Common network/protocol functions

Goals:

- Identify, study common architectural components, protocol mechanisms
- *Synthesis:* big picture
- *Depth:* important topics not covered in introductory courses

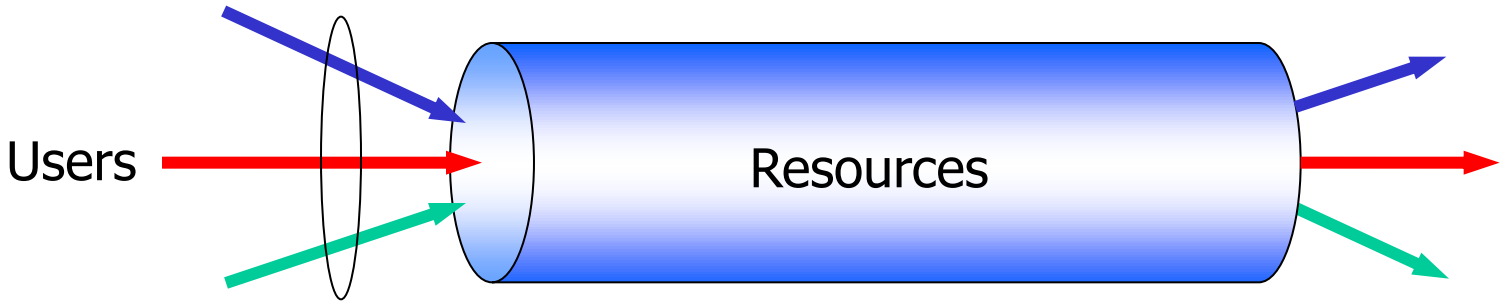
Overview:

- ✓ Signaling
- ✓ State
- **Multiplexing / Resource Allocation**
- Randomization
- Indirection
- Service location
- Network virtualization

with slides from Leon-Garcia and Widjaja, Shenker and Stoica

Multiplexing

Multiplexing: *Sharing* resource(s) among users of the resource.



In this lecture:

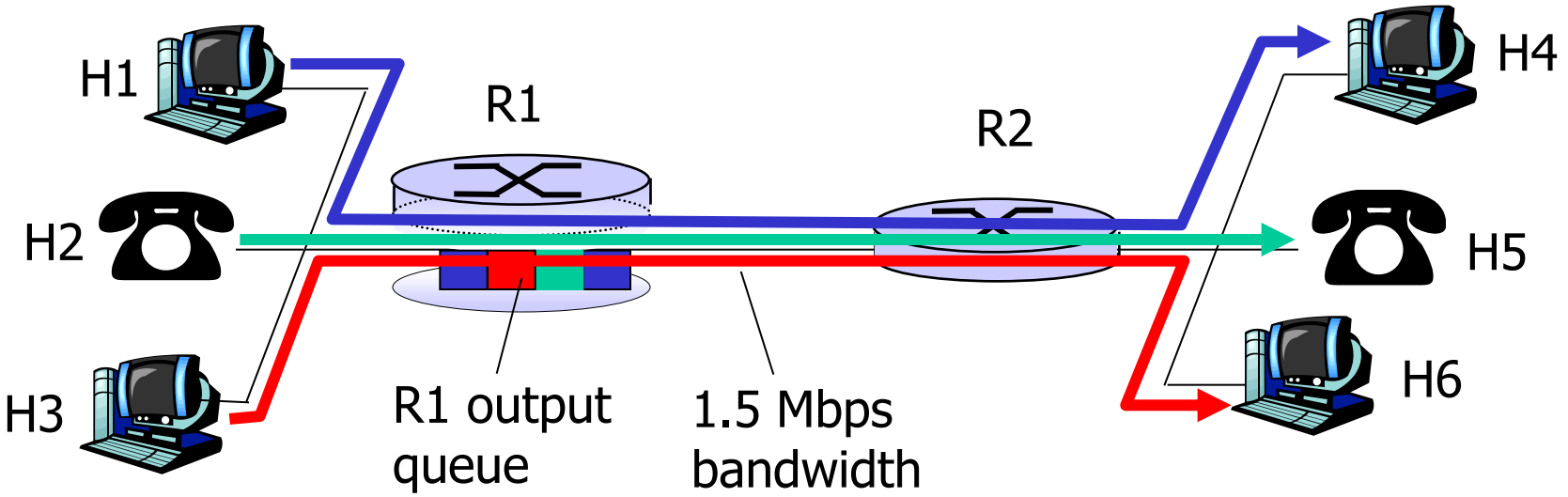
- The Resources are
  - Bandwidth (Link Capacity)
  - Queues (Buffers)
- The Users are
  - Phone Calls
  - TCP/UDP flows, packets

Other types of resources:

- CPU
- Storage
- Frequency spectrum

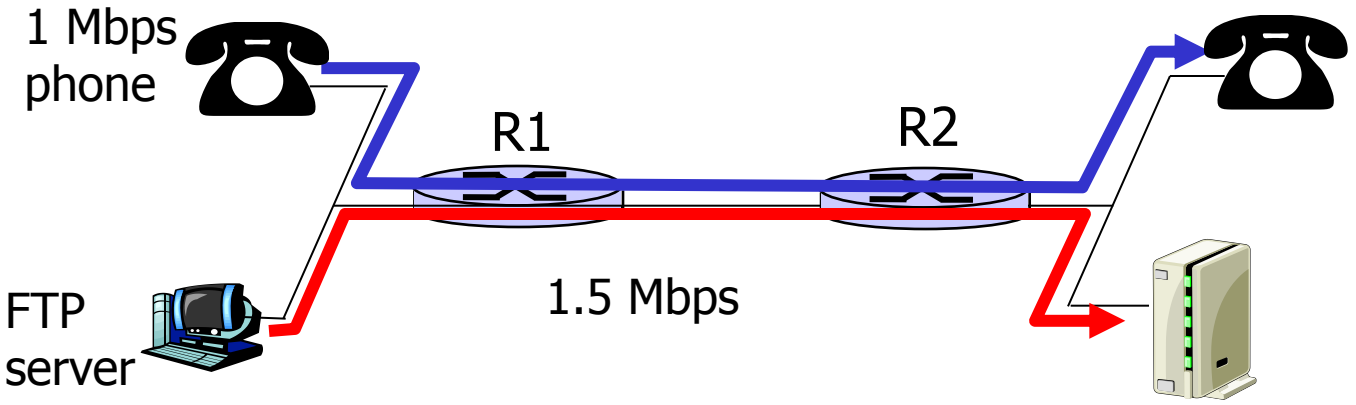
… and other types of users?

The resources and the users



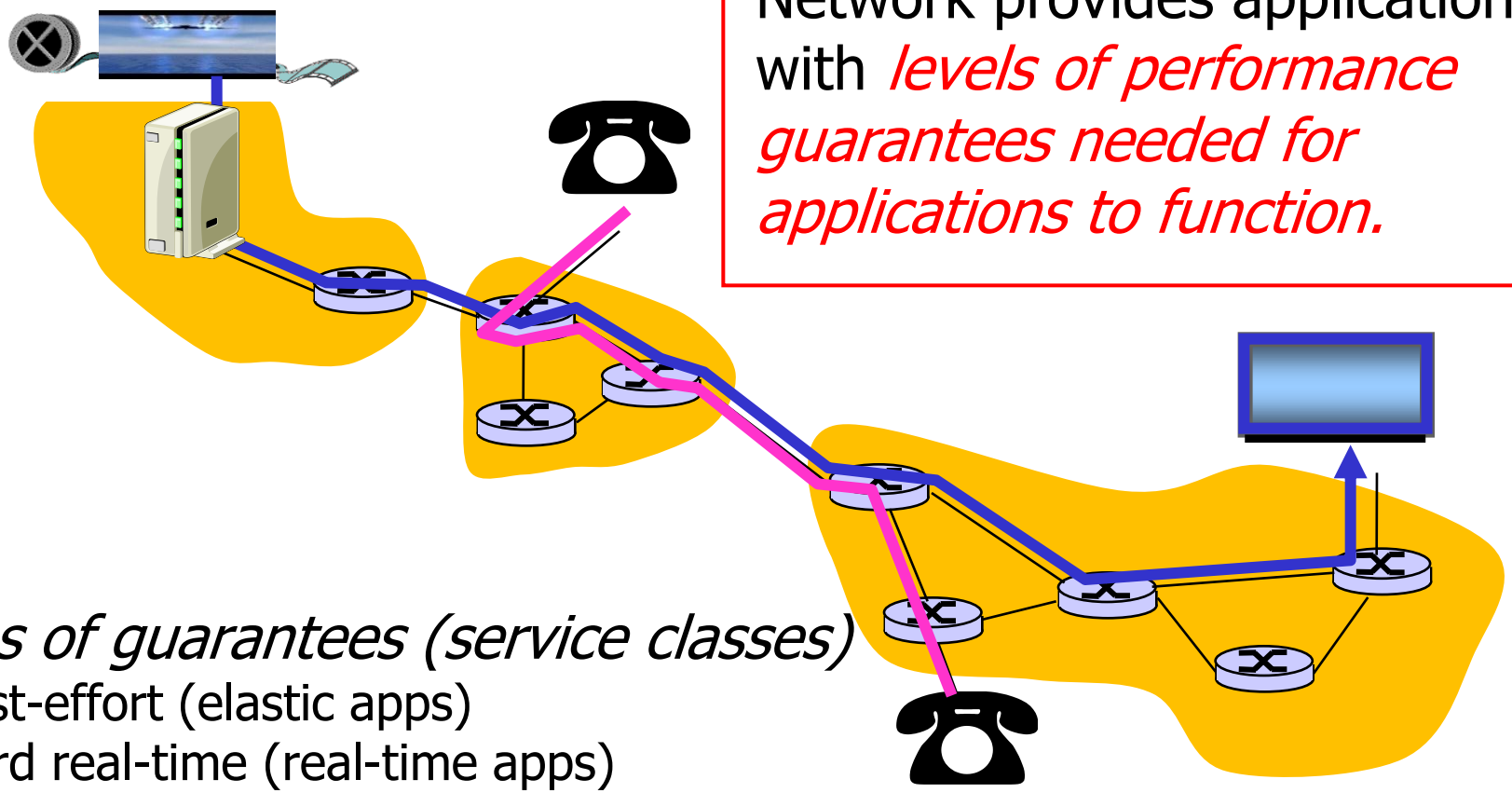
From Multiplexing to QoS

- *Basic facts of life:*
  - Bandwidth is finite
  - Cannot support traffic demands beyond capacity



- Example: 1Mbps IP phone, FTP share 1.5 Mbps link
  - bursts of FTP can congest router, cause large delays/audio loss
- What's to be done?
  - Move away from the best-effort paradigm
  - … provide "Quality of Service (QoS)"

QoS: What is it?



QoS

Network provides applications with *levels of performance guarantees needed for applications to function.*

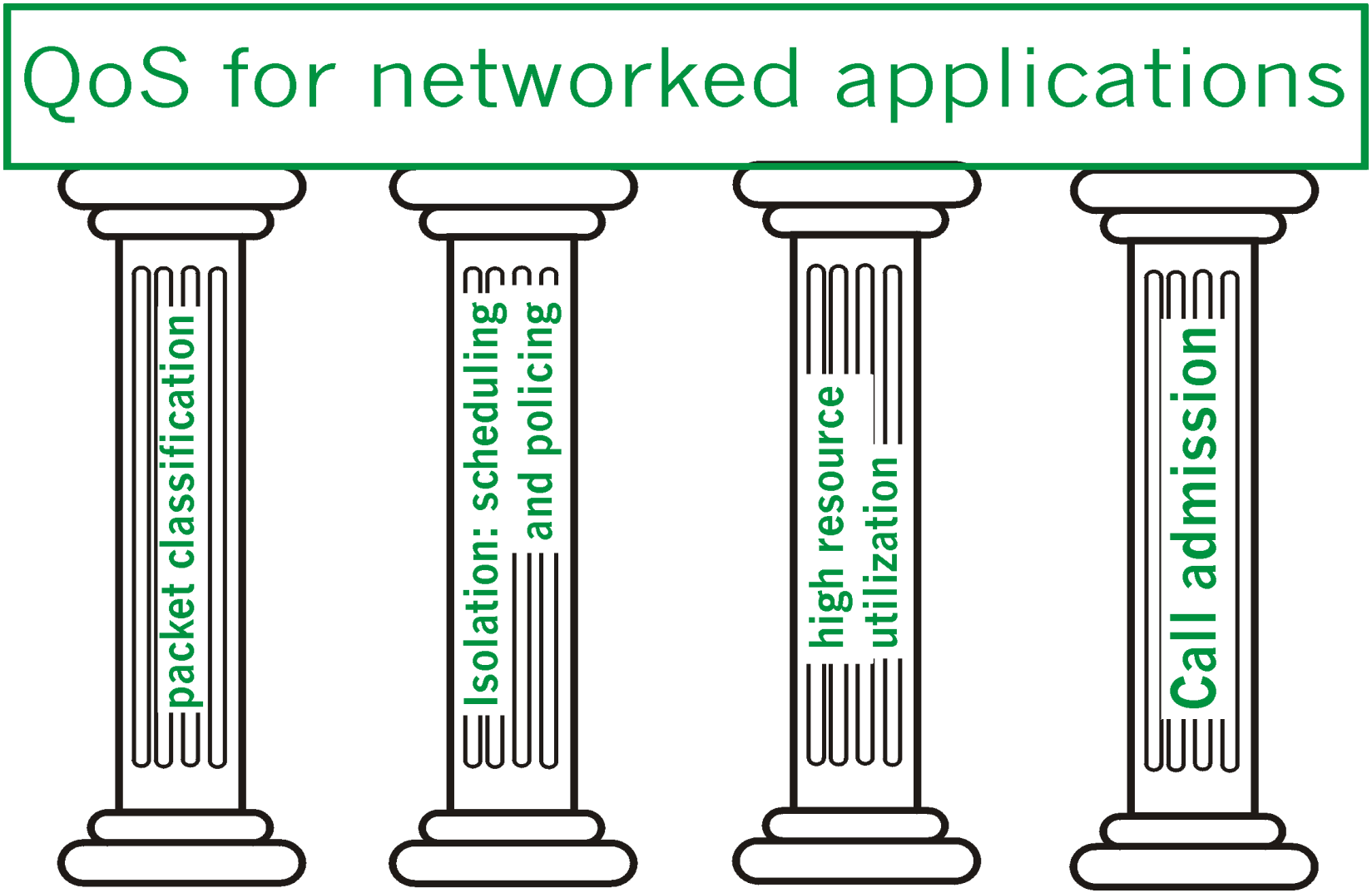
Types of guarantees (service classes)

- Best-effort (elastic apps)
- Hard real-time (real-time apps)
  - e.g., bounded loss / delay
- Soft real-time (tolerant apps)
  - e.g., probabilistic loss / delay

How to implement QoS?

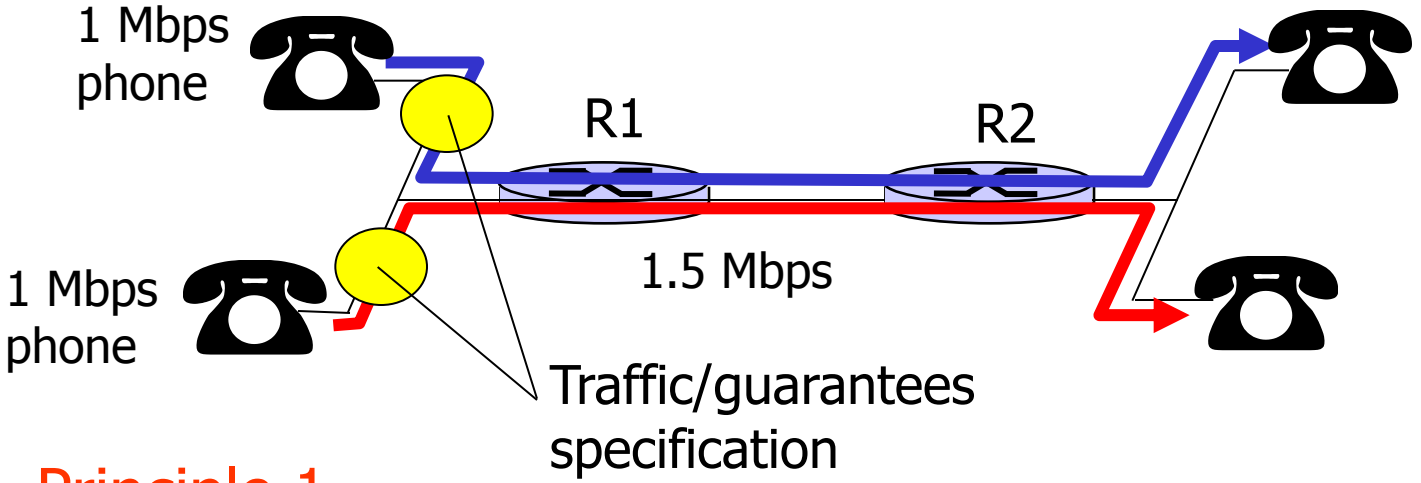
- A set of five principles

Summary of QoS Principles



Principle 1. Traffic/Guarantees specification

- Two 1Mbps IP phones share 1.5 Mbps link
  - want applications to specify: 1) how much bandwidth they need, 2) what levels of guarantees they want

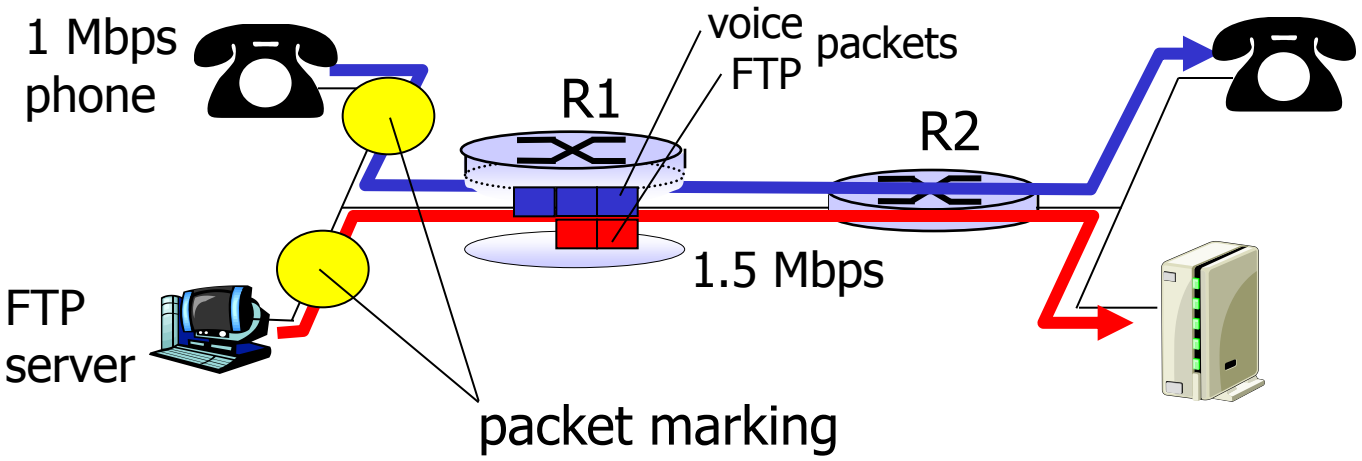


Principle 1

Traffic/guarantees specification (service contract) needed for router to plan whether it can provide certain levels of performance guarantees

Principle 2. Traffic classification

- 1Mbps IP phone, FTP share 1.5 Mbps link
  - bursts of FTP can congest router, cause audio loss
  - want to give priority to audio over FTP
  - Can FTP server declare how much bandwidth it needs?

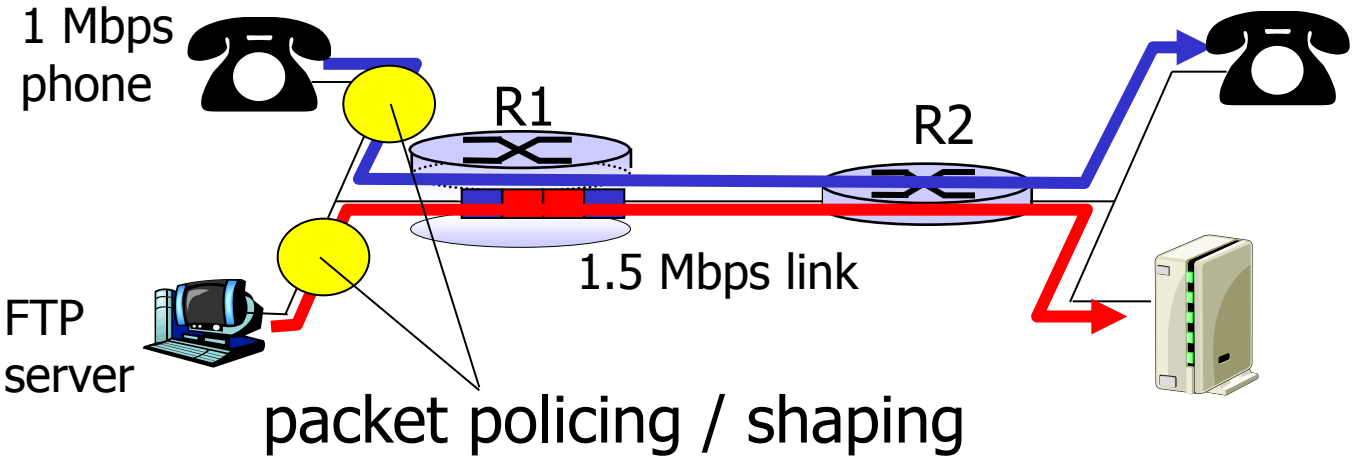


Principle 2

Packet marking needed for router to distinguish between different classes; and new router policy to treat packets accordingly

Principle 3. Traffic isolation

- what if applications misbehave (audio sends higher than declared rate)
  - Want to force source adhere to traffic specification

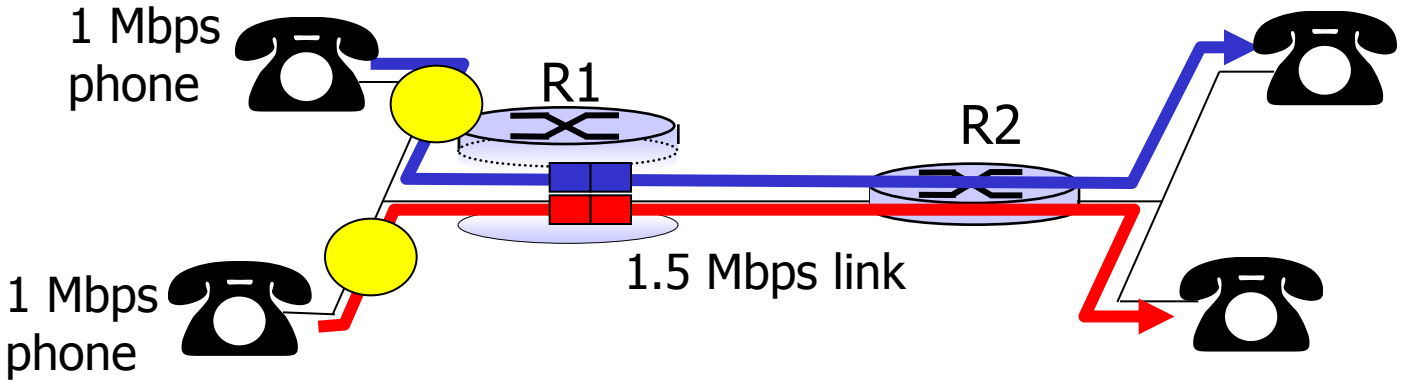


Principle 3

provide protection (*isolation*) for one class from others

Principle 4. Call admission

- Bandwidth is finite
  - Cannot support more than available
  - To provide isolation, some flows have to be sacrificed

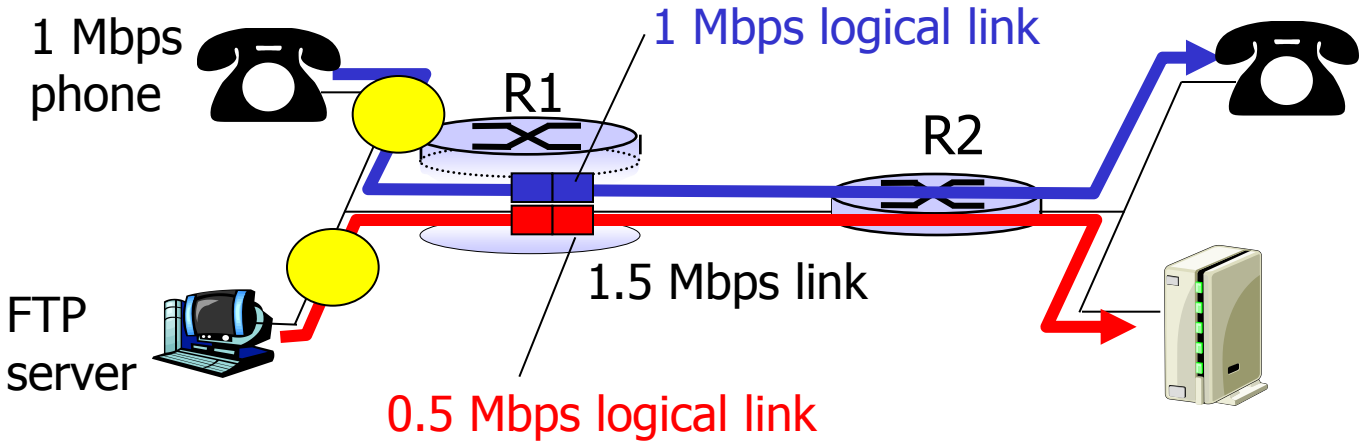


Principle 4

Call Admission: network may block call (e.g., busy signal) if it cannot meet needs.

Principle 5. Resource sharing

- Allocating *fixed* (non-sharable) bandwidth
  - Inefficient if flows don't use it
  - Circuit/packet switching; scheduling



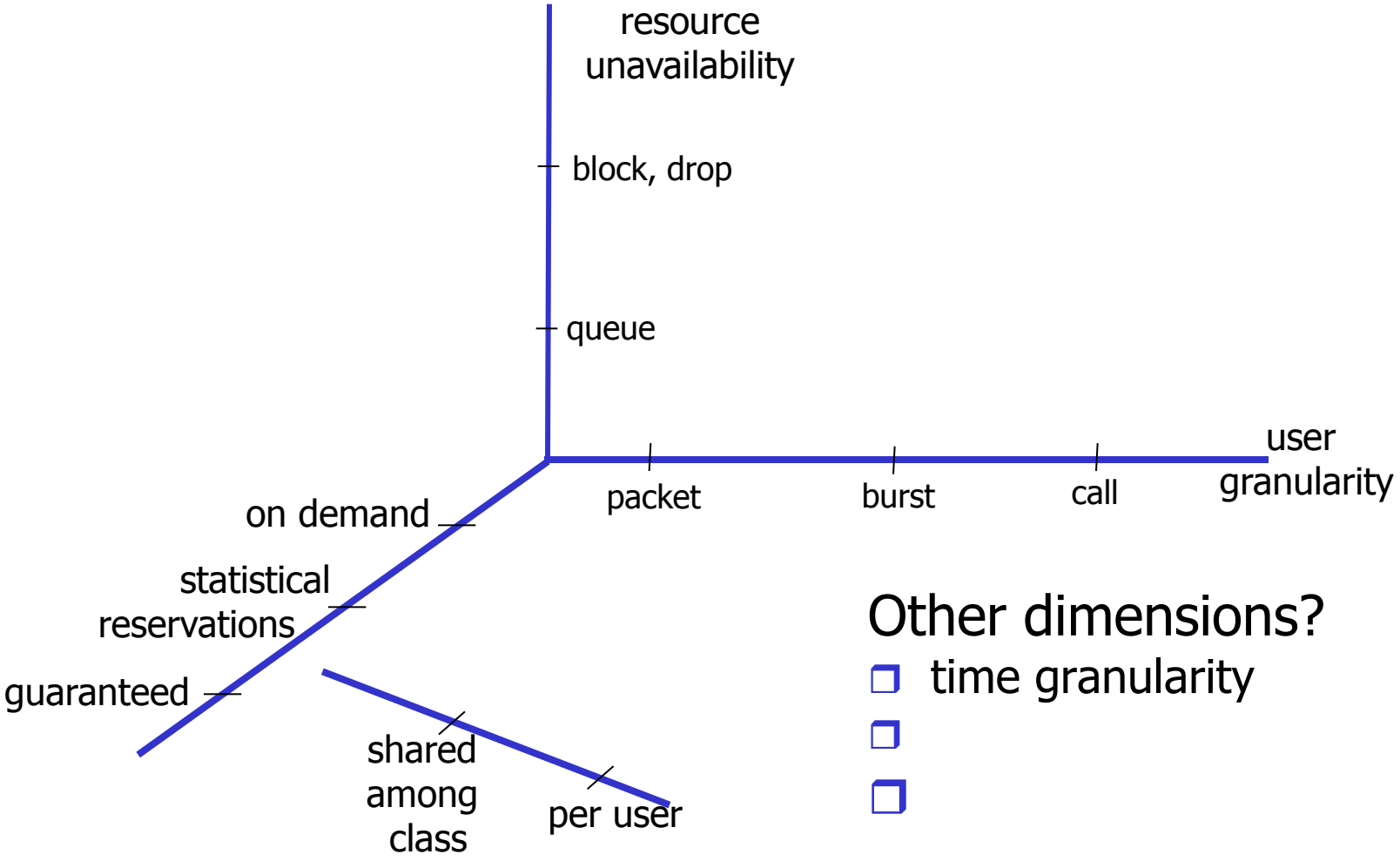
Principle 5

While providing isolation, it is desirable to use resources as efficiently as possible

Service Classes vs. Principles

	Traffic / Guarantees Specification	Traffic Classification	Traffic Isolation	Call Admission	Resource Sharing
Best Effort	Yes/No?	?	?	?	?
Hard real-time	?	?	?	?	?
Soft real-time	?	?	?	?	?

Back to Multiplexing: many dimensions



Other dimensions?

- time granularity
-
-

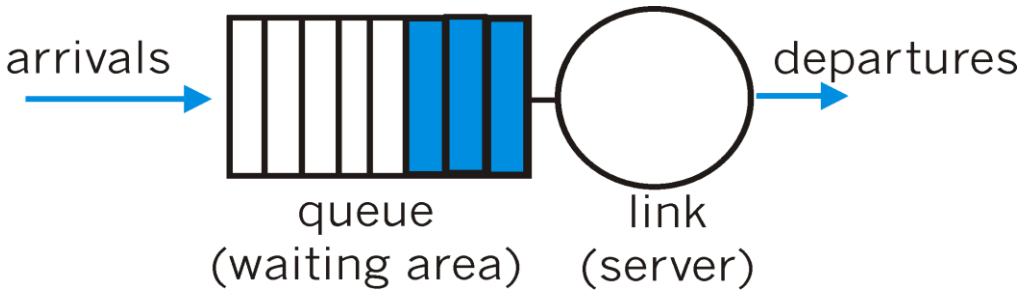
Outline

- Scheduling
- Policing
- Admission Control
- General class-based link sharing (multiplexing)
- Concrete IETF proposals to do things in practice
  - IntServ
  - DiffServ

- Focus on packet-level multiplexing!

Scheduling And Policing *Packets*

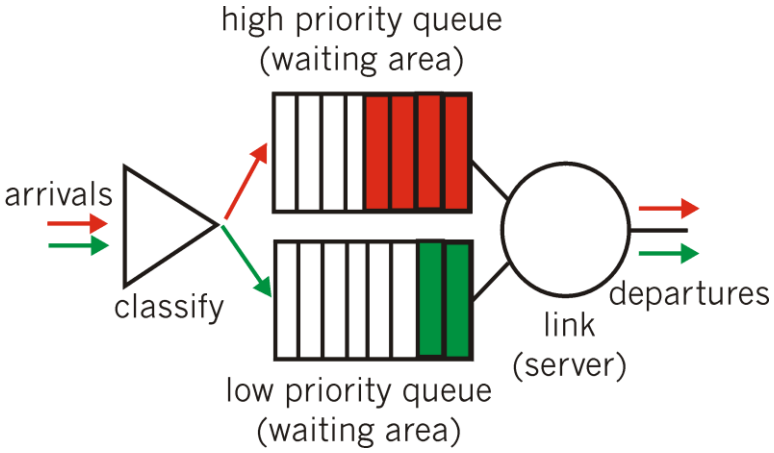
- Scheduling: choose next packet to send on link
- FIFO (first in first out) scheduling: send in order of arrival to queue
  - Real-world example: stop sign
  - Discard policy:
    - Tail drop: drop arriving packet
    - RED

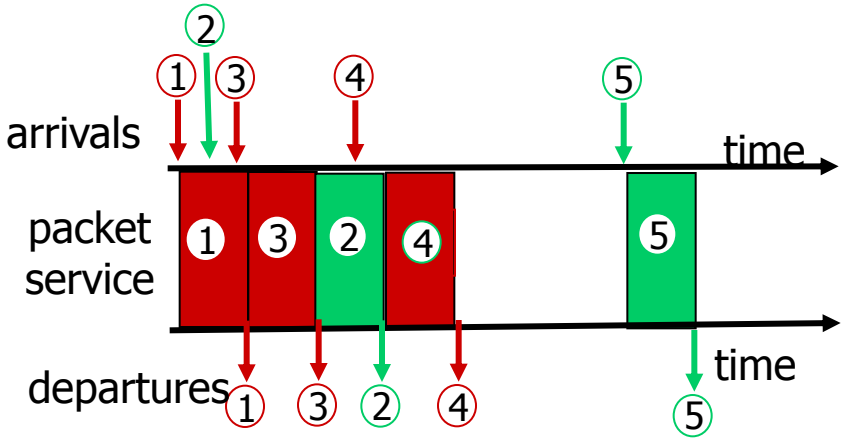


Scheduling Policies: more

Strict Priority scheduling: transmit highest priority queued packet

- Multiple *classes*, with different priorities
  - class may depend on marking or other header info, e.g. IP source/dest, port numbers, etc.
  - real world example: reservations versus walk-ins

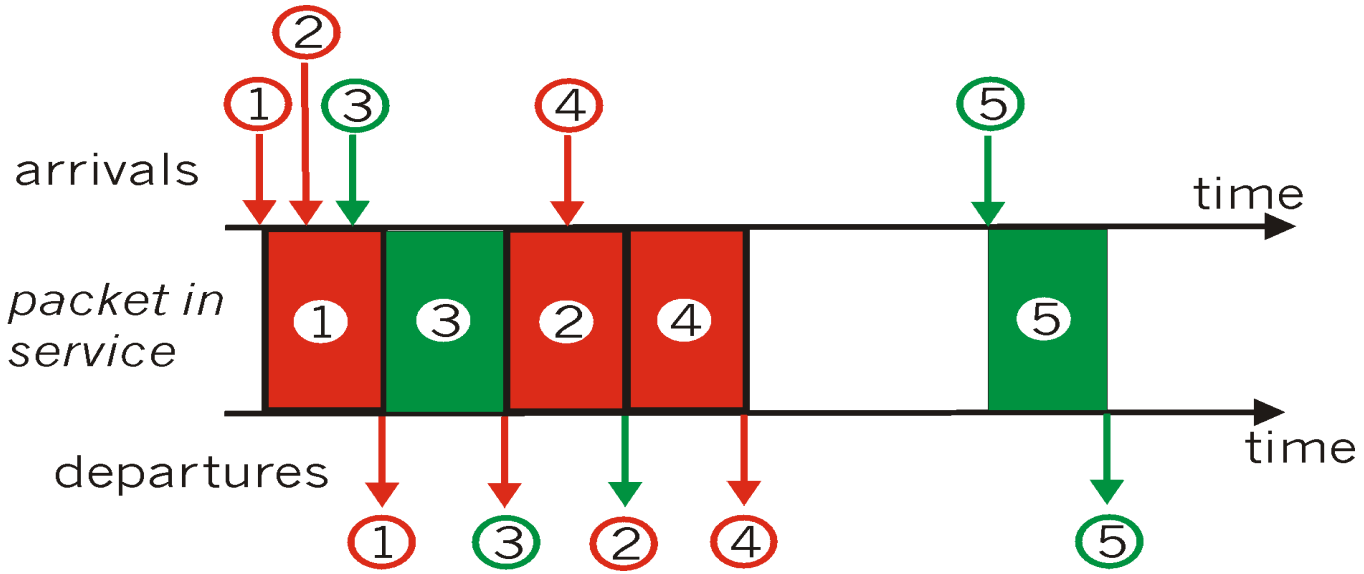




Scheduling Policies: still more

Round robin scheduling:

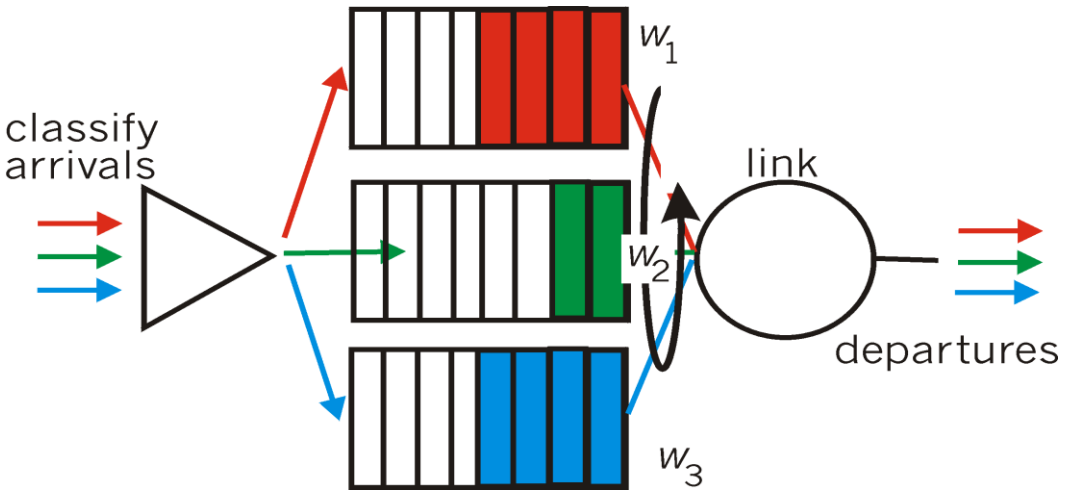
- Multiple classes
- Cyclically scan class queues, serving one from each class (if available)
- Real-world example: 4-way stop (distributed scheduling)



Scheduling Policies: still more

Weighted Fair Queuing:

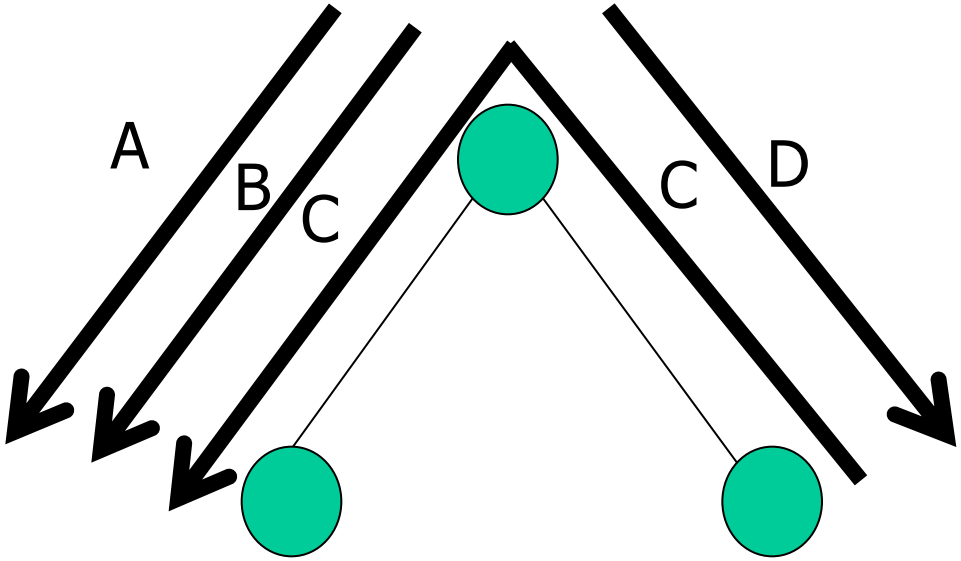
- generalized Round Robin
- each class gets weighted amount of service in each cycle



Excursion: Fairness (1)

- How to divide a resource fairly?
- Philosophical question…
  - many notions of fairness exist!

Fair shares for flows A,B,C,D?



Excursion: Fairness (2)

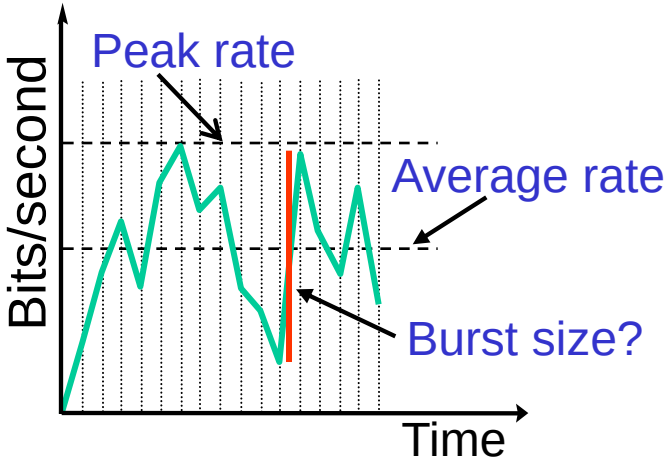
- Important concept: max-min fairness

Max-Min Fairness

A max-min fair scheduler maximizes the minimum rate of any data flow.
(First, the smallest rate is maximized, then the second smallest, etc.)

Policing Mechanisms

Goal: Limit traffic to not exceed declared parameters

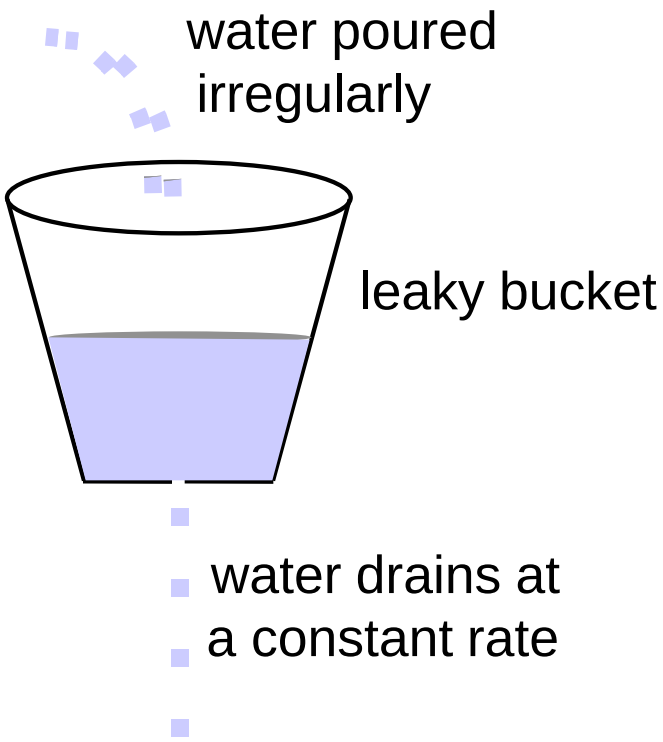


Three commonly-used criteria:

- *(Long term) Average Rate:* how many pkts can be sent per unit time (in the long run)
  - crucial question: what is interval length: 100 packets per sec or 6000 packets per min have same average!
- *Peak Rate:* e.g., 6000 pkts per min. (ppm) avg.; 15000 ppm peak rate
- *(Max.) Burst Size:* max. number of pkts sent consecutively (with no intervening idle)

Leaky Bucket Algorithm

Used to police arrival rate + burst size of a packet flow(s)



Leak rate corresponds to long-term rate

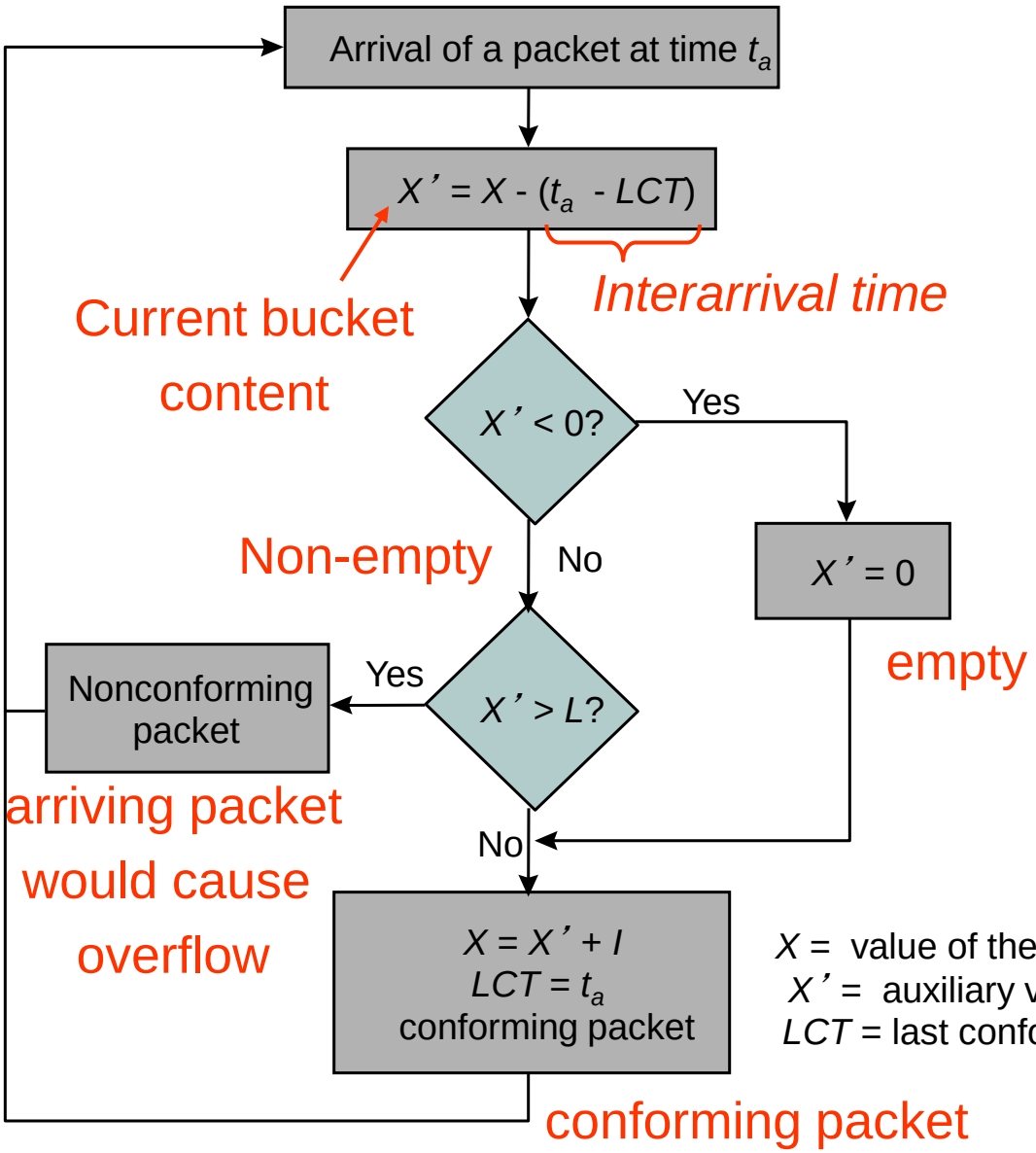
Bucket depth corresponds to maximum allowable burst arrival

1 packet per unit time
Assume constant-length packet

Let X = bucket content at last conforming packet arrival

Let t_a – last conforming packet arrival time = depletion in bucket

Leaky Bucket Algorithm



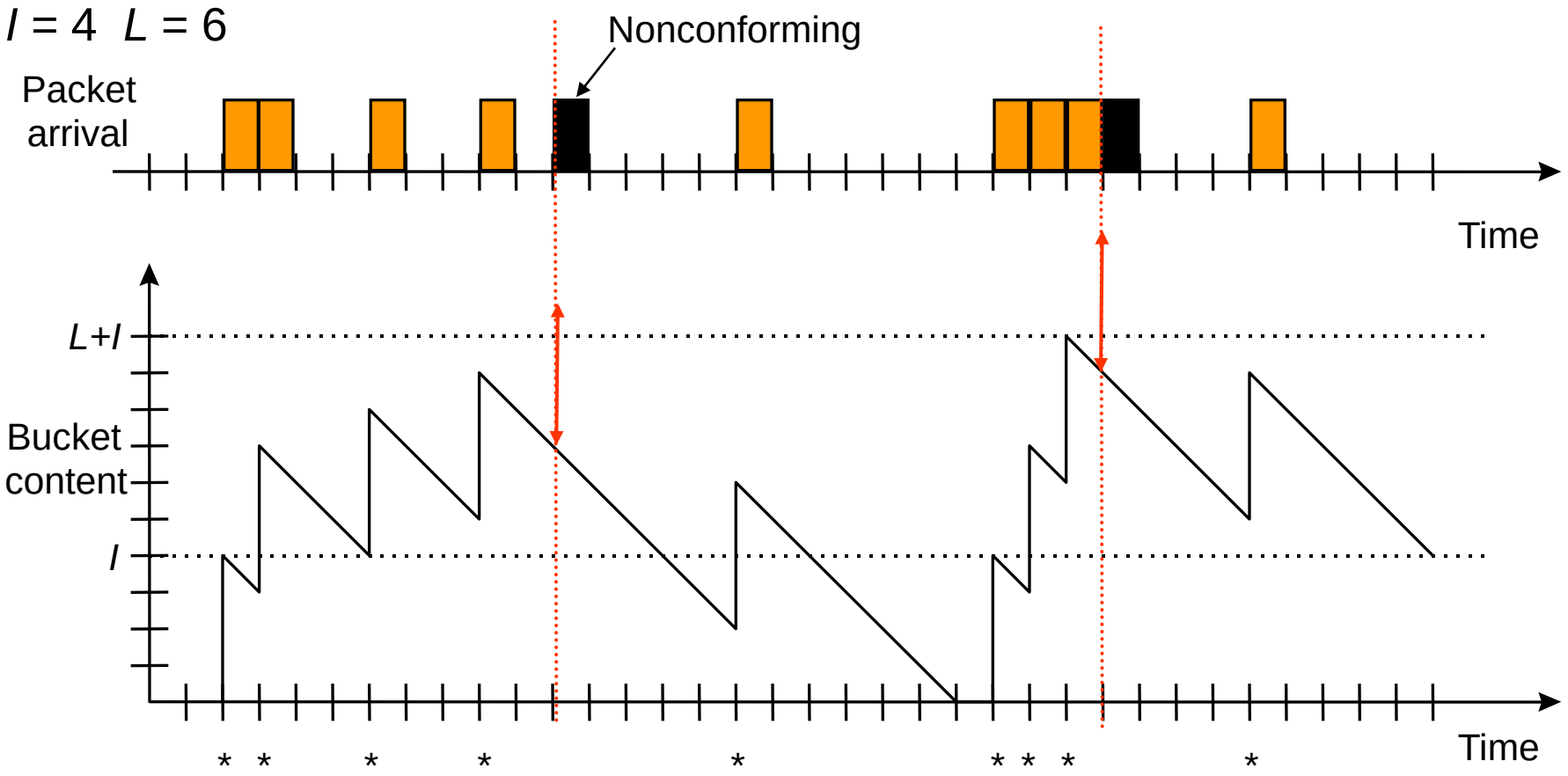
Depletion rate:
1 packet per unit time

$b = L+I$ = Bucket Depth

I = increment per arrival, nominal interarrival time

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

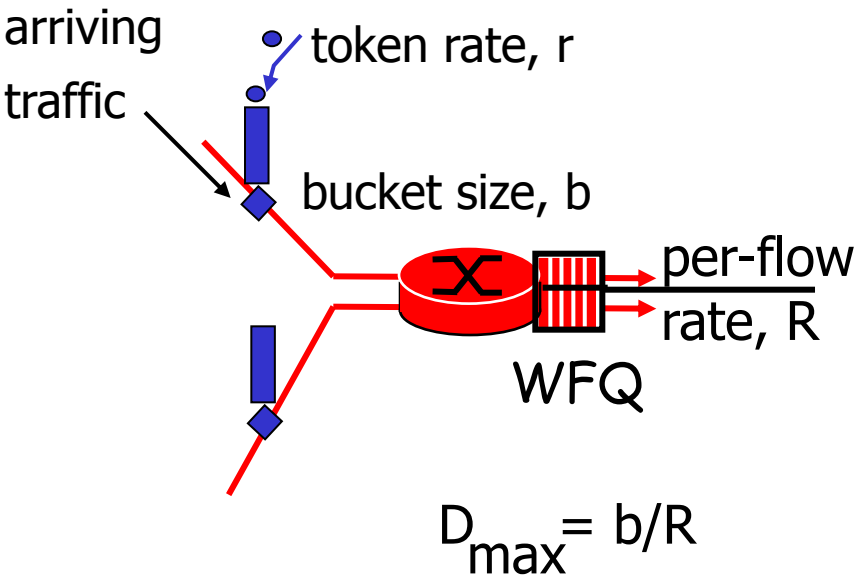
Leaky Bucket Example

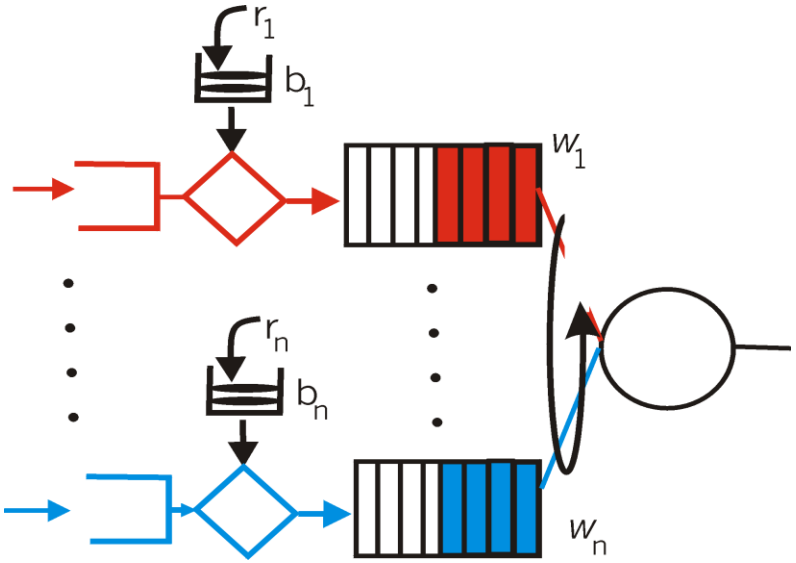


Non-conforming packets not allowed into bucket & hence not included in calculations

Policing Mechanisms (more)

- Leaky bucket, WFQ combine to provide guaranteed upper bound on delay, i.e., *QoS guarantee*!





Admission Control

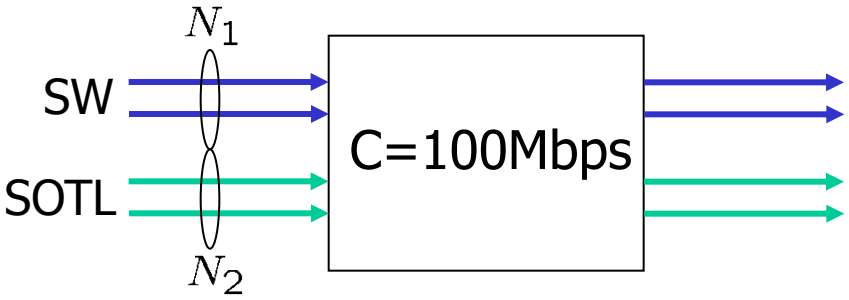
- Users watch either one of two movies
  - Star Wars (with the declared parameters)

$$A_1(s,t) \leq \min\{P_1(t-s), r_1(t-s)+b_1\}$$
$$P_1 = 5Mbps,\ r_1 = 2Mbps,\ b_1 = .7Mb$$

  - Silence of the Lambs (with the declared parameters)

$$A_2(s,t) \leq \min\{P_2(t-s), r_2(t-s)+b_2\}$$
$$P_2 = 4Mbps,\ r_2 = 1Mbps,\ b_2 = .5Mb$$

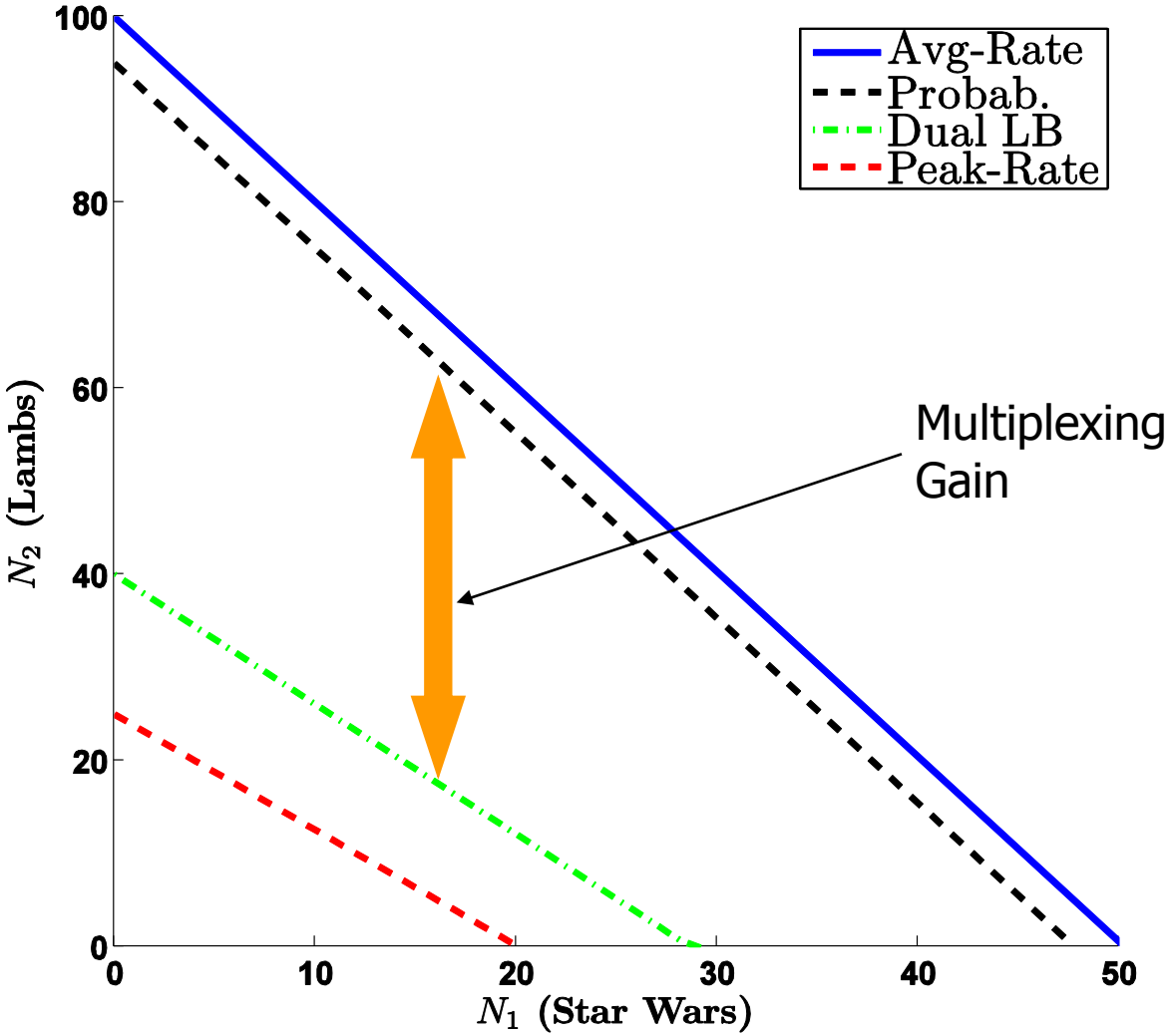
- *Concrete Problem*: How many users can be admitted at a C=100Mbps link such that the delay for each user/movie is less than d=200ms?



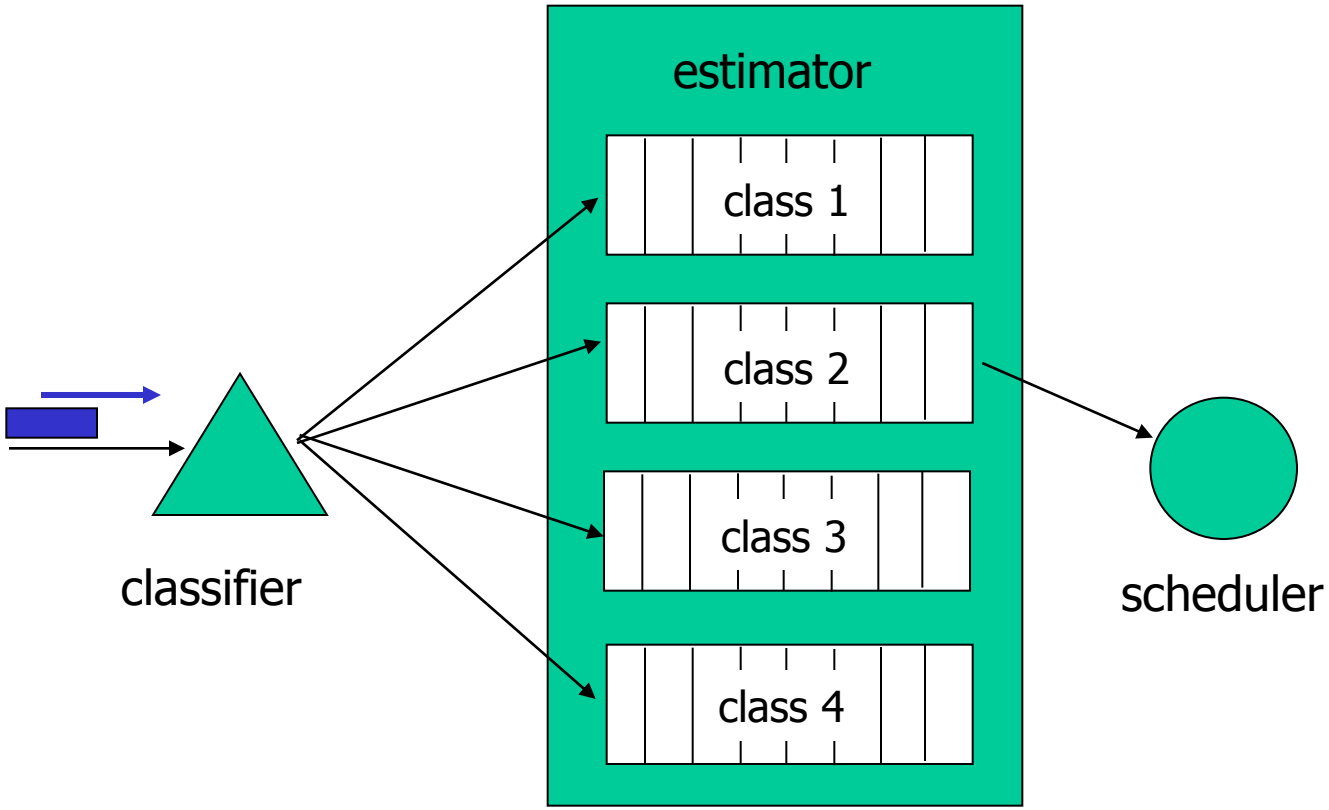
Admission Control (Contd.)

- Peak rate admission control
  - Provides hard-guarantees
- Dual Leaky-bucket admission control
  - Provides hard-guarantees
- Statistical admission control
  - Provides soft-guarantees
- Average rate admission control
  - Only qualitative guarantees (e.g., delay is always finite)

Admission Control. Numerical Example



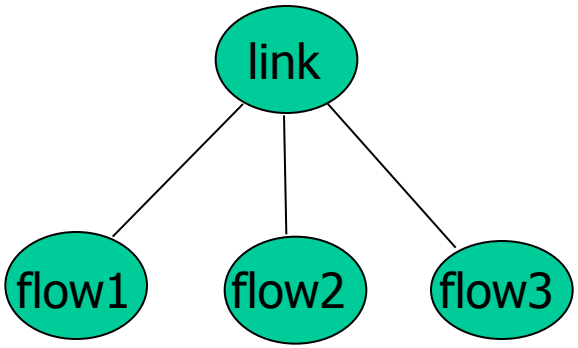
General Model of Class-based Link Scheduling

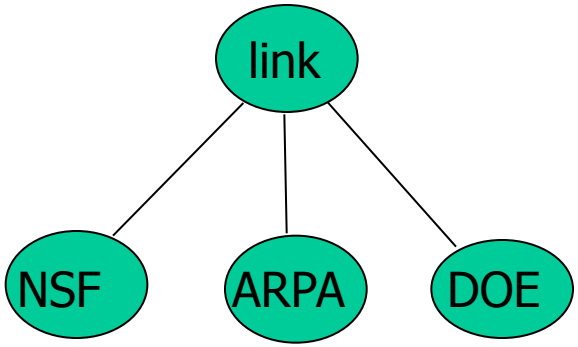


Link sharing among classes

The question: sharing link among classes of packets in times of overload

- isolation among classes
- sharing between classes when link not fully used





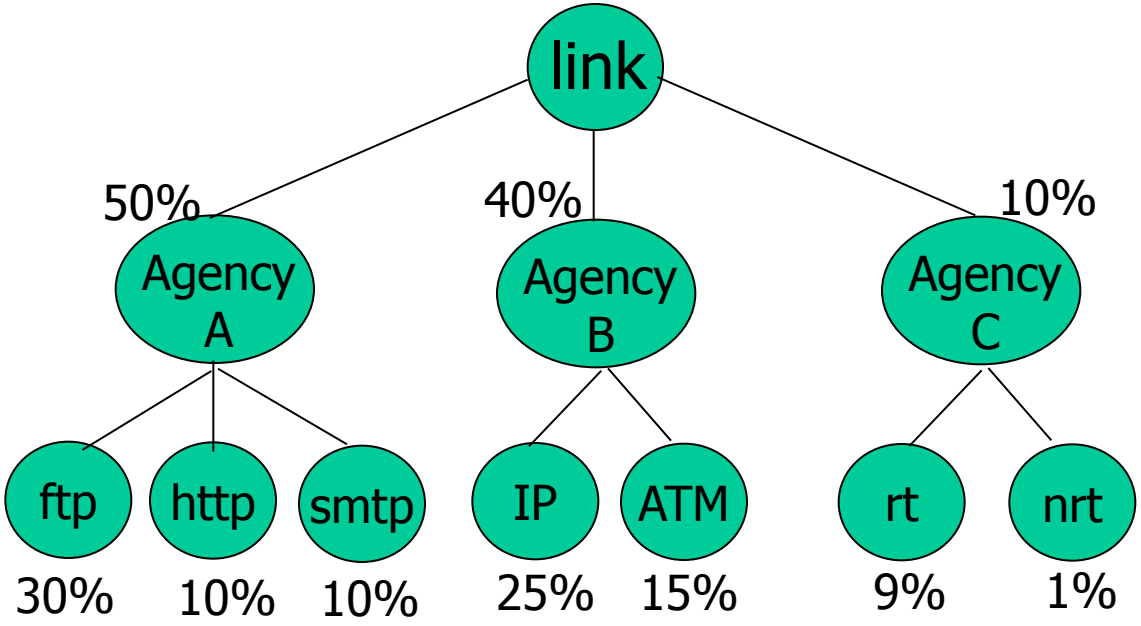
Link Scheduling Framework

- each class guaranteed some share (fraction) of bandwidth (over suitable time interval) *if needed*
- *Use it or lose it:* unused bandwidth should be used by others who can use it

Under-limit class: used less than guaranteed share
Over-limit class: used more than guaranteed share. Not a bad thing if not needed by others!
At-limit class

Unsatisfied class: has a persistent backlog and is under limit ☹ (persistent backlog intentionally not defined)
Satisfied: not unsatisfied ☺

Link Scheduling Hierarchies

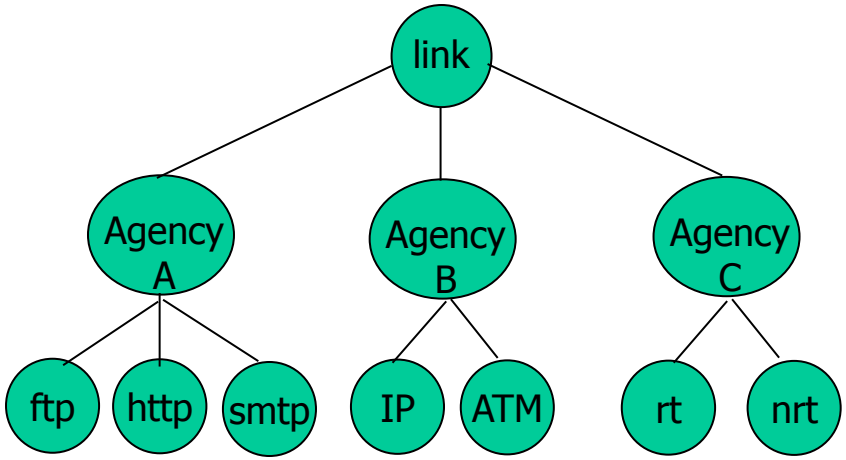


Classes may be divided into subclasses, which can then further divide class bandwidth according to link scheduling guidelines

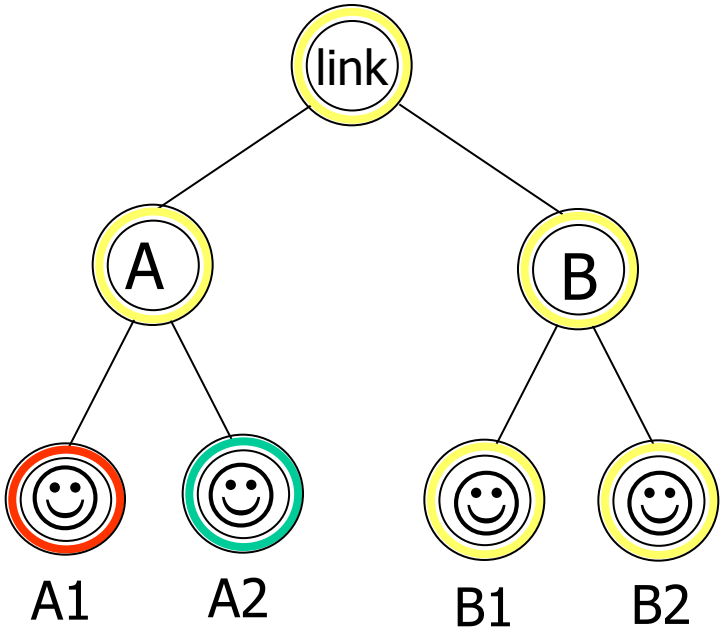
Link Scheduling Guidelines

A class can continue unregulated if one of the following hold:

- the class is not overlimit
- the class has a not-overlimit ancestor at level i, and there are no unsatisfied classes in link sharing structure at levels lower than i

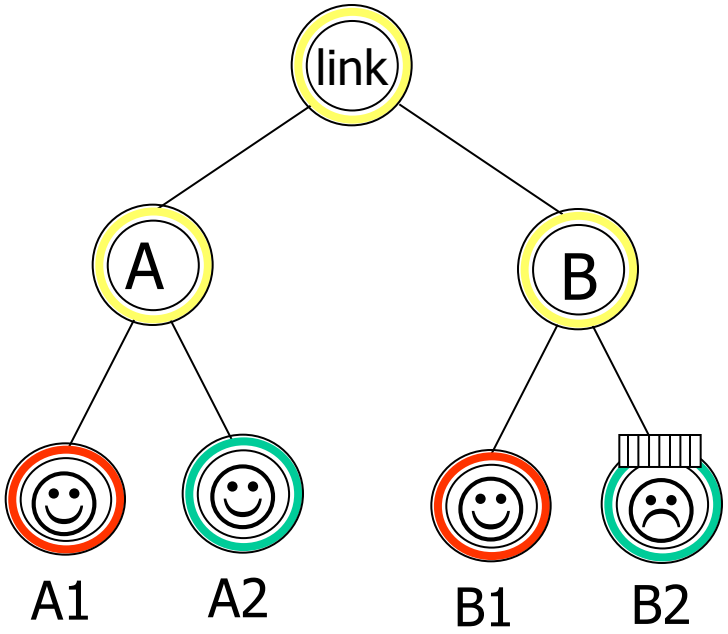


Example 1



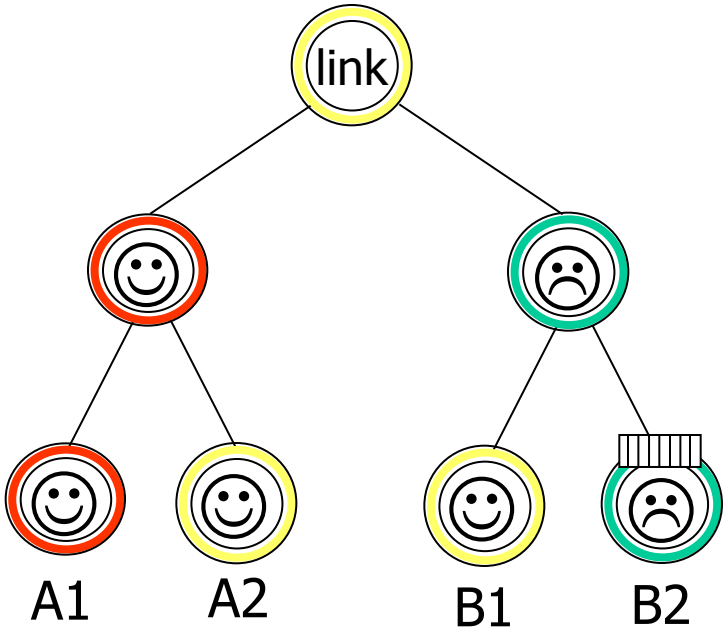
Q; which classes need to be regulated?

Example 2



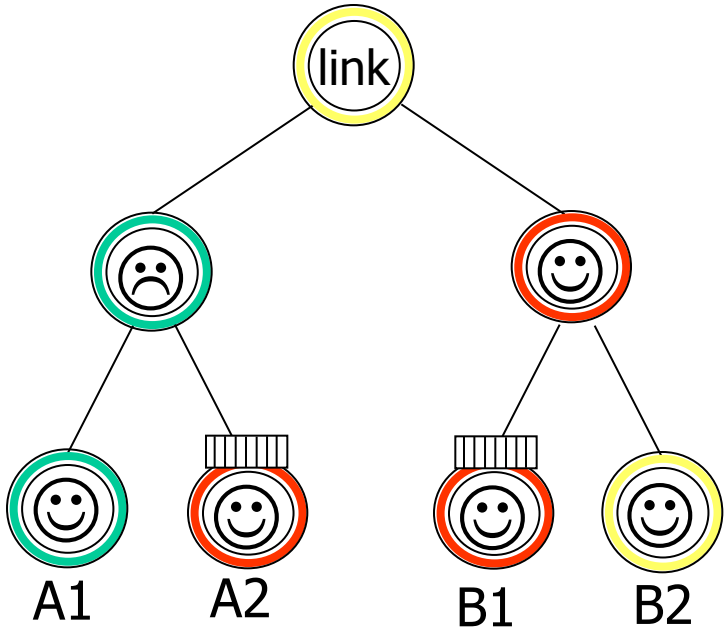
Q; which classes need to be regulated?

Example 3



Q; which classes need to be regulated?

Example 4



Q; which classes need to be regulated?

Link Sharing Summary

- Timescales over which persistent backlog and under/over limit defined are crucial
- Provide “rationale” basis for determining who is available to be scheduled in a multi-class, multi-objective system (elegantly)
- Devil is in the details
  - E.g., malicious users, parallel flows ...

QoS in the Internet. Part I. IETF Integrated Services

- Architecture for providing QOS guarantees in IP networks for individual application sessions
- Resource reservation: routers maintain state info of allocated resources, QoS req's
- Admit/deny new call setup requests:

Question: can newly arriving flow be admitted with performance guarantees while not violating QoS guarantees made to already admitted flows?

Call Admission

Arriving session must …

- declare its QOS requirement
  - R-spec: defines the QOS being requested
- characterize traffic it will send into network
  - T-spec: defines traffic characteristics
- signaling protocol: needed to carry R-spec and T-spec to routers (where reservation is required)
  - RSVP

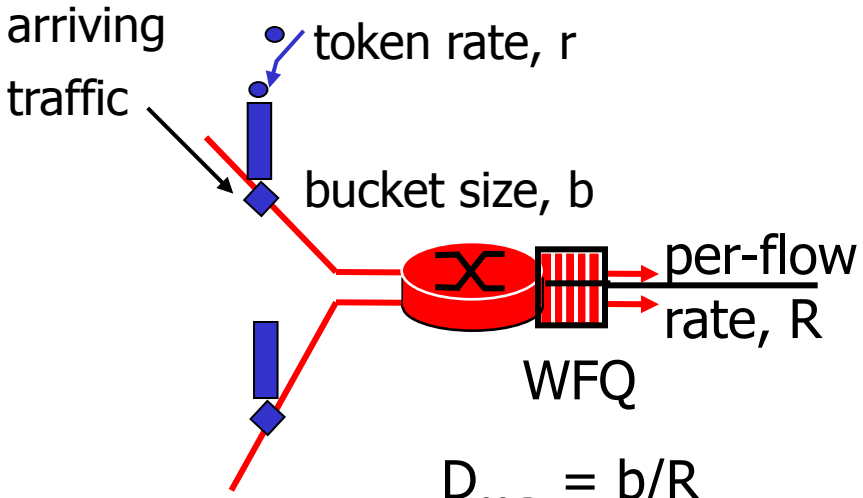
Intserv QoS: Service models [rfc2211, rfc 2212]

Guaranteed service:

- worst case traffic arrival: leaky-bucket-policed source
- simple (mathematically provable) *bound* on delay [Parekh 1992, Cruz 1988]

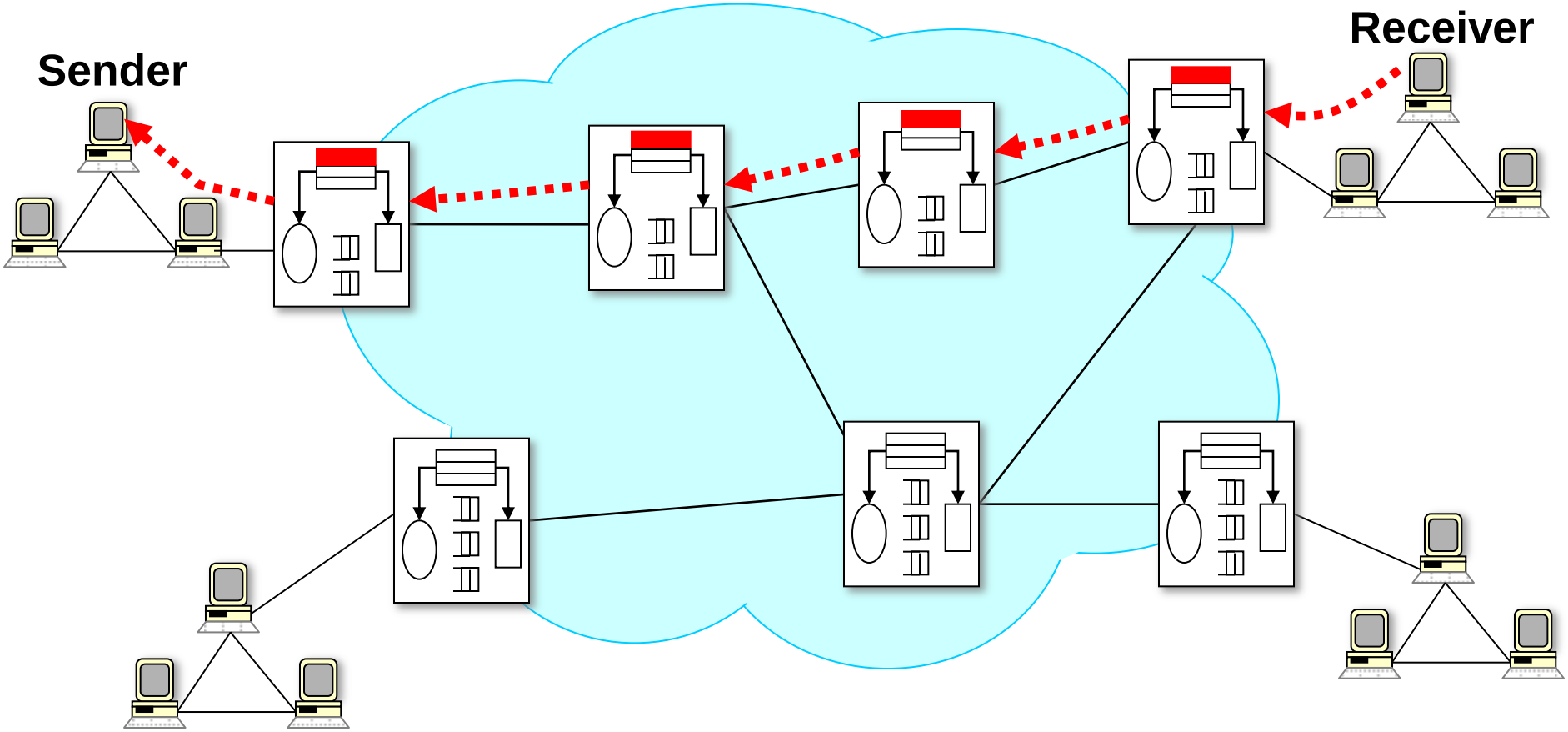
Controlled load service:

- "a quality of service closely approximating the QoS that same flow would receive from an unloaded network element."



Integrated Services Example

- Install per flow state

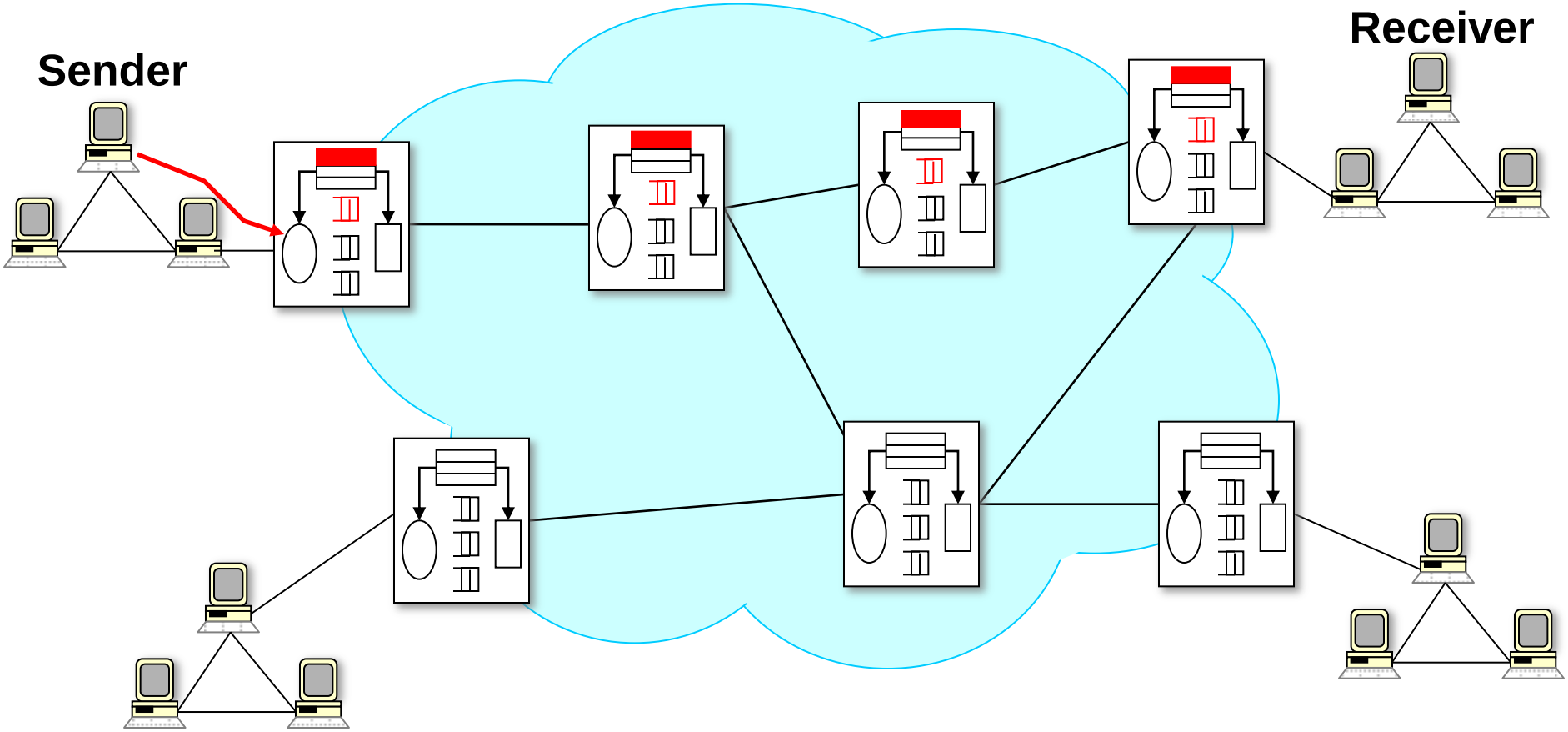


Recall RSVP

- Signaling protocol for establishing per flow (soft) state
- Carry resource requests from hosts to routers
- Collect needed information from routers to hosts
- At each hop
  - Consult admission control and policy module
  - Set up admission state or informs the requester of failure
- Decouples routing from reservation

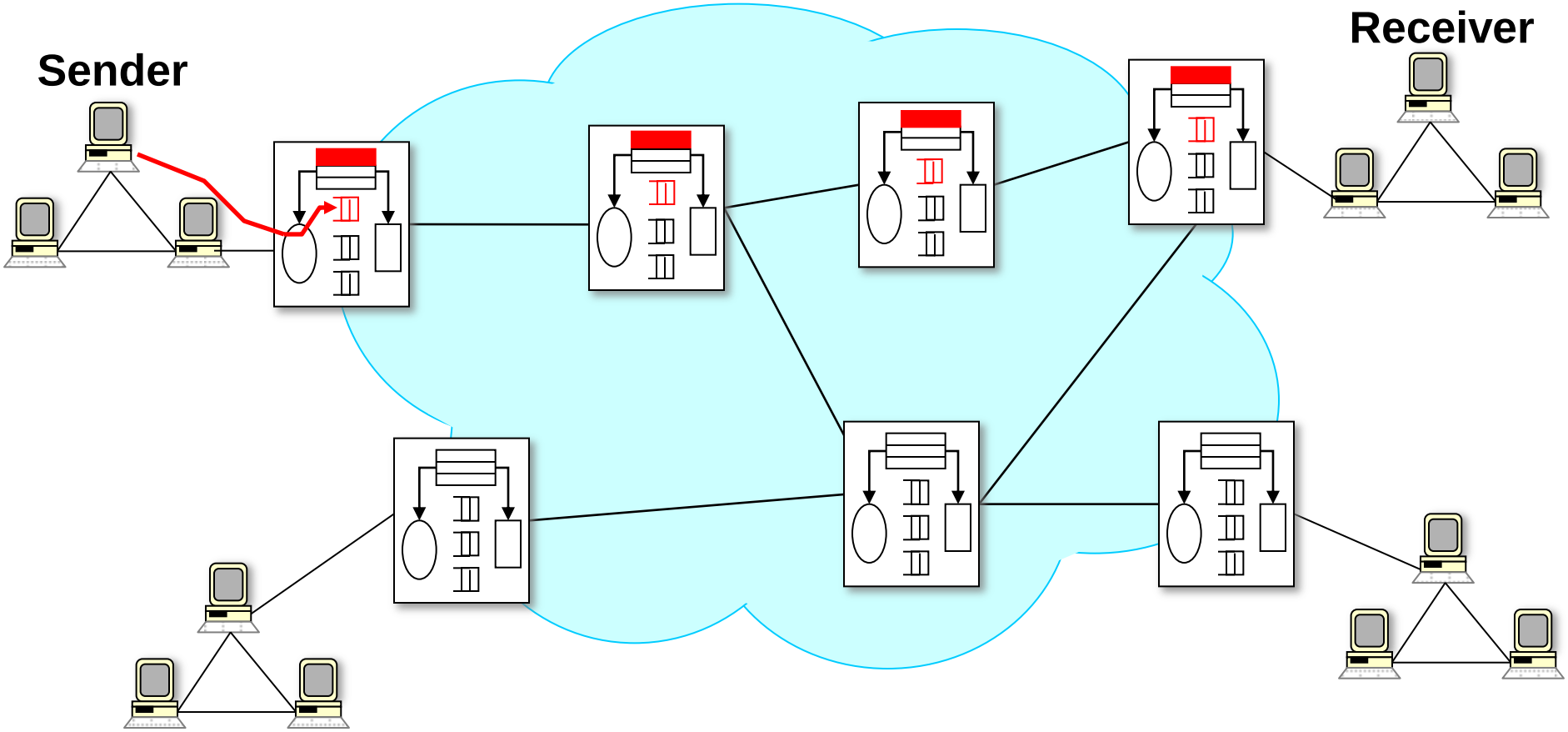
Integrated Services Example: Data Path

- Per-flow classification



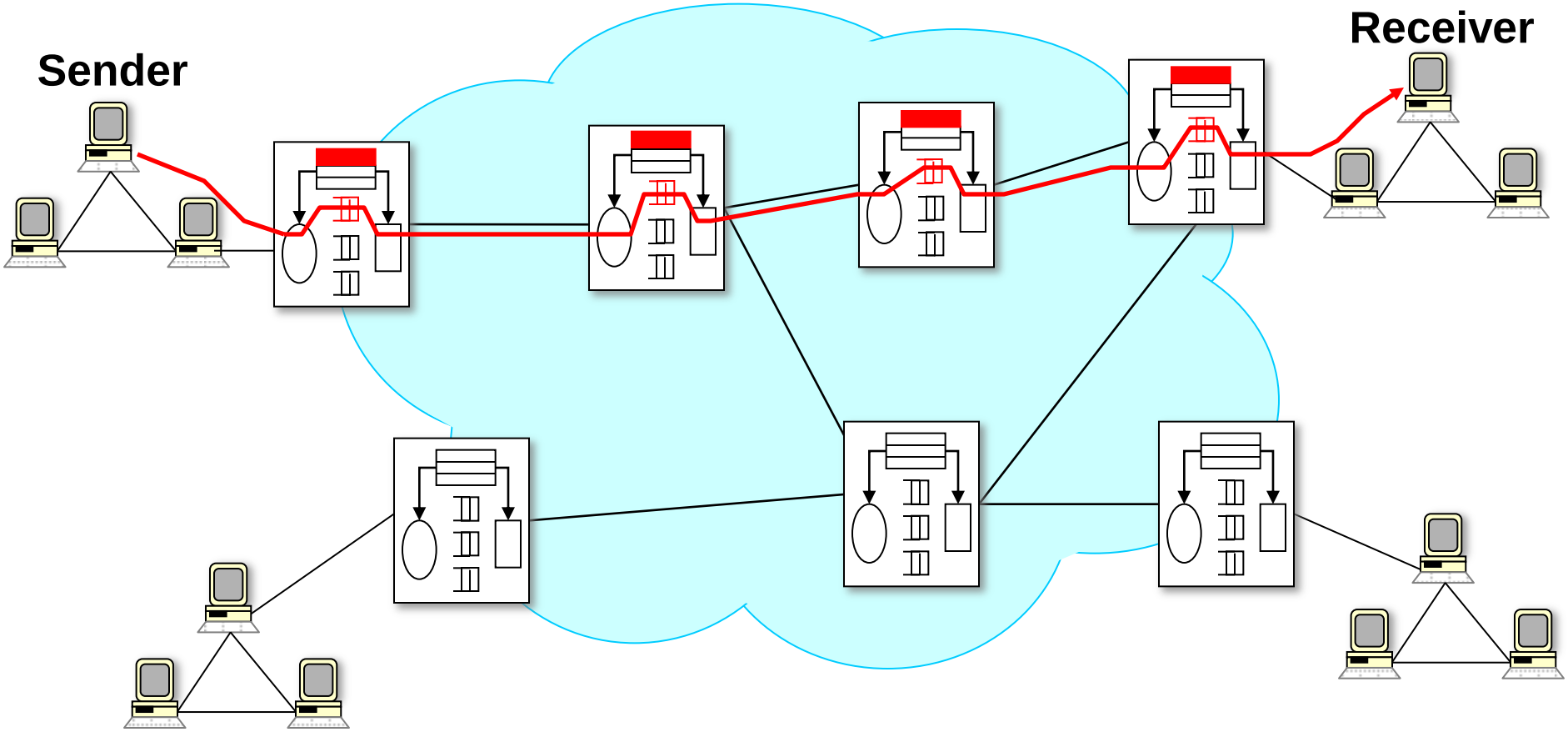
Integrated Services Example: Data Path

- Per-flow buffer management

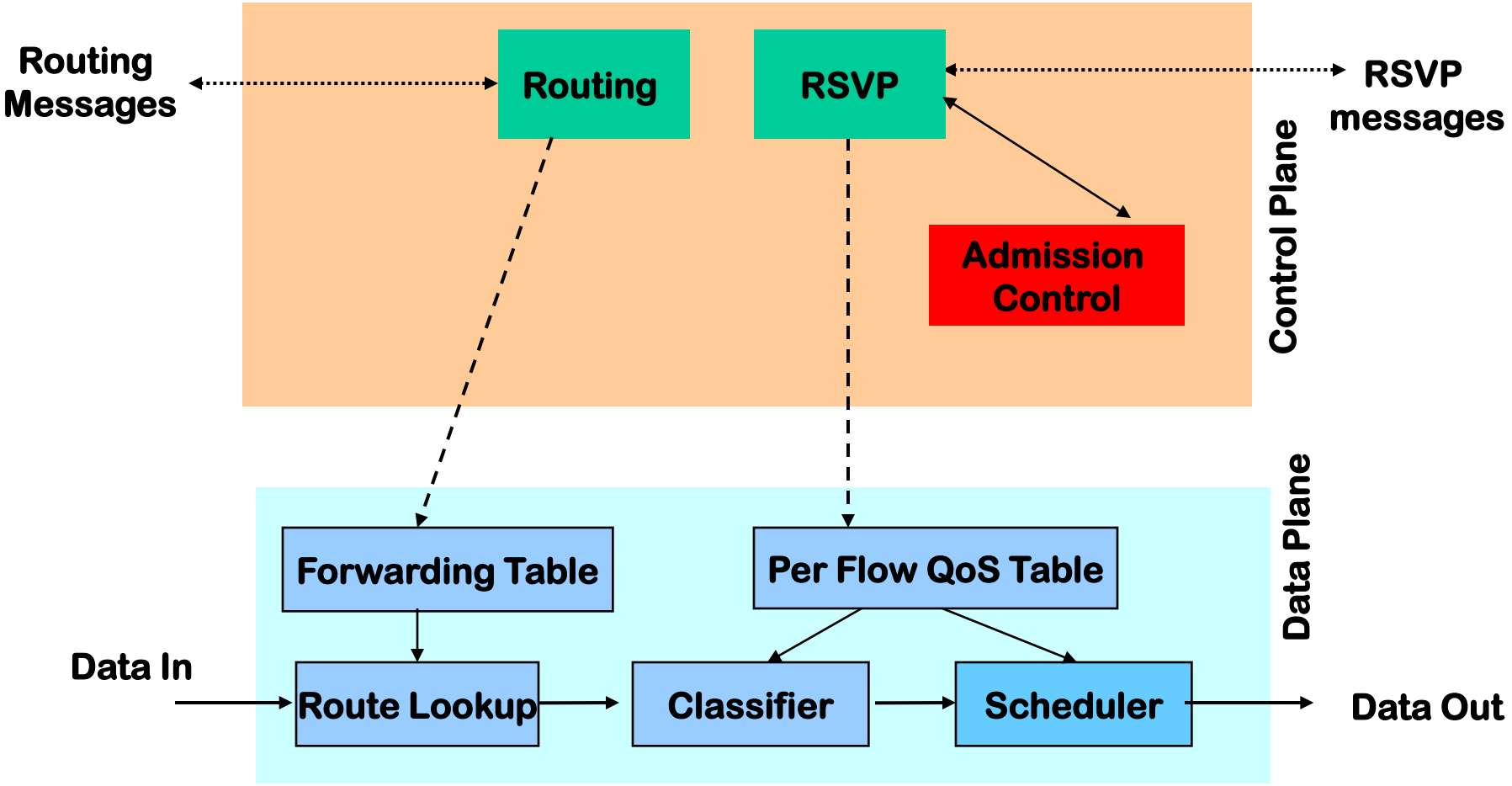


Integrated Services Example

- Per-flow scheduling



How Things Fit Together



QoS in the Internet. Part II. IETF Differentiated Services

- Want "qualitative" service classes
  - "behaves like a wire"
  - relative service distinction: Platinum, Gold, Silver
- *Scalability:* Simple functions in network core, relatively complex functions at edge routers (or hosts)
  - signaling, maintaining per-flow router state difficult with large number of flows
- Don't define service classes, provide functional components to build service classes

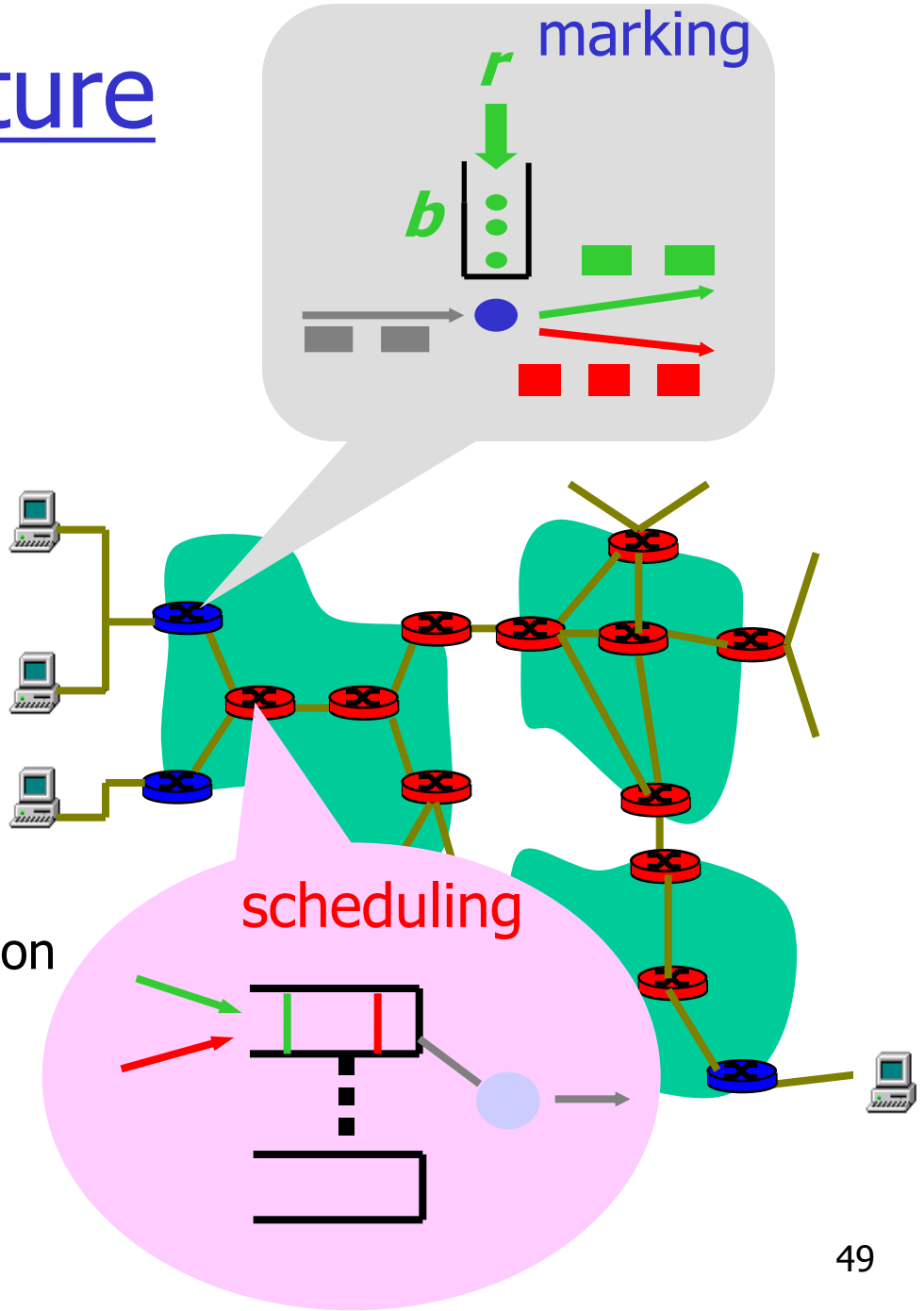
Diffserv Architecture

Edge router:

- per-flow traffic management
- marks packets as in-profile and out-profile

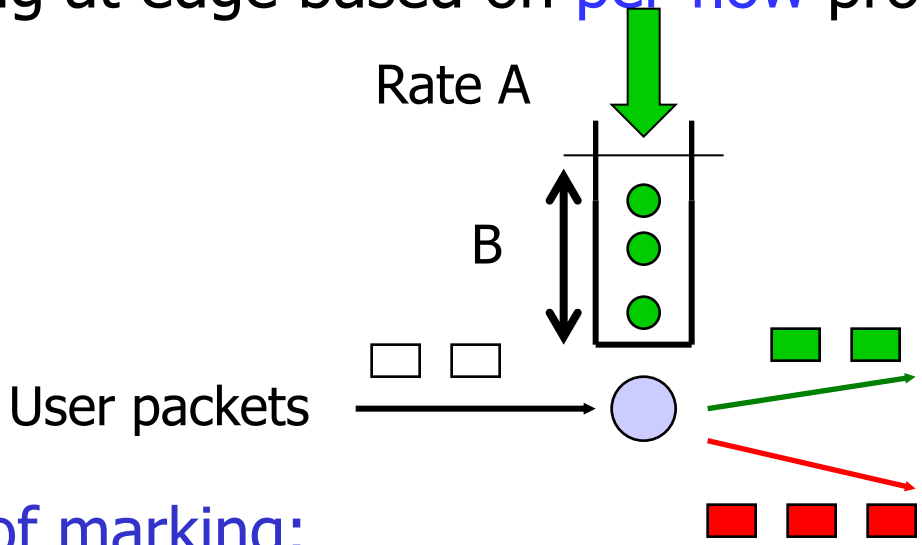
Core router:

- per class traffic management
- buffering and scheduling based on marking at edge
- preference given to in-profile packets



Edge-router Packet Marking

- Profile: pre-negotiated rate A, bucket size B
- Packet marking at edge based on per-flow profile

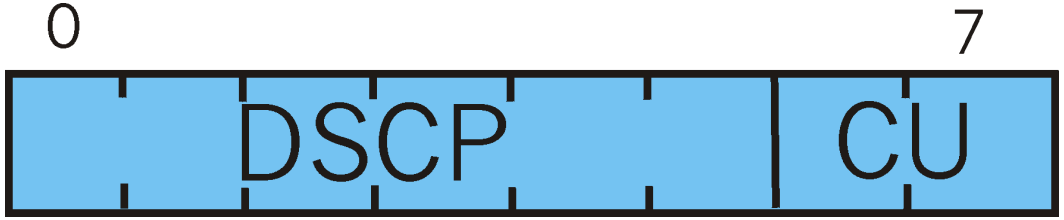


Possible usage of marking:

- class-based marking: packets of different classes marked differently
- intra-class marking: conforming portion of flow marked differently than non-conforming one

Classification and Conditioning

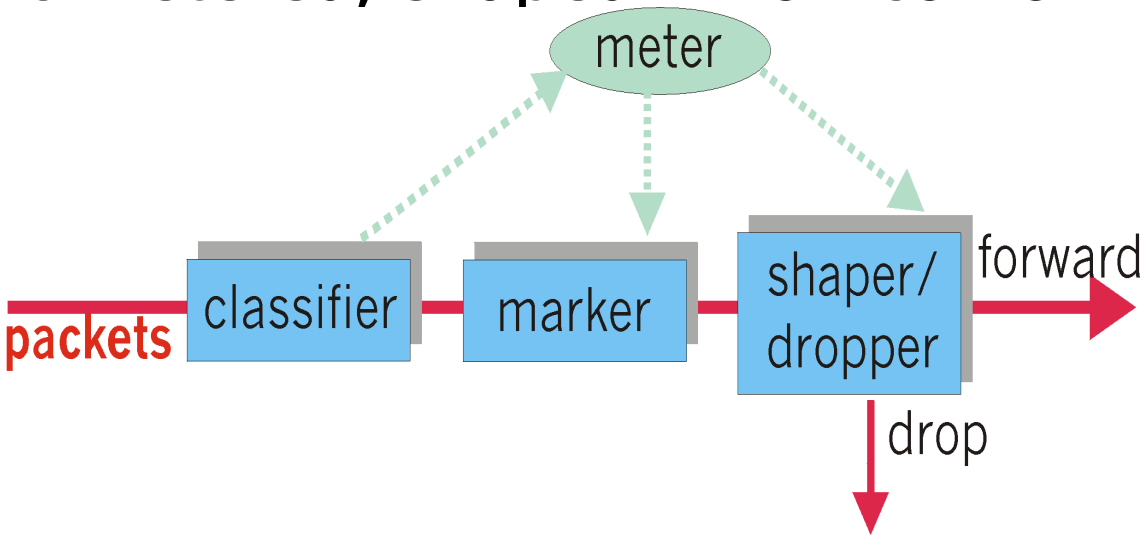
- Packet is marked in the Type of Service (TOS) in IPv4, and Traffic Class in IPv6
- 6 bits used for Differentiated Service Code Point (DSCP) and determine PHB that the packet will receive
- 2 bits are currently unused



Classification and Conditioning

May be desirable to limit traffic injection rate of some class:

- User declares traffic profile (e.g., rate, burst size)
- Traffic metered, shaped if non-conforming



Forwarding – Per Hop Behavior (PHB)

- PHB result in a different observable (measurable) forwarding performance behavior
- PHB does not specify what mechanisms to use to ensure required PHB performance behavior
- Examples:
  - Class A gets x% of outgoing link bandwidth over time intervals of a specified length
  - Class A packets leave first before packets from class B

Forwarding (PHB)

PHBs being developed:

- Expedited Forwarding: pkt departure rate of a class equals or exceeds specified rate
  - logical link with a minimum guaranteed rate
- Assured Forwarding: 4 classes of traffic
  - each guaranteed minimum amount of bandwidth
  - each with three drop preference partitions