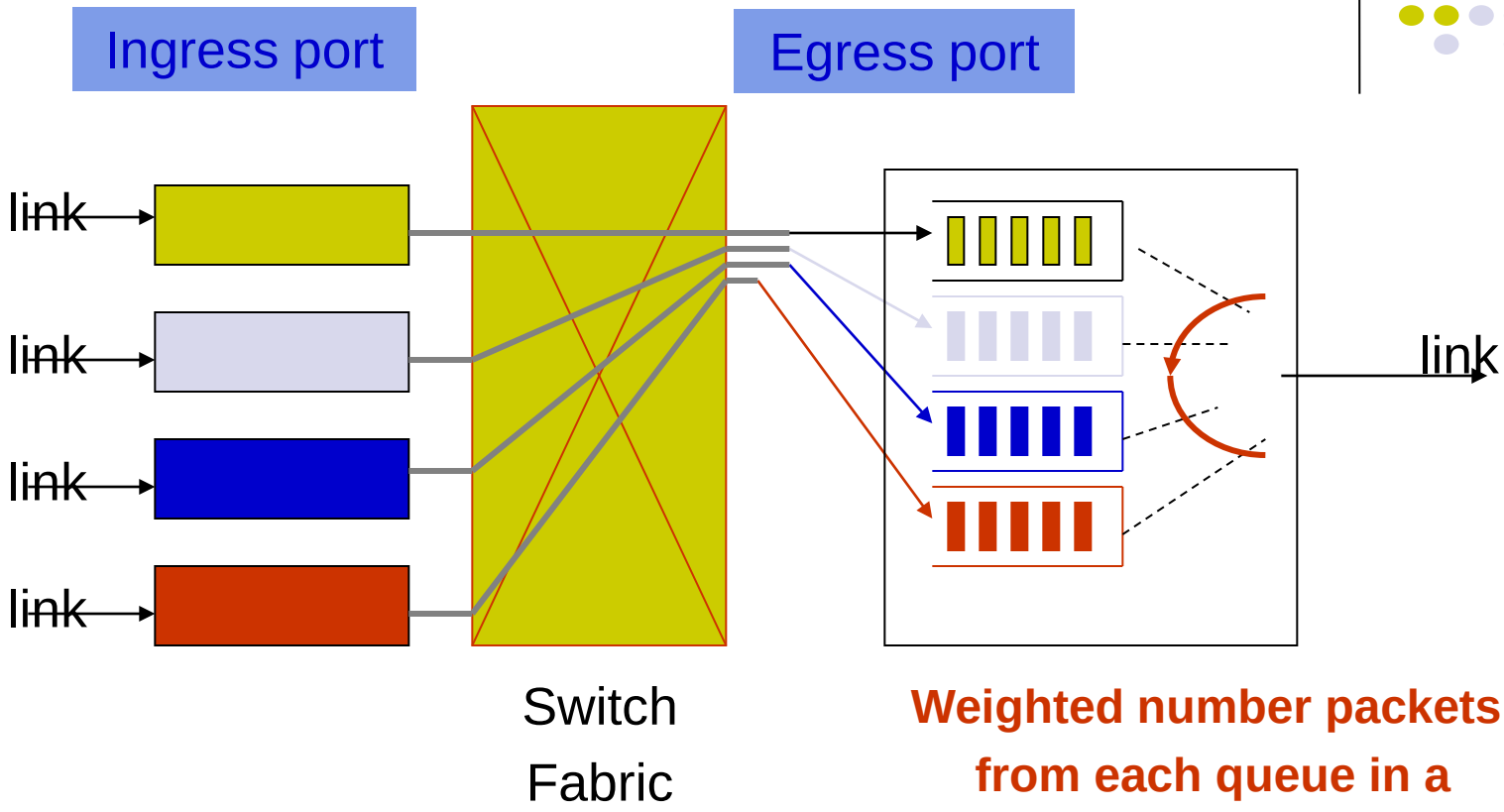
Fair Queuing



The Red source packets got dropped at the egress of the outgoing line card

➔ forces TCP to slow down

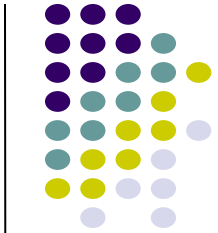
Weighted fair queuing (WFQ)



Special cases:

- Priority Queuing allow a queue to be served immediately once the link is available regardless of how much bandwidth it uses of the link
- Fair queuing with all equal weights

DiffServ Service Classes



Expedited Forwarding (EF)

- Provides a low-loss, low-latency, low-jitter, and assured bandwidth service. Real-time applications such as voice over IP (VoIP), video, and online trading programs require such a robust network-treatment.

Assured Forwarding (AFxy)

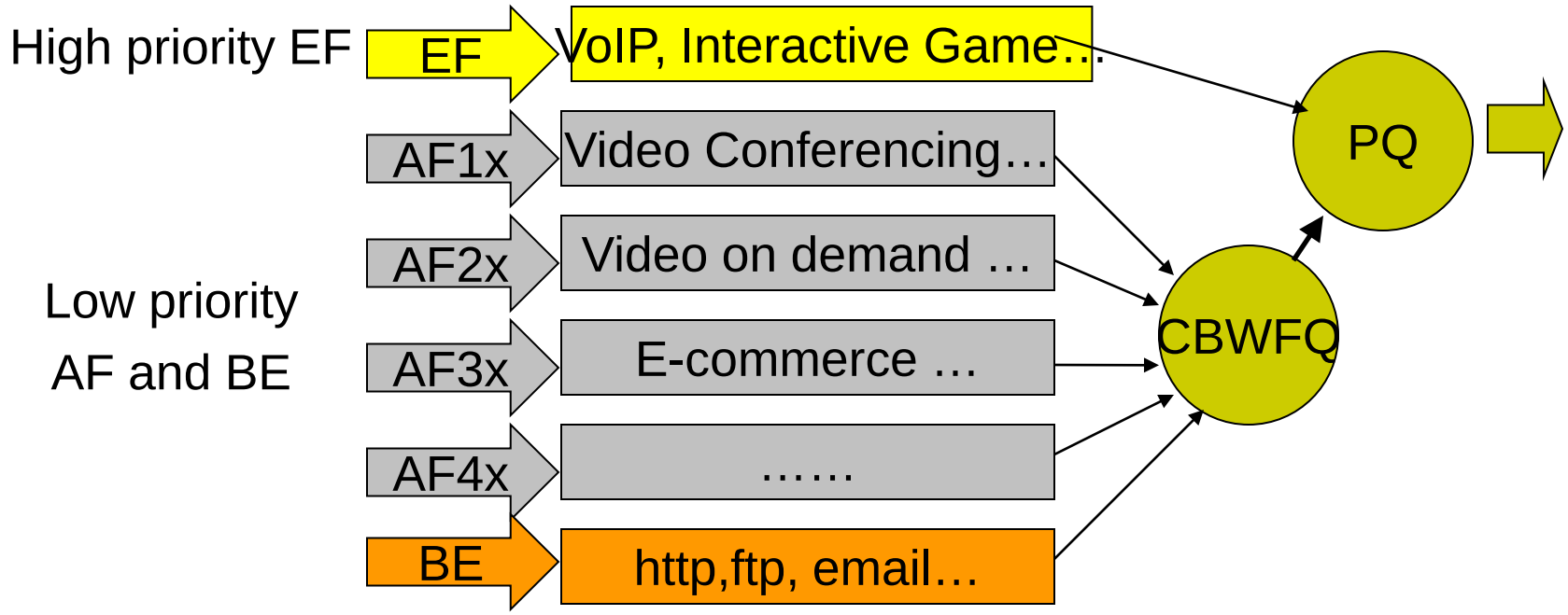
- Provides certain forwarding assurance by allocating certain bandwidth and buffer space. Applications with certain QoS requirements but not real-time can use AF service. For example: streaming video.

Best Effort Service

- No service guarantee except for a minimum bandwidth to prevent service starvation.

Cisco Solution

- LLQ or MDRR



Total reservable bandwidth is about 75%. BE reservation fixed around 25%.
EF traffic is constrained and should not exceed 33%; small queue and packet size.
AFs reserve the rest bandwidth.

Other solutions

- Assign each class certain bandwidth