Common network/protocol functions

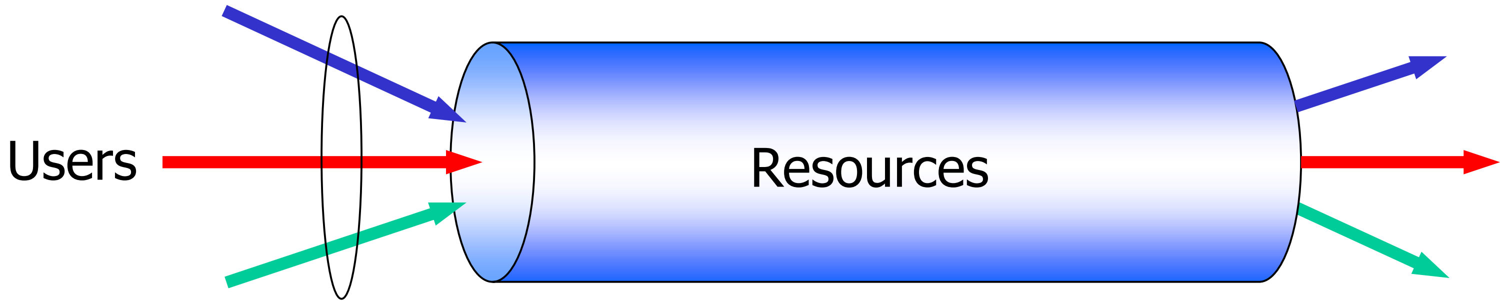
- Goals:
- Identify, study common architectural components, protocol mechanisms
- *Synthesis:* big picture
- *Depth:* important topics not covered in introductory courses

- Overview:
- Signaling
- State
- Randomization
- Indirection
- Network virtualization
- **Multiplexing / Resource Allocation**

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

Multiplexing

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



In this lecture:

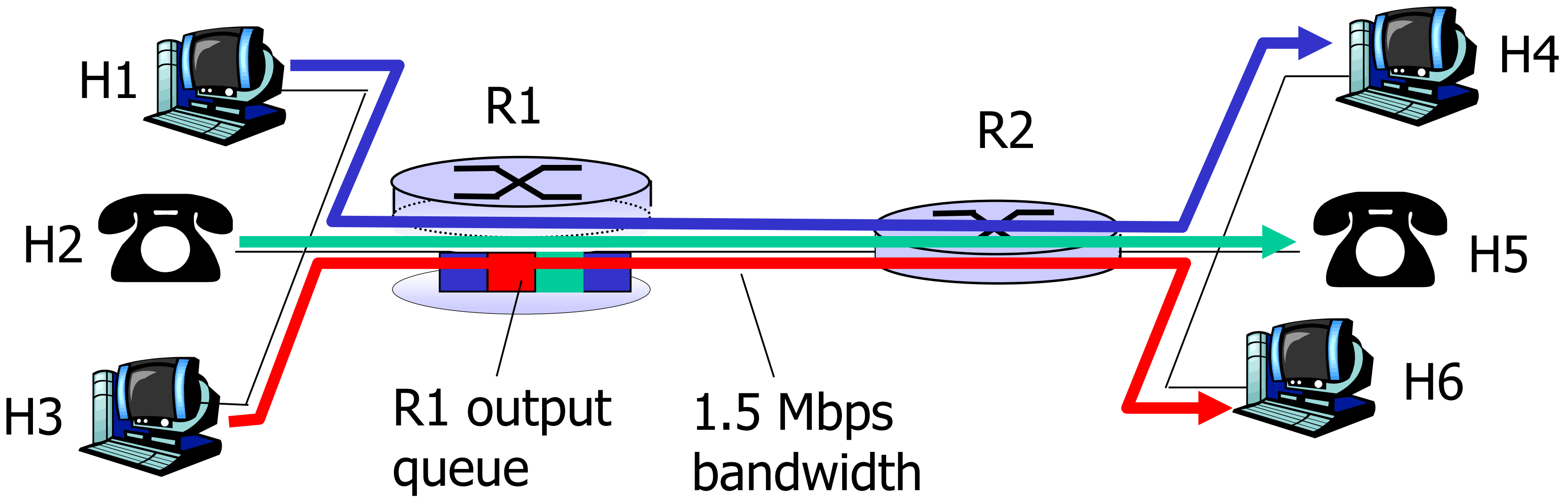
- The Resources are
  - Bandwidth (Link Capacity)
  - Queues (Buffers)
- The Users are
  - Phone Calls
  - TCP/UDP flows, packets

Other types of resources:

- CPU
- Storage
- Frequency spectrum

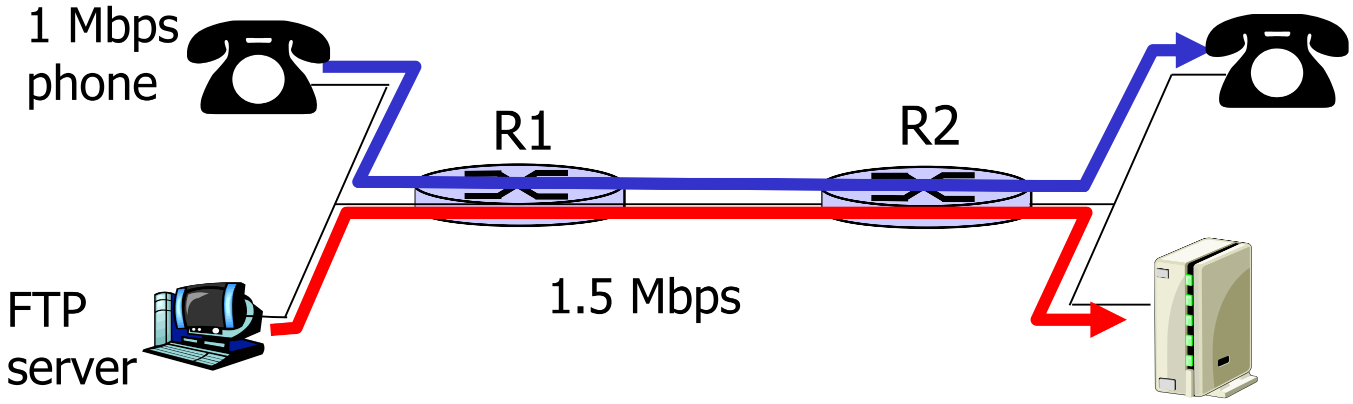
… and other types of users?

The resources and the users



From Multiplexing to QoS

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

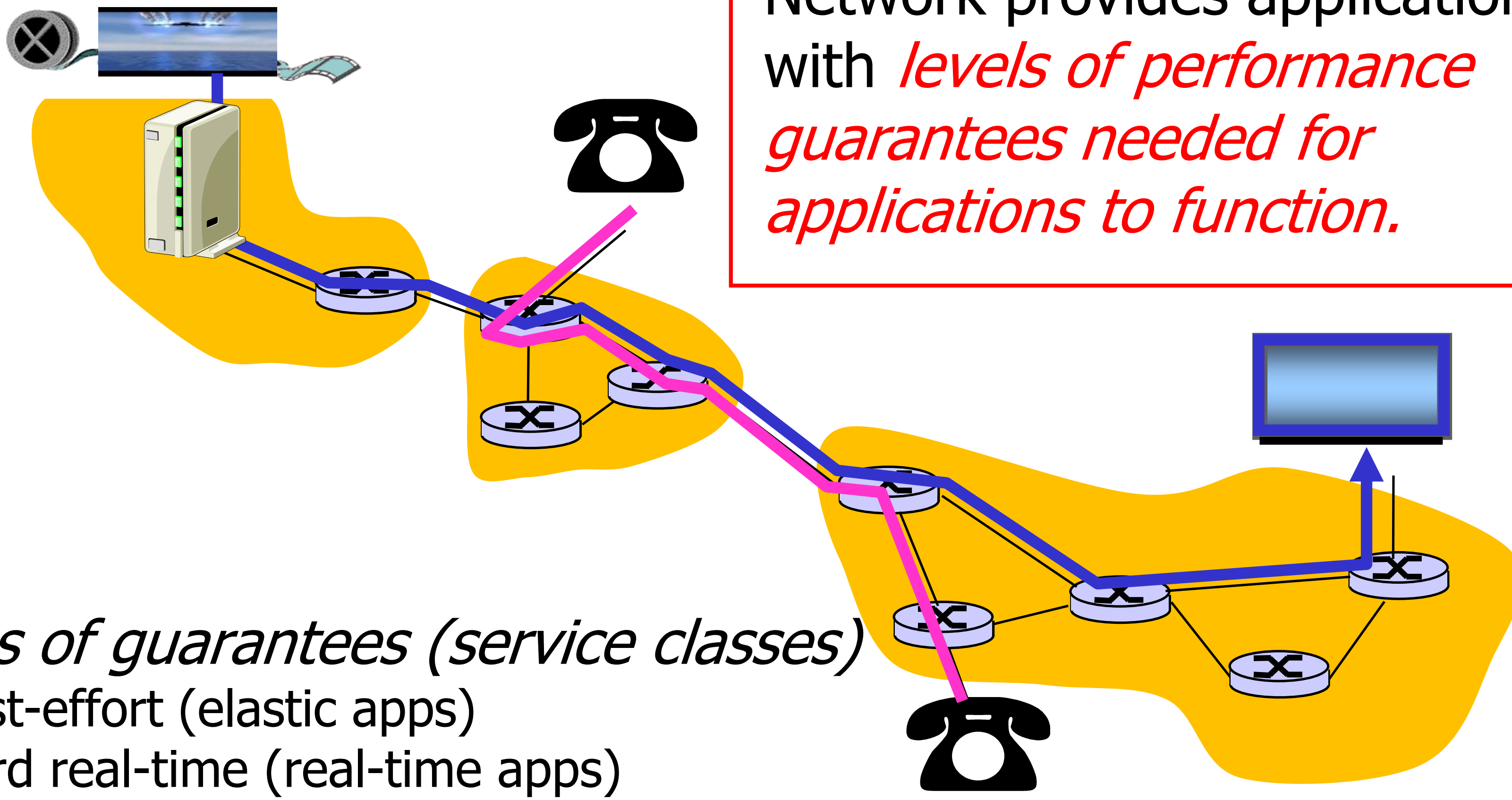


- Example: 1Mbps IP phone, FTP share 1.5 Mbps link
  - bursts of FTP can congest router, cause large delays/audio loss
- What's to be done?
  - Move away from the best-effort paradigm
  - … provide "Quality of Service (QoS)"

QoS: What is it?

QoS

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



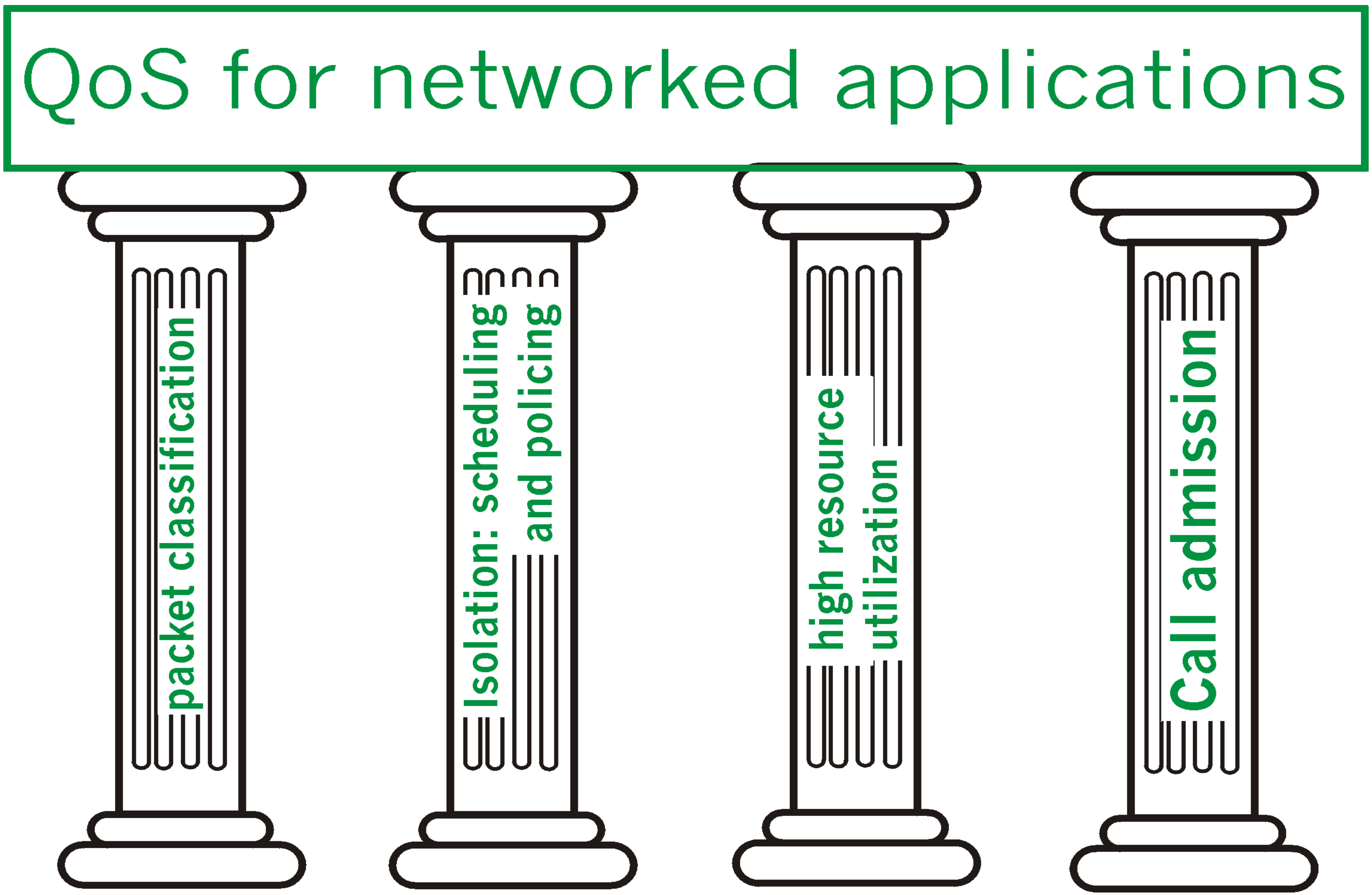
Types of guarantees (service classes)

- 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?

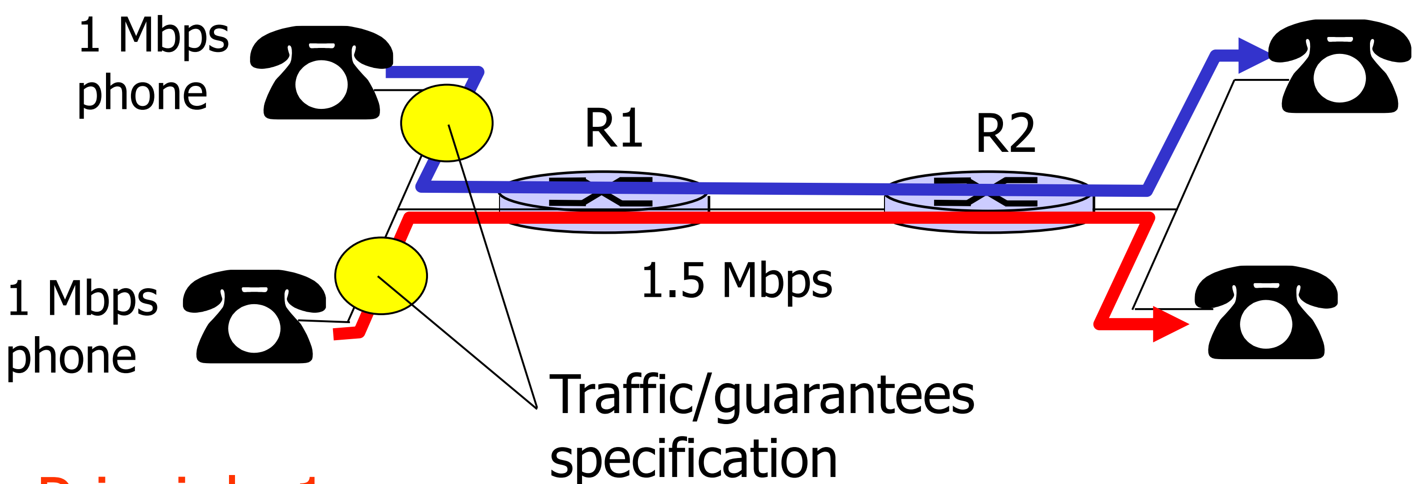
- A set of five principles

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

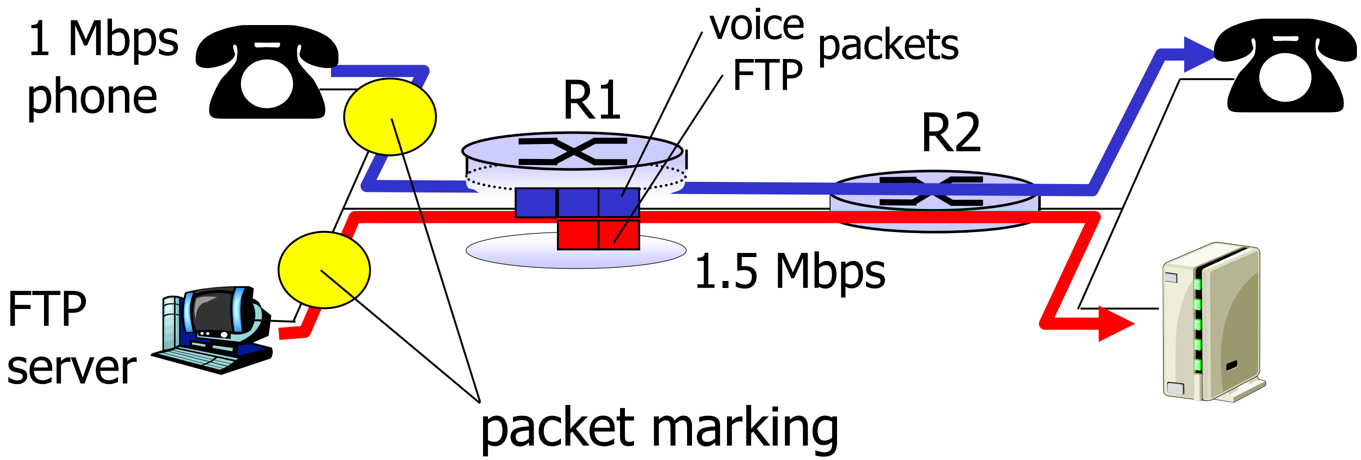


Principle 1

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?

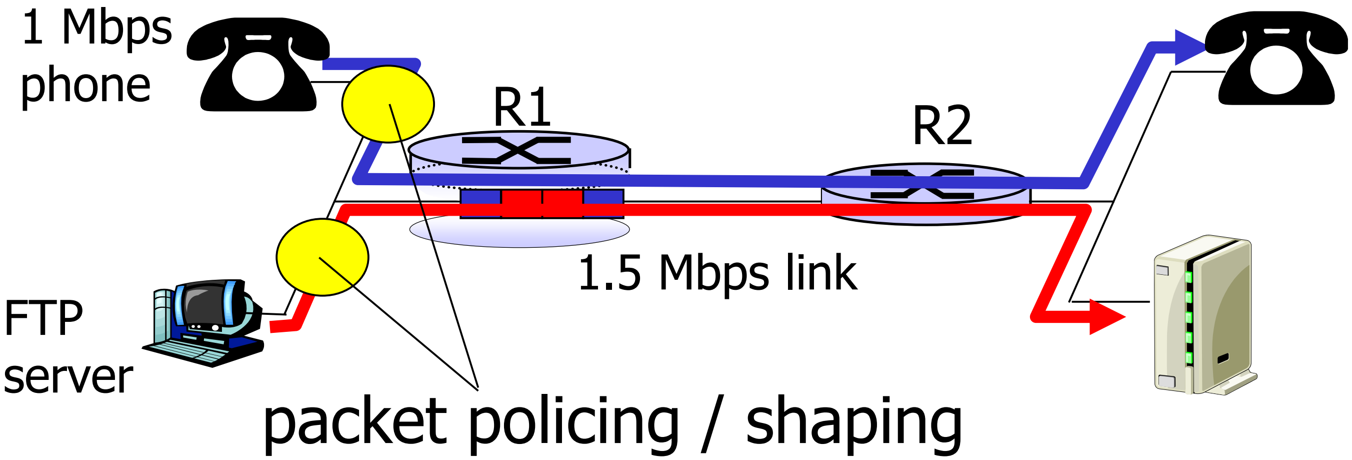


Principle 2

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

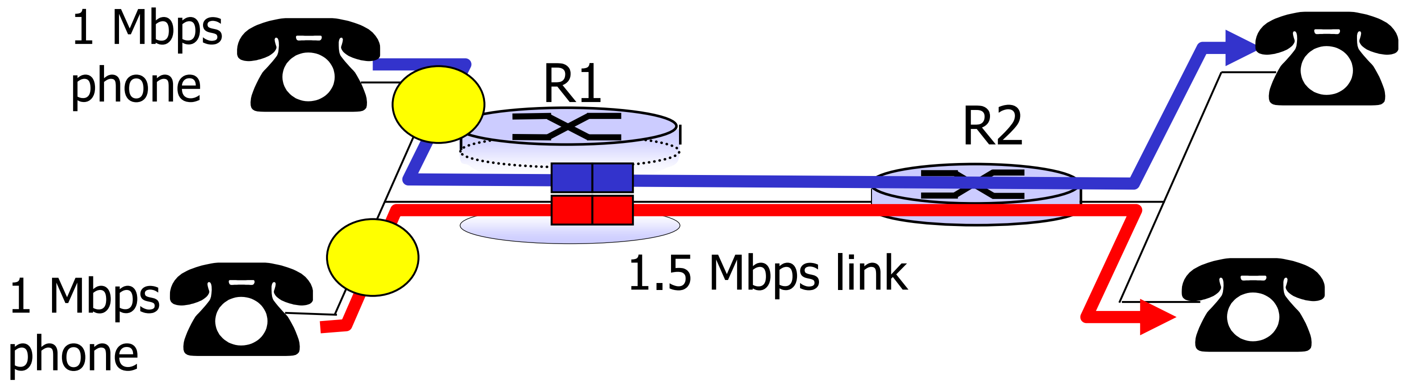


Principle 3

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

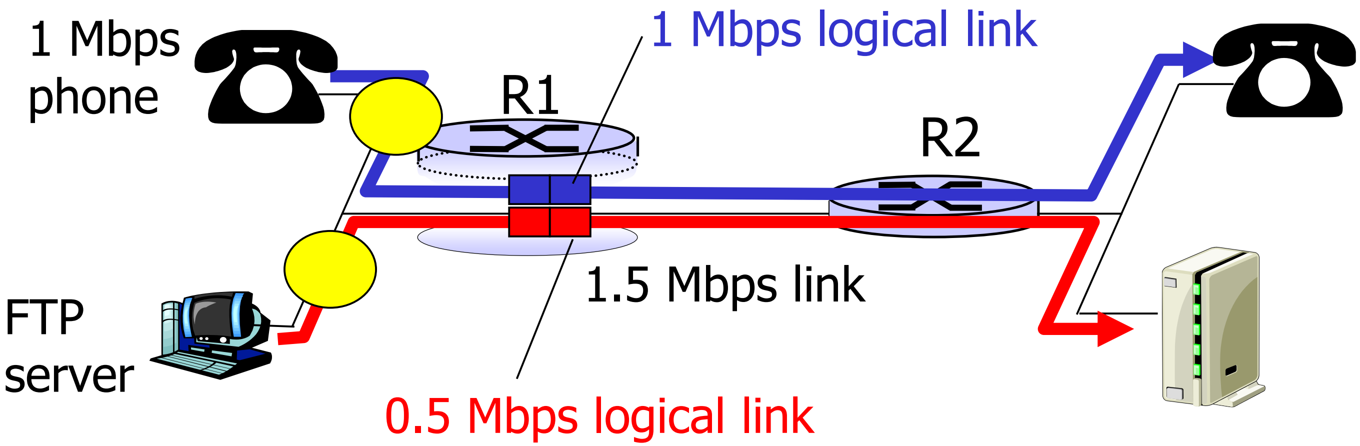


Principle 4

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	?	?	?	?	?

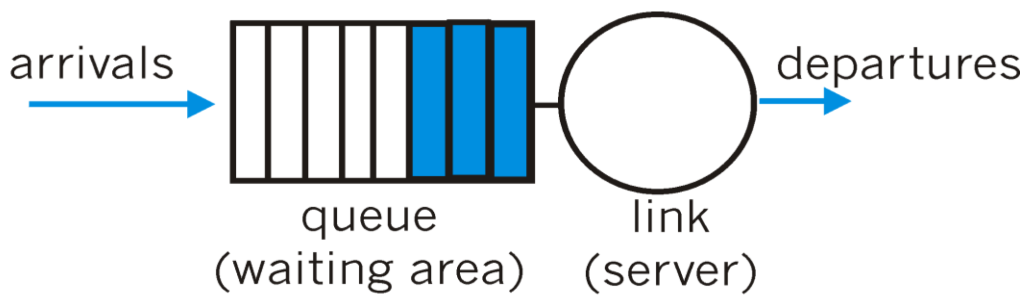
Outline

- Scheduling
- Policing
- Admission Control

- IETF proposals to do things in practice
  - IntServ
  - DiffServ

Scheduling And Policing *Packets*

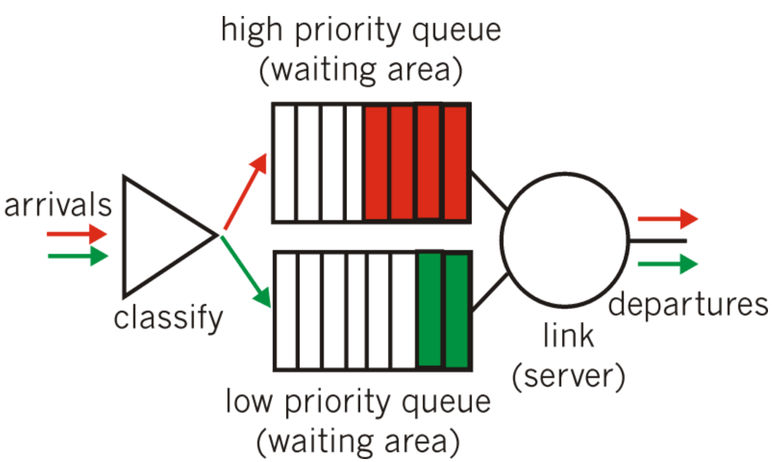
- Scheduling: choose next packet to send on link
- FIFO (first in first out) scheduling: send in order of arrival to queue
  - Real-world example: stop sign
  - Discard policy:
    - Tail drop: drop arriving packet
    - RED

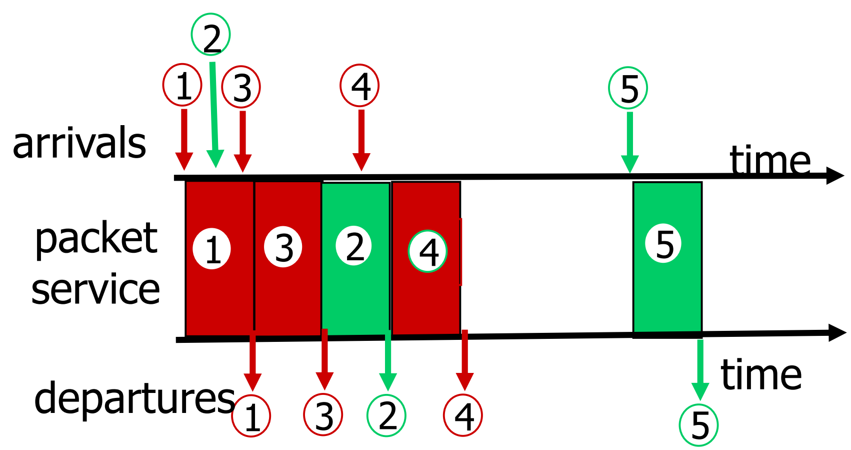


Scheduling Policies: more

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

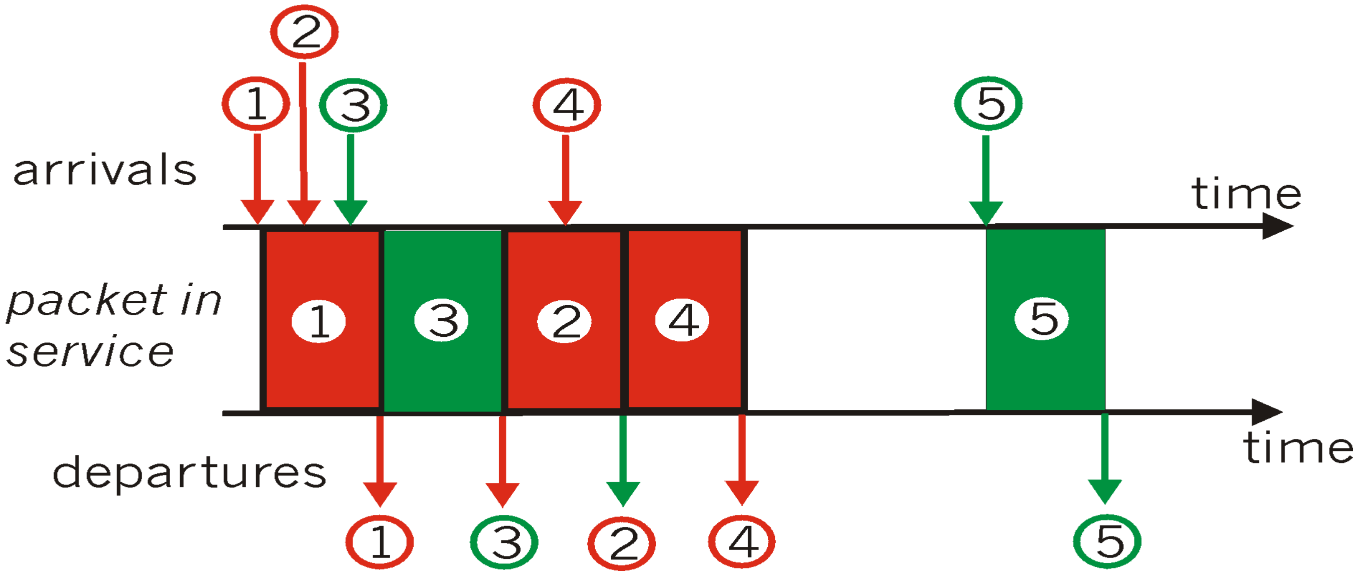




Scheduling Policies: still more

Round robin scheduling:

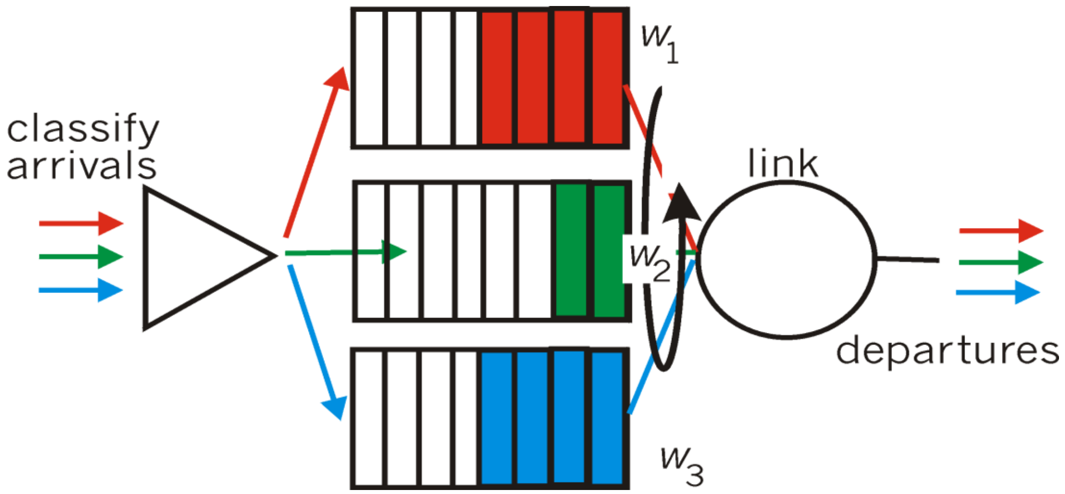
- Multiple classes
- Cyclically scan class queues, serving one from each class (if available)
- Real-world example: 4-way stop (distributed scheduling)



Scheduling Policies: still more

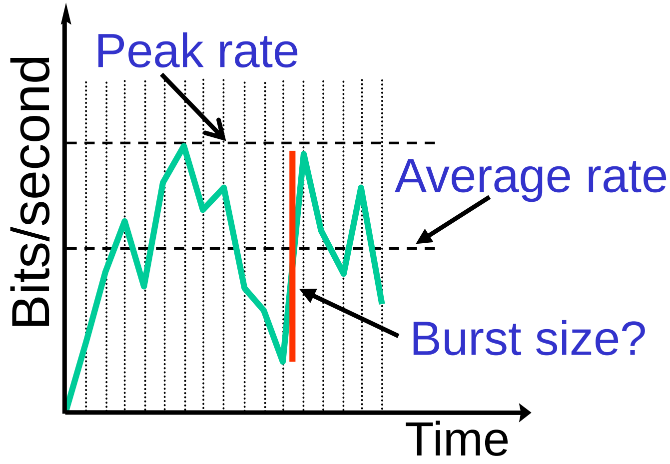
Weighted Fair Queuing:

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



Policing Mechanisms

Goal: Limit traffic to not exceed declared parameters

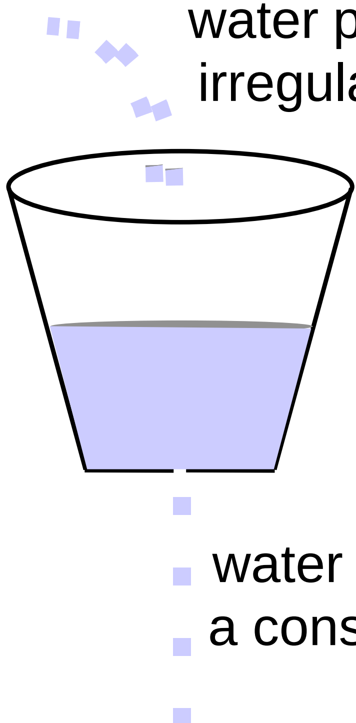


Three commonly-used criteria:

- *(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

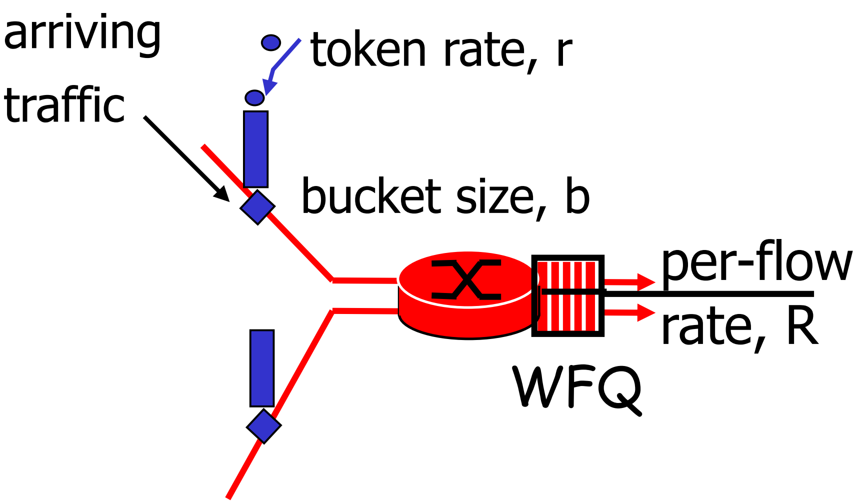
1 packet per unit time
Assume constant-length packet

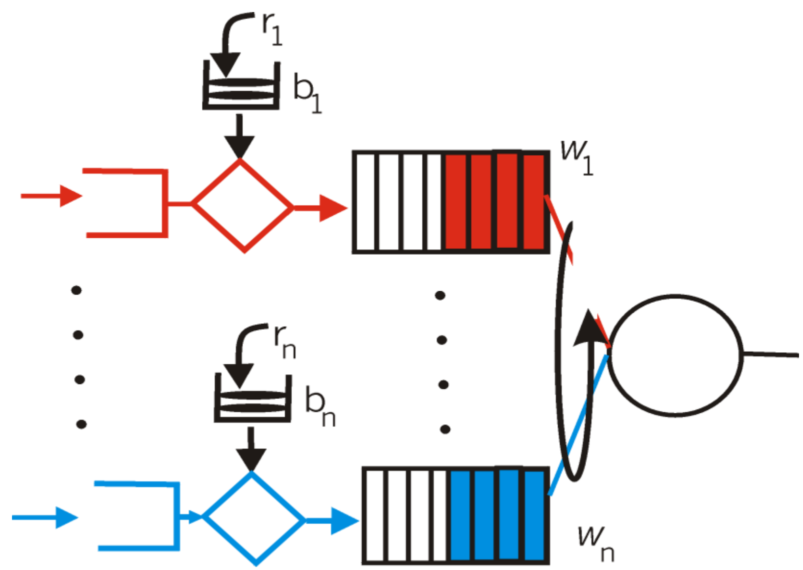
Let X = bucket content at last conforming packet arrival

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

Policing Mechanisms (more)

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





$$D_{max} = b/R$$

Admission Control

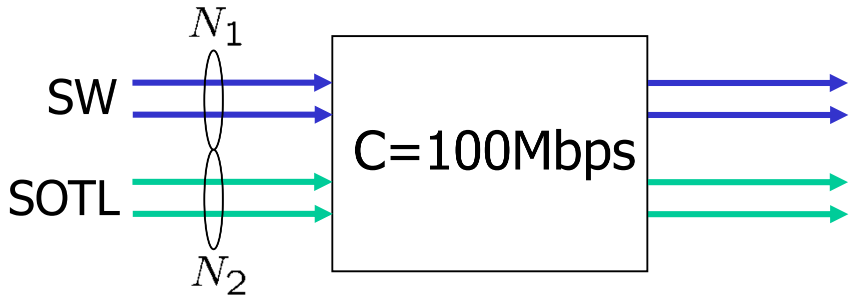
- Users watch either one of two movies
  - Star Wars (with the declared parameters)

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

  - Silence of the Lambs (with the declared parameters)

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

- *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, e.g., $P(Delay > 200ms) \leq 10^{-6}$
- Average rate admission control
  - Only qualitative guarantees (e.g., delay is always finite)

Admission Control (cont.)

- Peak rate admission control
  - Provides hard-guarantees
  - The formula: $N_1 P_1 + N_2 P_2 \leq C$
- Dual Leaky-bucket admission control
  - Provides hard-guarantees
  - The formula: $N_1 r_1 + N_2 r_2 \leq C$, $\frac{N_1 b_1 + N_2 b_2}{C} \leq d$
- Statistical admission control
  - Provides soft-guarantees, e.g., $P(Delay > 200ms) \leq 10^{-6}$
- Average rate admission control
  - Only qualitative guarantees (e.g., delay is always finite)
  - The formula: $N_1 r_1 + N_2 r_2 \leq C$

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

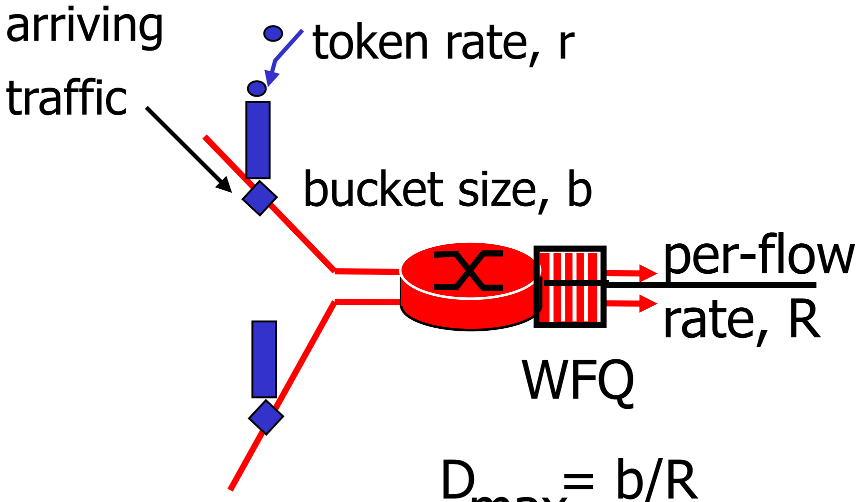
Intserv QoS: Service models [rfc2211, rfc 2212]

Guaranteed service:

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

Controlled load service:

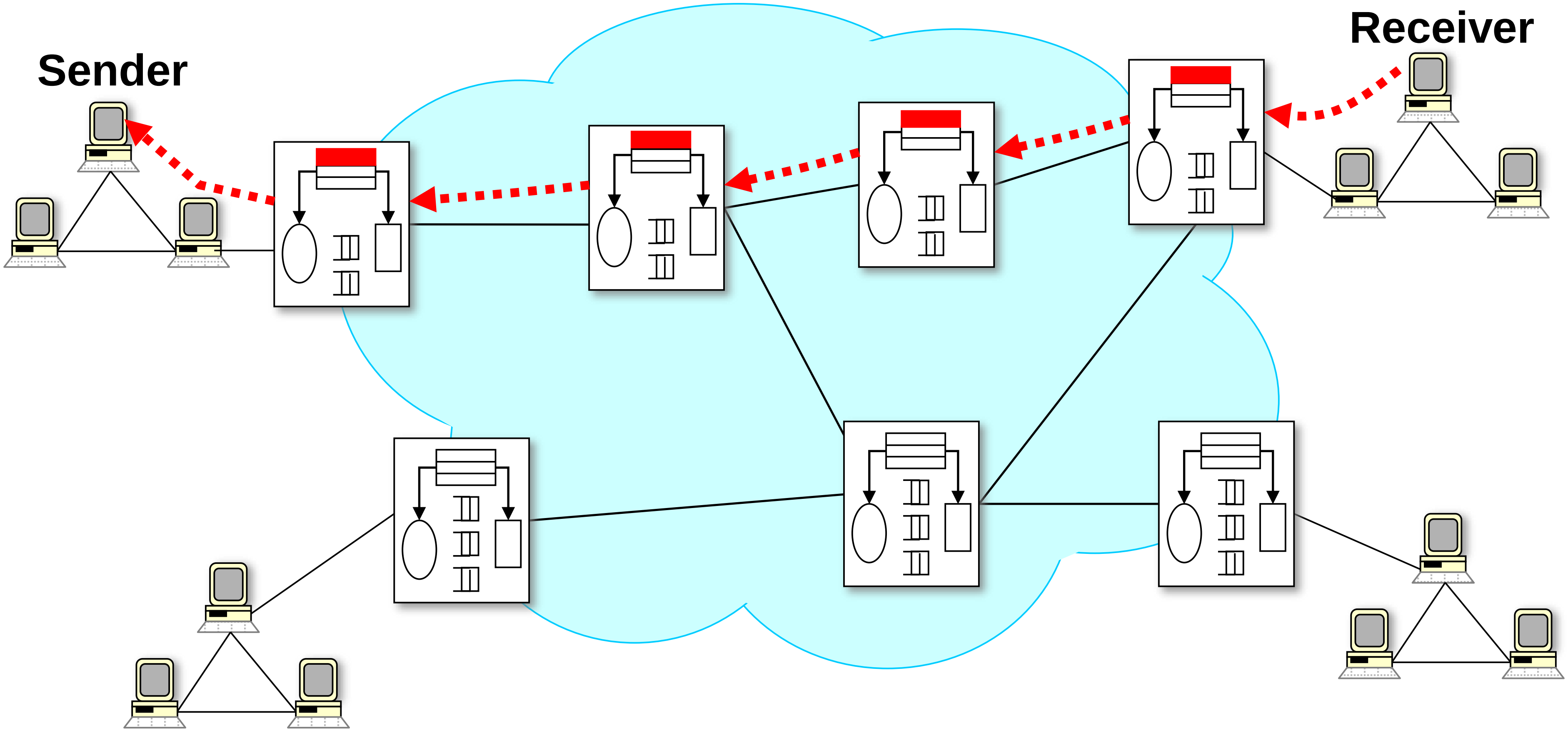
- "a quality of service closely approximating the QoS that same flow would receive from an unloaded network element."



$D_{max} = b/R$

Integrated Services Example

- Install per flow state

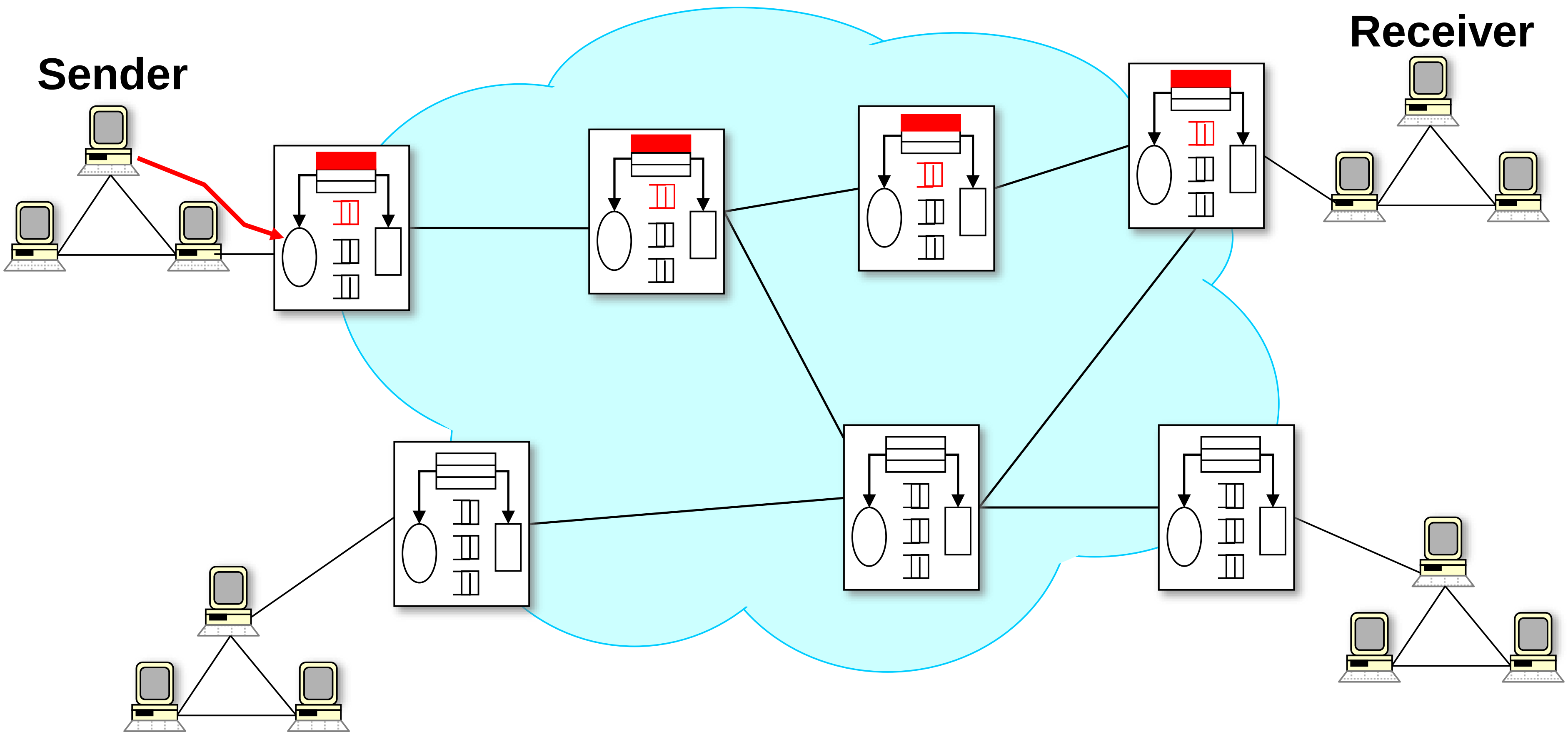


Recall RSVP

- 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

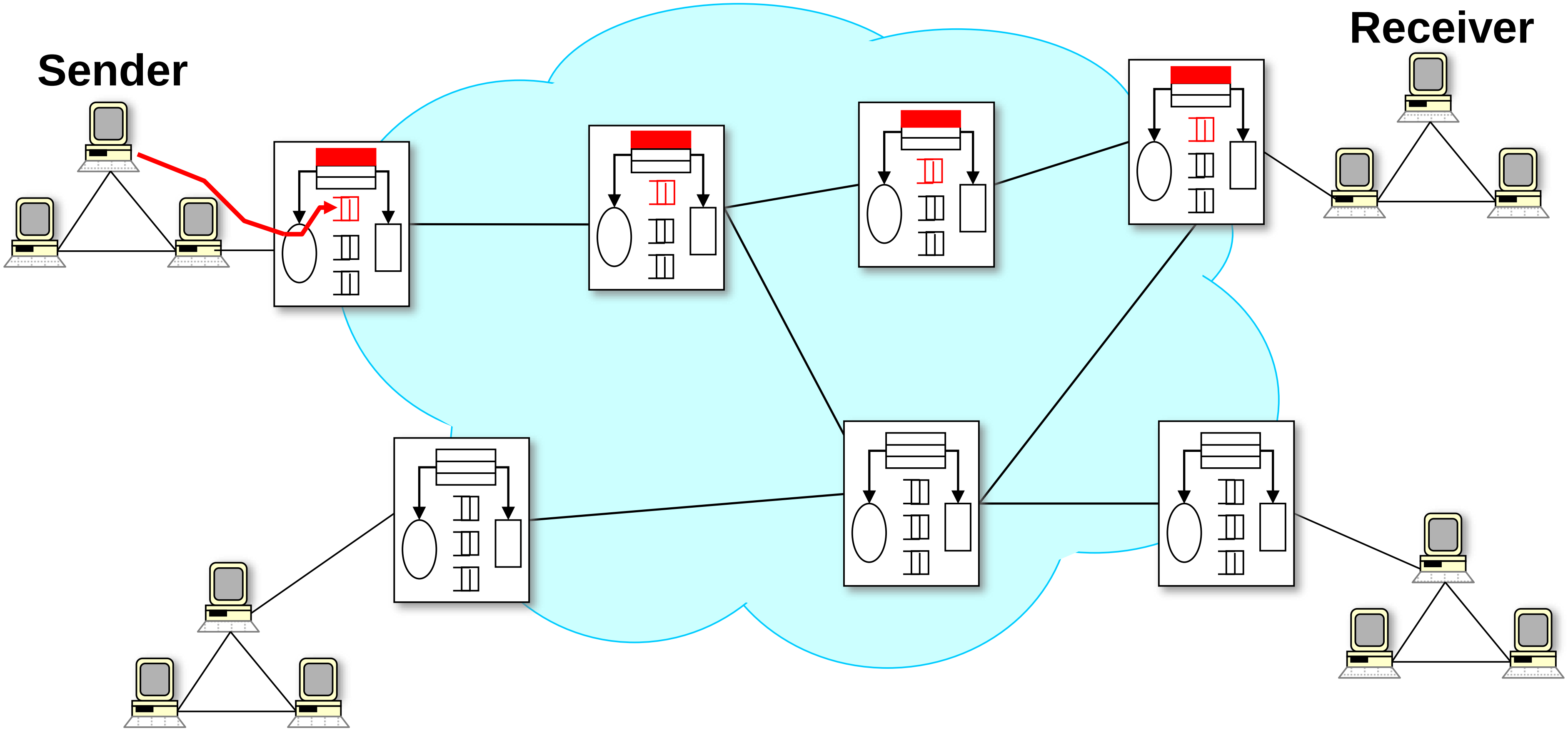
Integrated Services Example: Data Path

- Per-flow classification



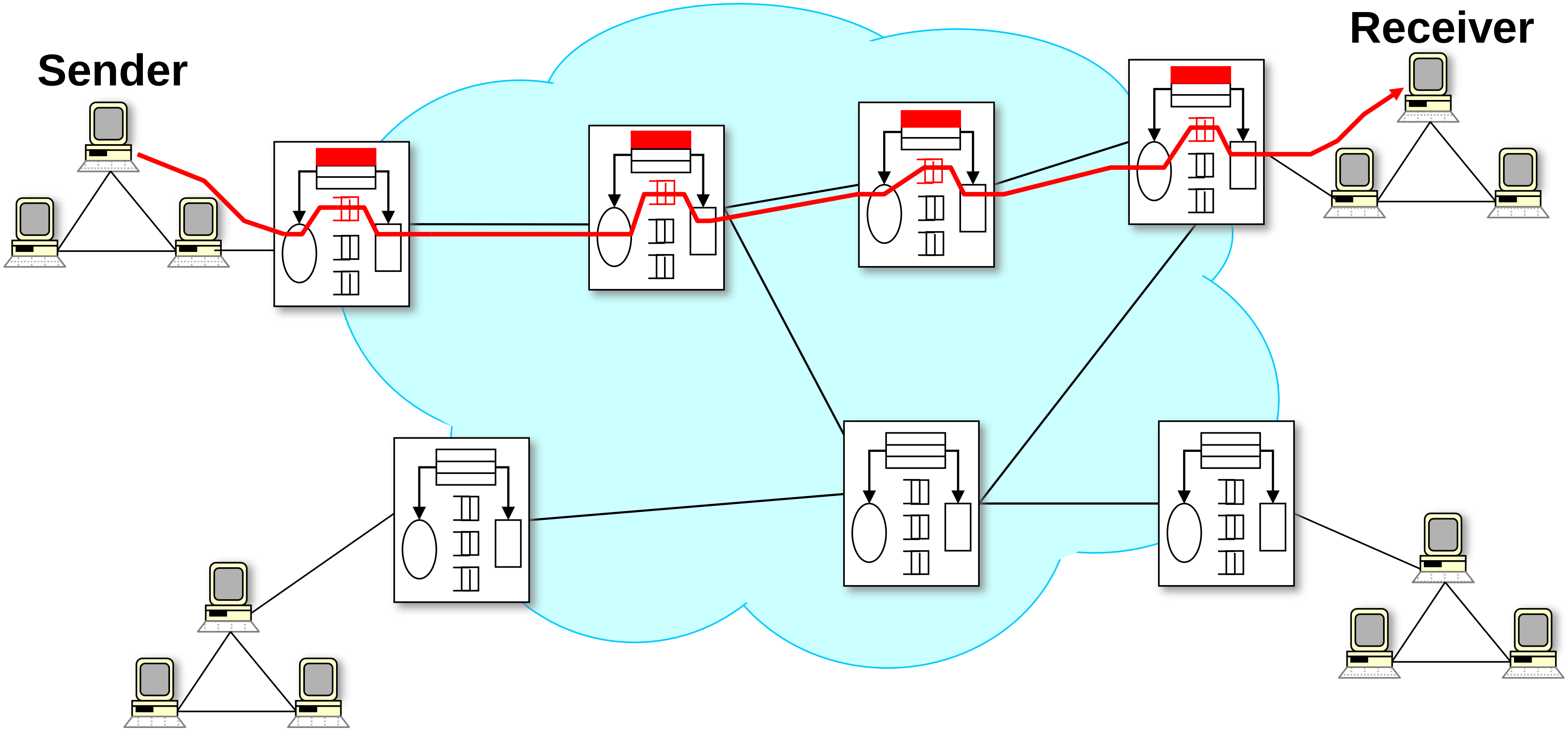
Integrated Services Example: Data Path

- Per-flow buffer management

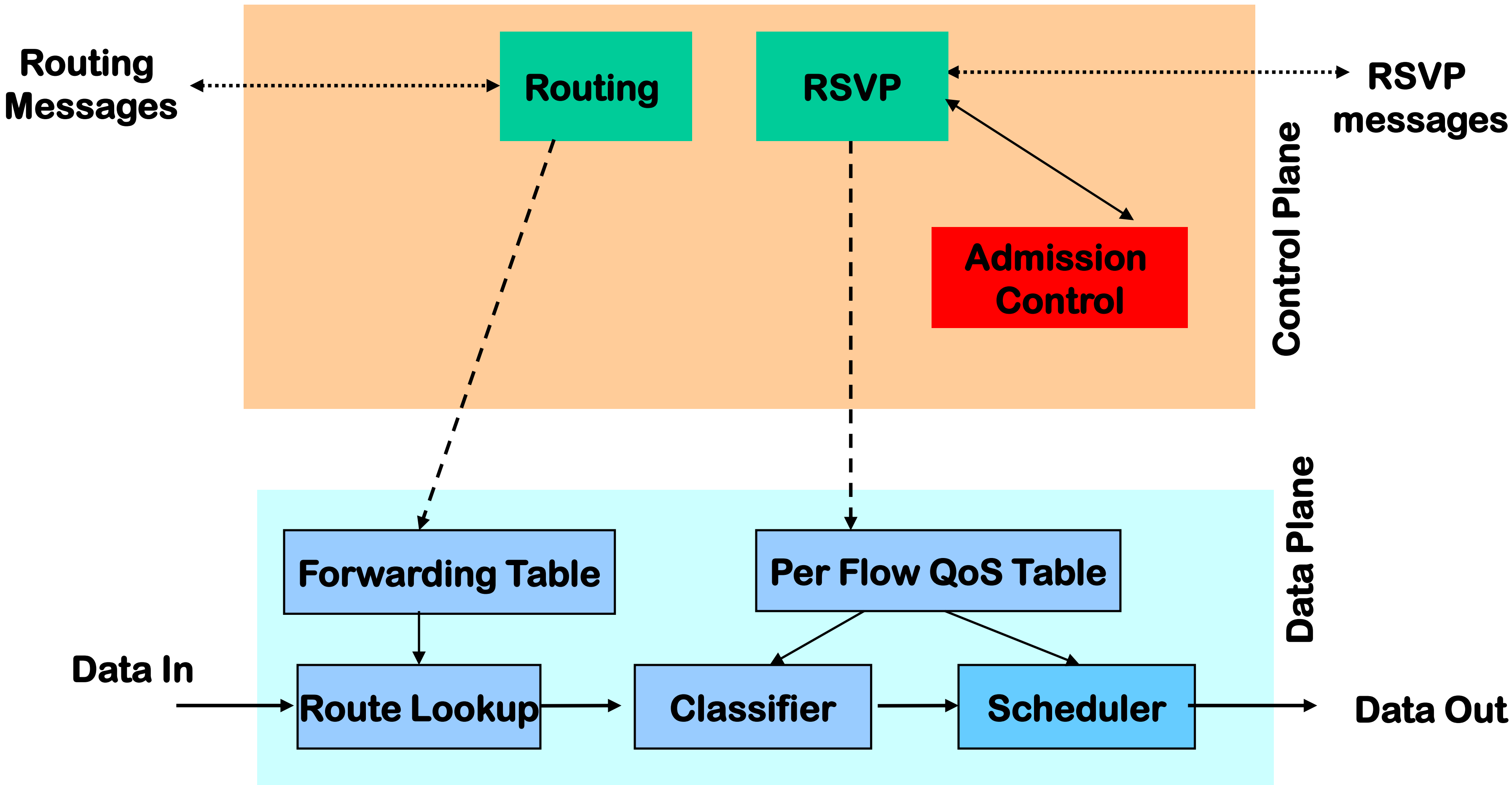


Integrated Services Example

- 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