Internet Protocols
Fall 2006

Lectures 17-18

QoS

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Outline

- QoS
  - Fair Queuing
  - Intserv
  - Diffserv

What's the Problem?

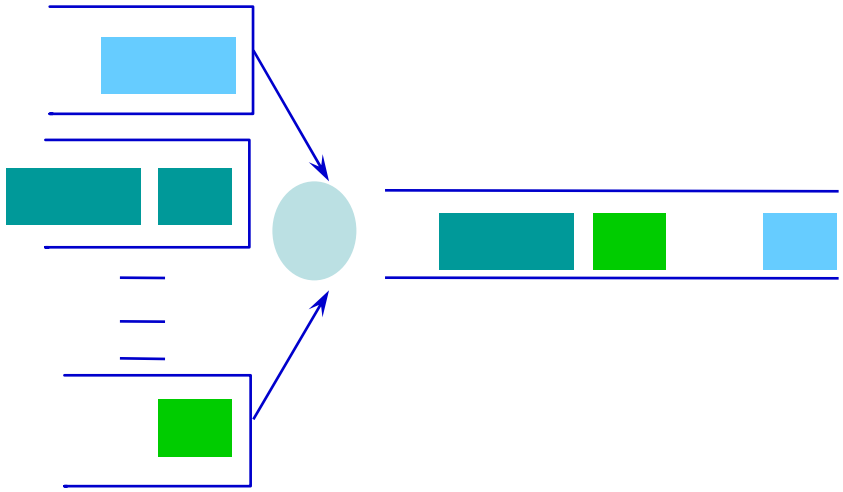
- Internet gives all flows the same "best effort" service
  - no promises about when or whether packets will be delivered
- Not all traffic is created equal
  - different "owners", different application requirements
  - some applications require service "assurances"
- How can we give traffic different "quality of service"?
  - Thus begins the problem of QoS

Three Basic Problems

- Want to control how a link is shared:
  - Link sharing
- Want to give some traffic better service
  - Differentiated service
- Want to gives some flows "assured" service
  - Integrated service (and perhaps differentiated service)

Link Sharing

- First approach suggested by Nagle (1987)
- Round-robin among different flows
  - one queue per flow



Round-Robin Discussion

- Advantages: protection among flows
  - Misbehaving flows will not affect the performance of well-behaving flows
    - Misbehaving flow – a flow that does not implement any congestion control
  - FIFO does not have such a property
- Disadvantages:
  - More complex than FIFO: per flow queue/state
  - Biased toward large packets – a flow receives service proportional to the number of packets

Solution?

- Bit-by-bit round robin
- Can you do this in practice?
- No, packets cannot be preempted (why?)
- …we can only approximate it

Fair Queueing (FQ)

- Define a fluid flow system: a system in which flows are served bit-by-bit
- Then serve packets in the increasing order of their deadlines
- Advantages
  - Each flow will receive exactly its fair rate
- Note:
  - FQ achieves max-min fairness

Max-Min Fairness

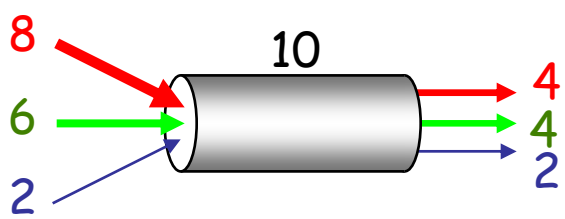
- Denote
  - C – link capacity
  - N – number of flows
  - r_i – arrival rate
- Max-min fair rate computation:
  1. compute C/N
  2. if there are flows i such that $r_i <= C/N$, update C and N

$$C = C - \sum_{i\ s.t\ r_i \le C/N} r_i$$

  3. if no, $f = C/N$; terminate
  4. go to 1
- A flow can receive at most the fair rate, i.e., $\min(f, r_i)$

Example

- $C = 10$; $r_1 = 8$, $r_2 = 6$, $r_3 = 2$; $N = 3$
- $C/3 = 3.33 \rightarrow C = C - r3 = 8$; $N = 2$
- $C/2 = 4$; $f = 4$

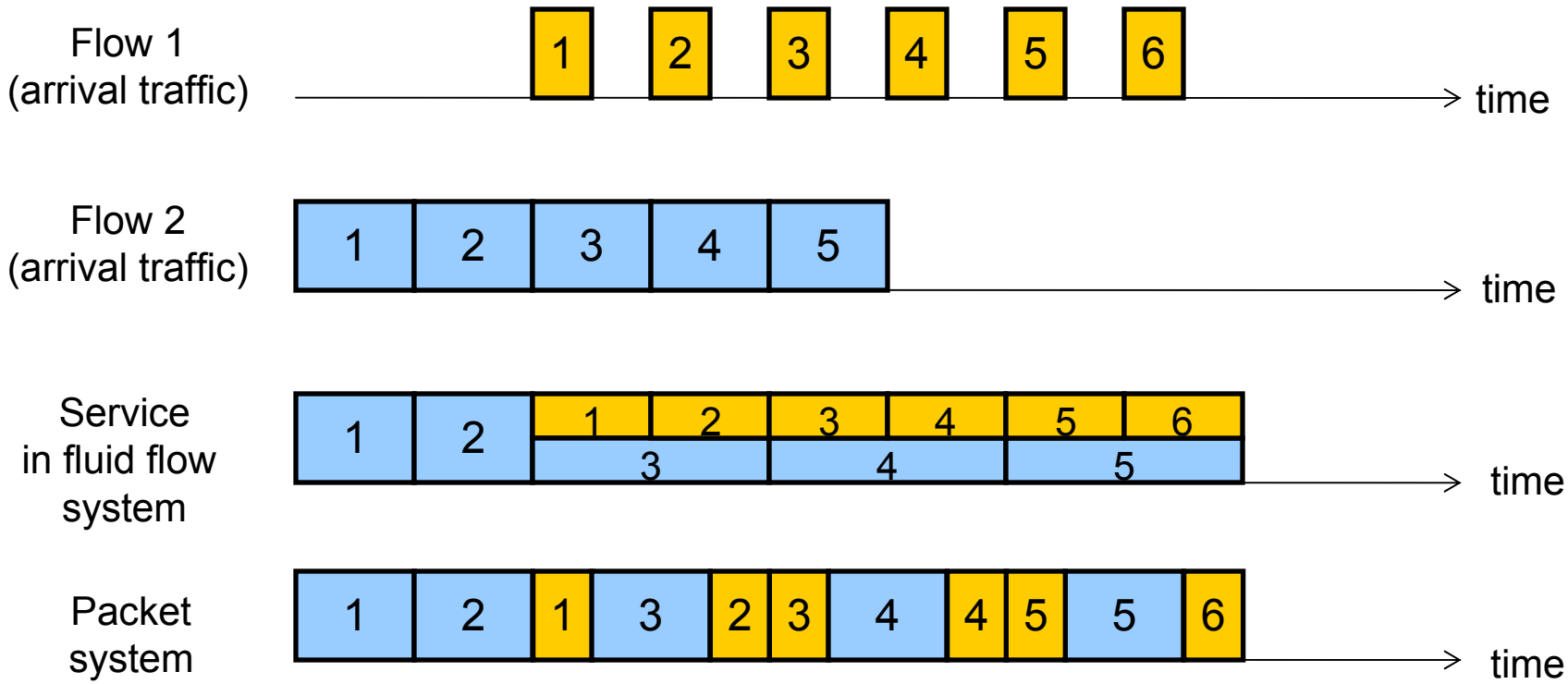


$f = 4$:
min(8, 4) = 4
min(6, 4) = 4
min(2, 4) = 2

Implementing Fair Queueing

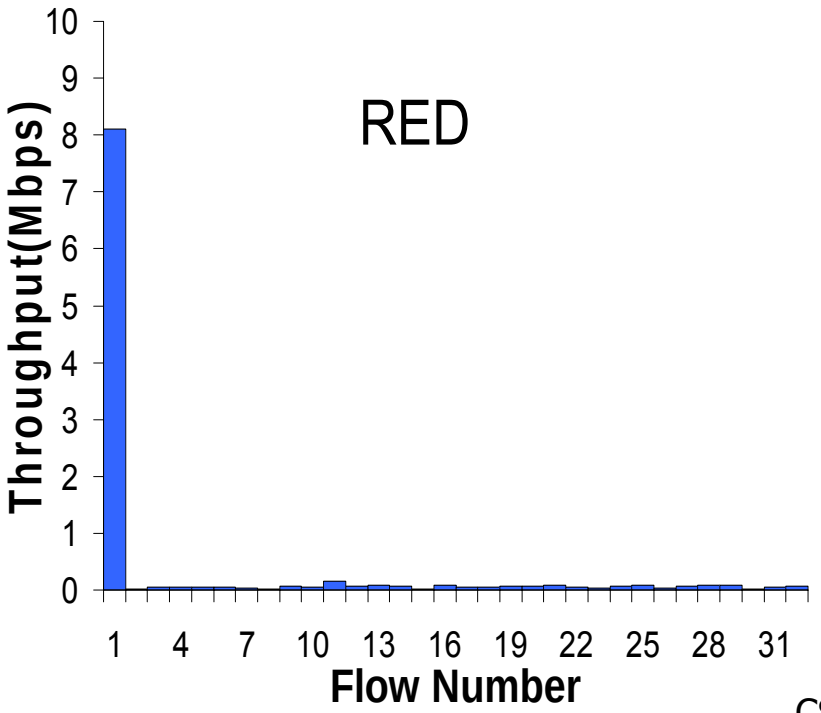
- Idea: serve packets in the order in which they would have finished transmission in the fluid flow system

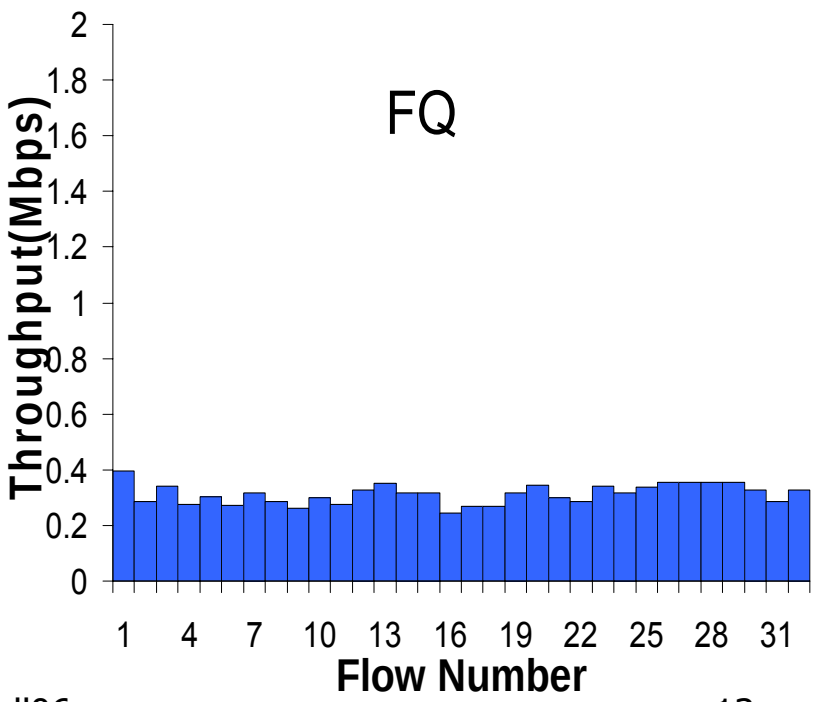
Example


Flow 1
(arrival traffic)
1
2
3
4
5
6
time
Flow 2
(arrival traffic)
1
2
3
4
5
time
Service
in fluid flow
system
1
2
1
2
3
4
5
6
3
4
5
time
Packet
system
1
2
1
3
2
3
4
4
5
5
6
time

FQ Advantages

- FQ protect well-behaved flows from ill-behaved flows
- Example: 1 UDP (10 Mbps) and 31 TCP's sharing a 10 Mbps link





Big Picture

- FQ does not eliminate congestion → it just manages the congestion
- You need both end-host congestion control and router support for congestion control
  - end-host congestion control to adapt
  - router congestion control to protect/isolate

Three Basic QoS Questions

- How does a router service this packet?
  - scheduling (various forms of priority and RR)
  - dropping (fancy versions of RED)
- How did the router know what to do with this packet?
  - bits in packet header or explicit signaling
- How can one control the level of traffic?
  - service level agreements (SLAs) or admission control

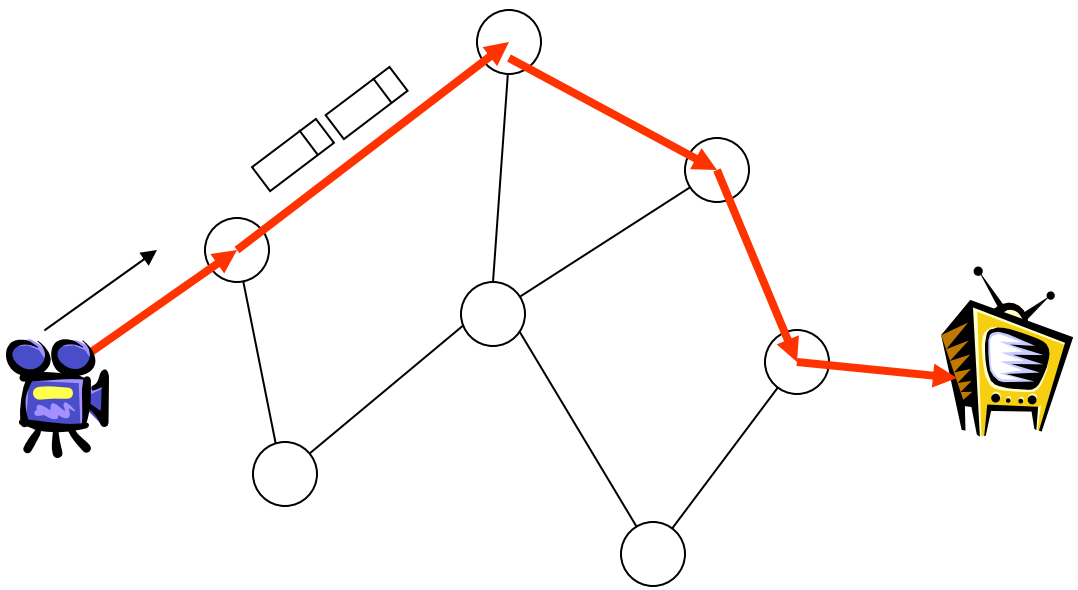
Integrated Services

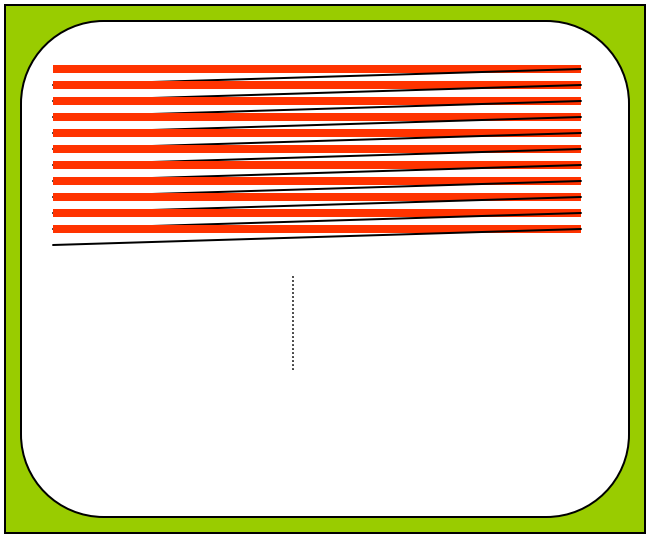
- An attempt to integrate service for "real-time" applications into the Internet
- Known as IntServ
- A total, massive, and humiliating failure
  - 1000s of papers
  - IETF standards
  - and no deployment....

Key Differences

- All assurances on per-flow basis
- Traffic can be turned away
- Note:
  - all this co-exists with best-effort service
  - similar mechanisms proposed for ATM but
    - QoS central in ATM, best-effort an afterthought
    - Best-effort central in Internet, QoS an afterthought

Example: Video





Simplify by assuming that
Camera sends at a fixed rate

Nick Mckeown

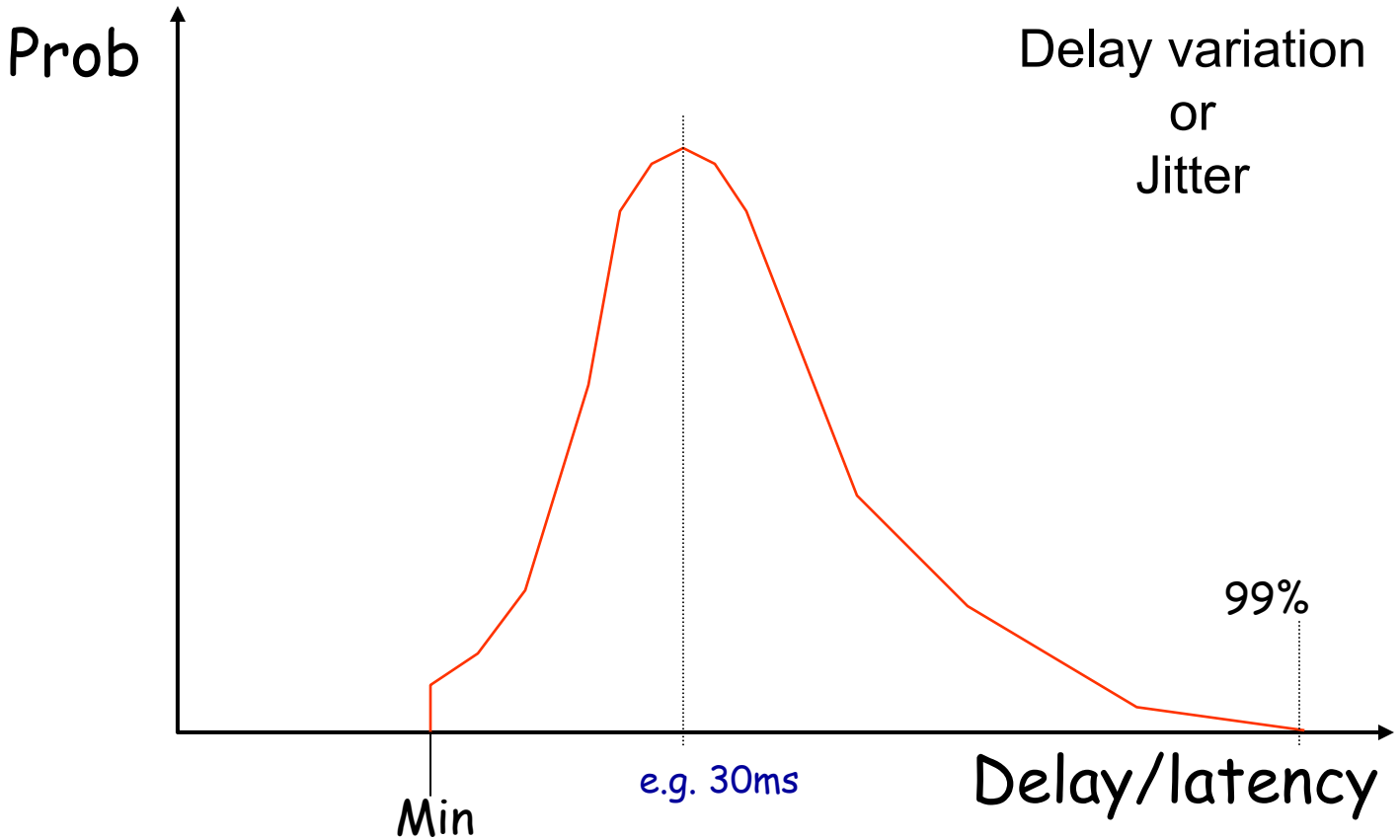
Circuit-Switched Networks

- Each packet experiences exactly the same delay
- Packet data is displayed as soon as it arrives
- Signal at receiving end is faithful representation

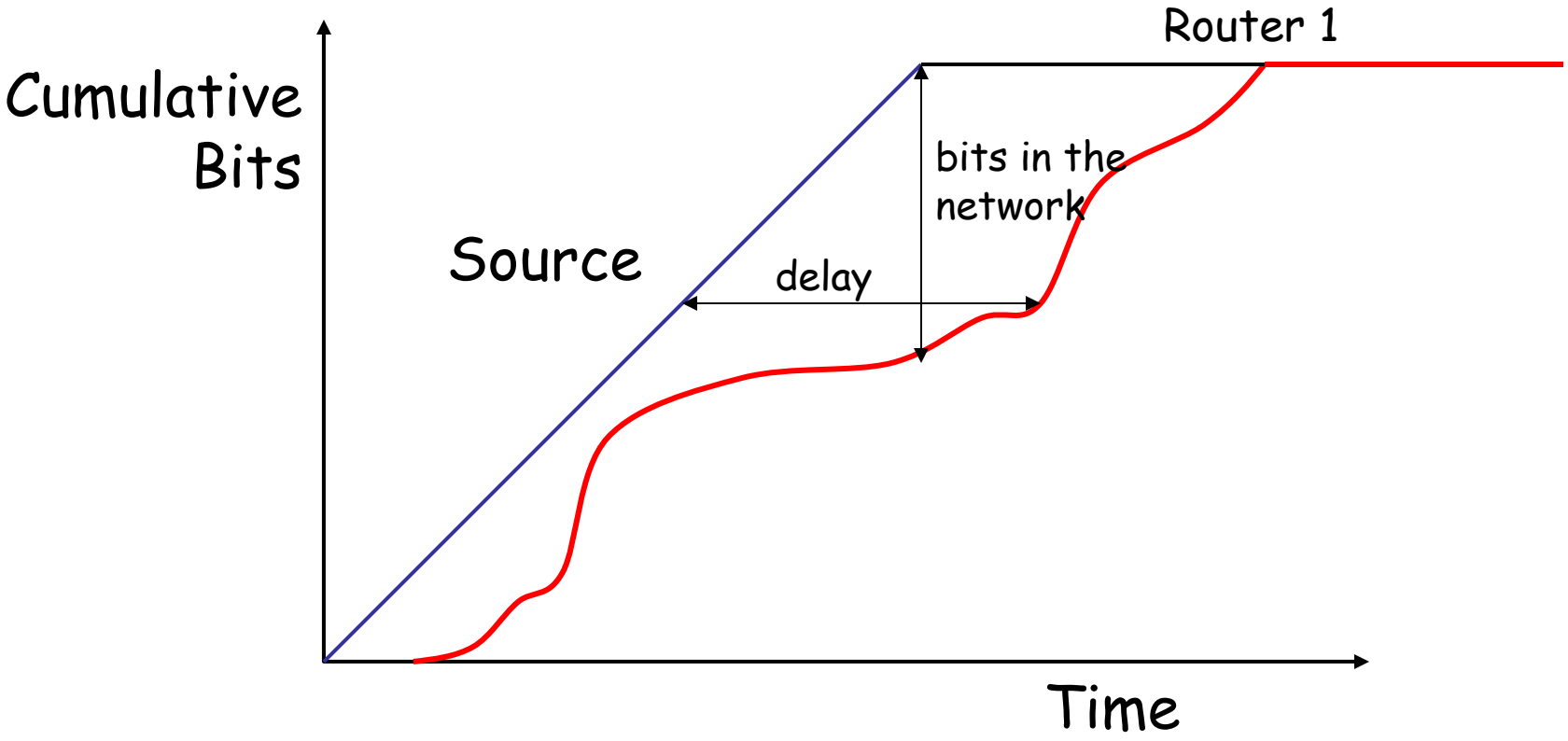
Internet

- Individual packets experience different delays
- Can’t treat network as “wire”
- Application must adapt to network service

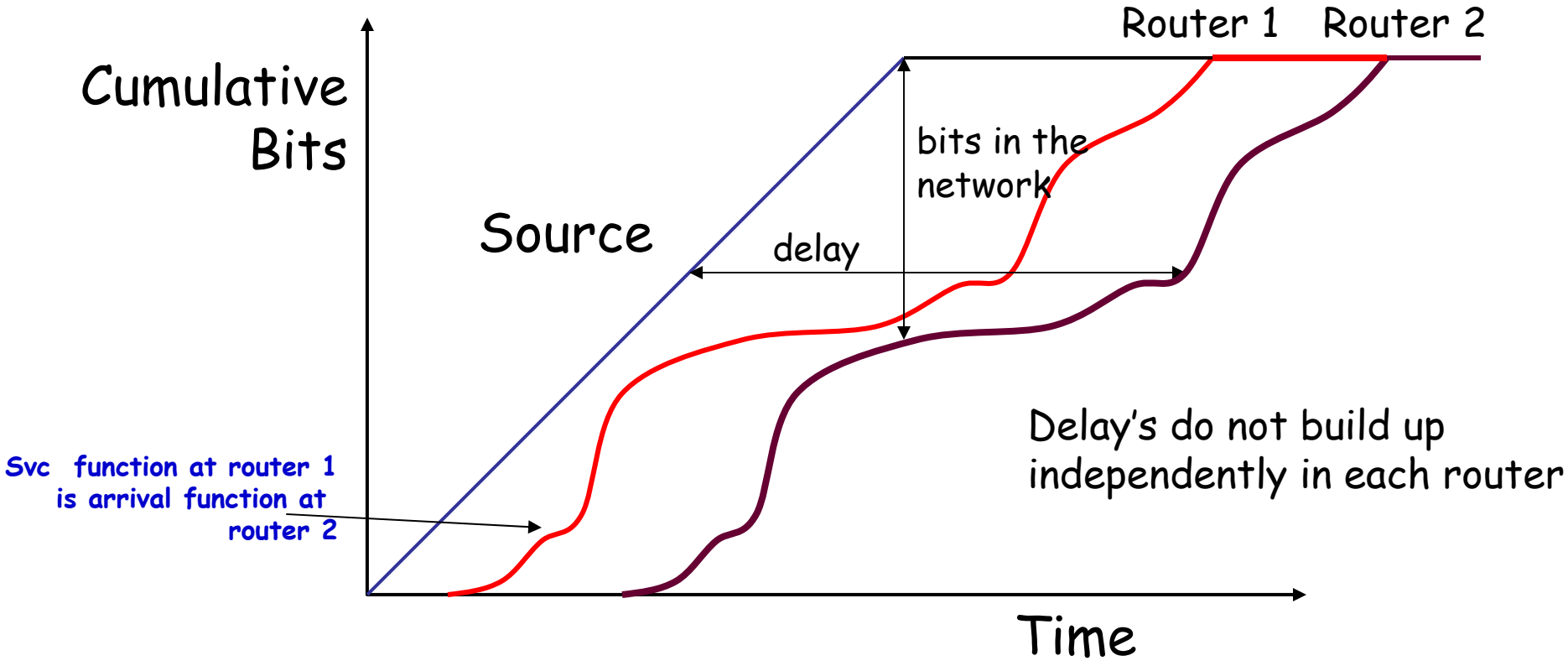
Router Effect on Delay



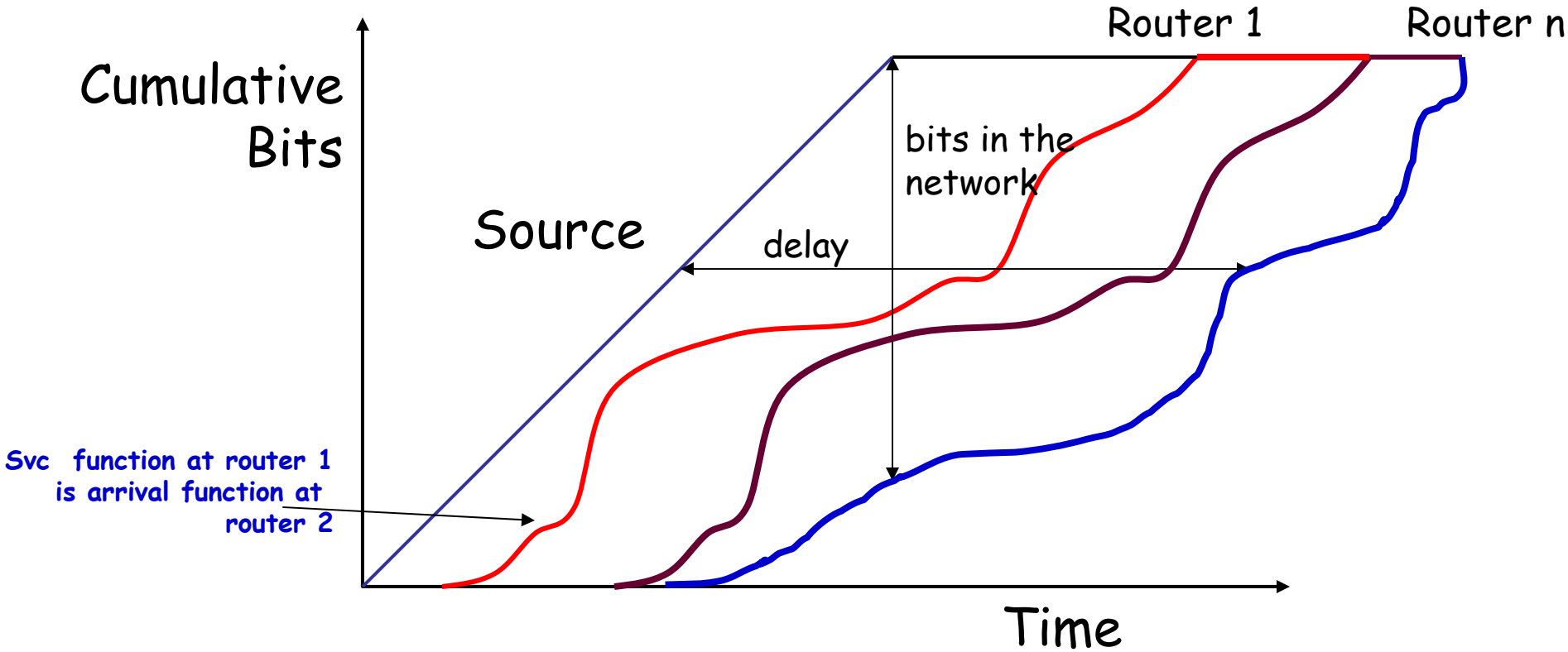
Router Effects on Traffic



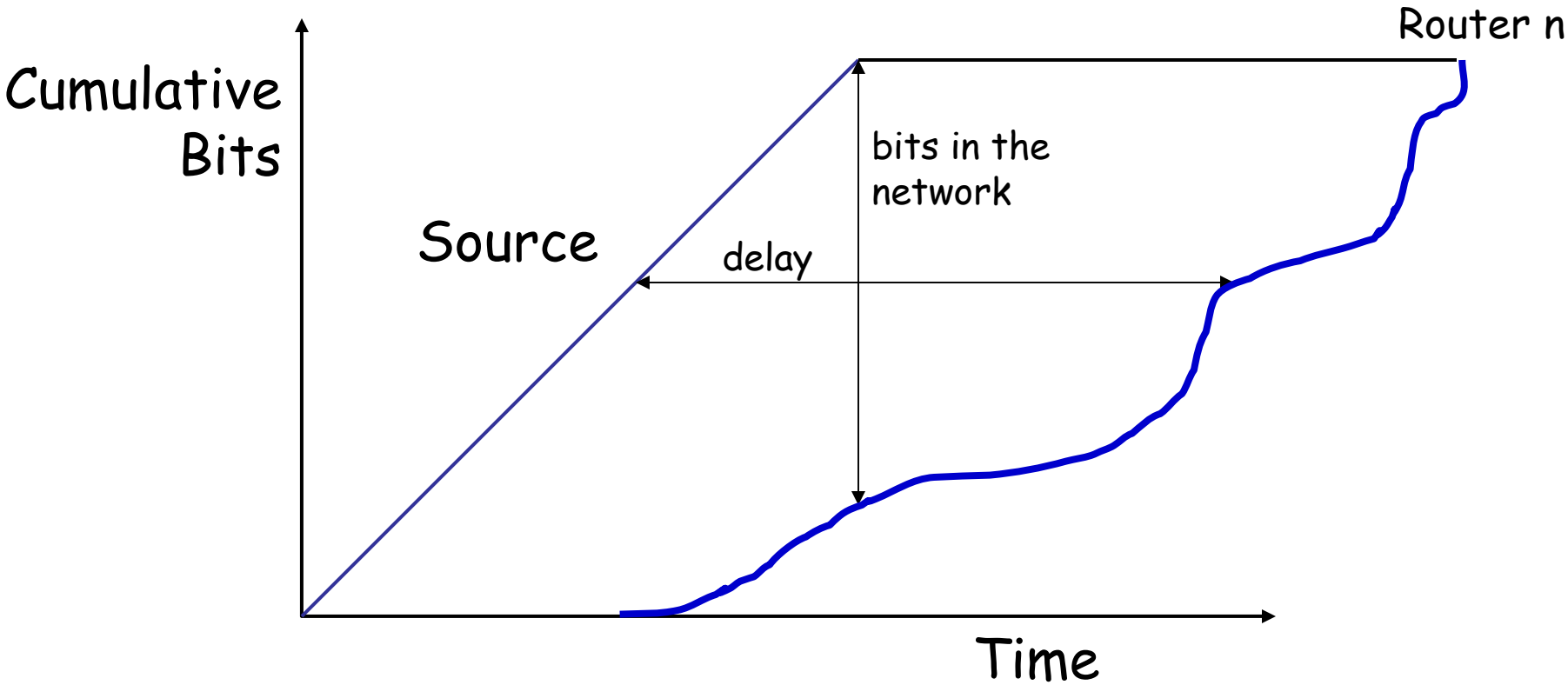
Network Effects on Traffic



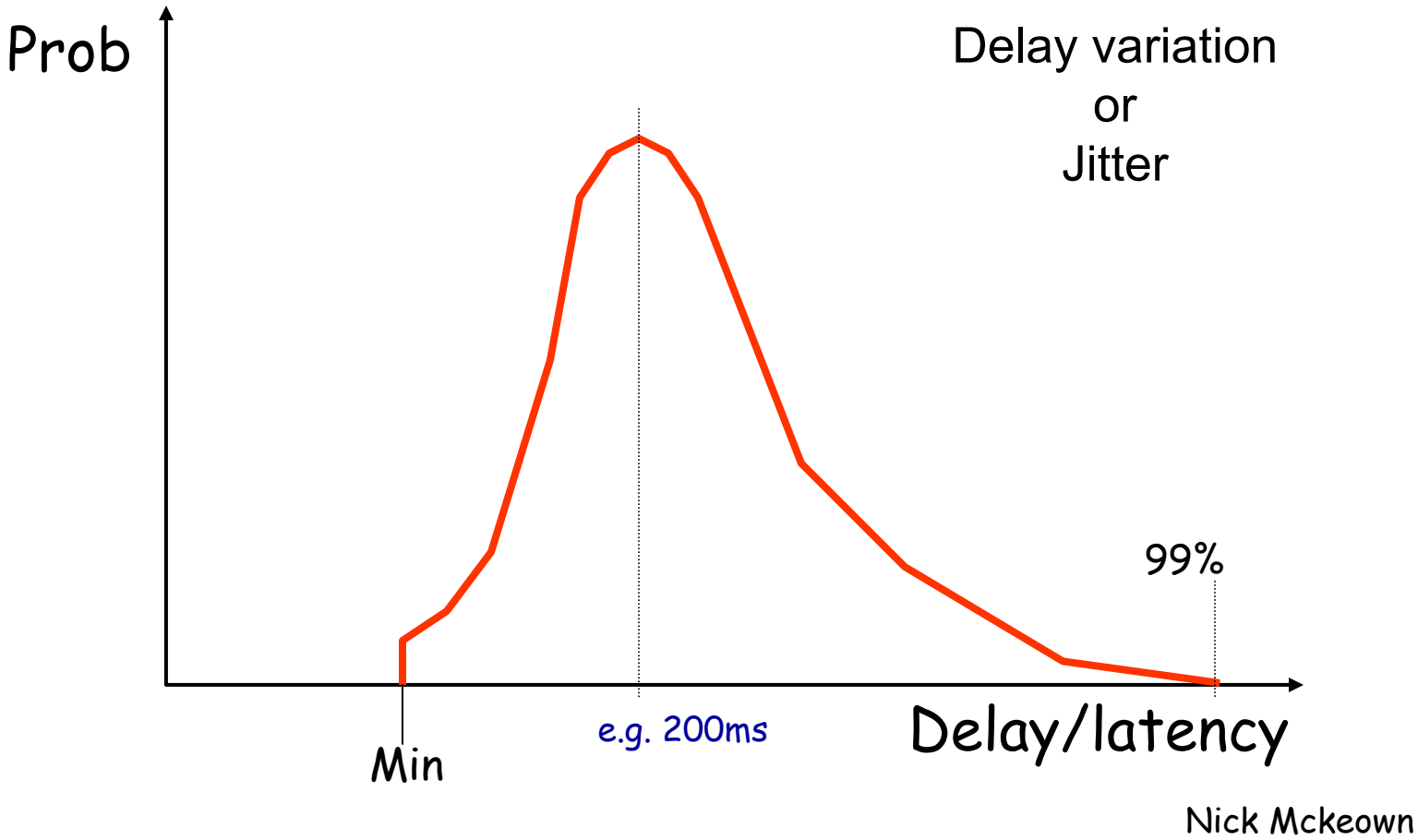
Network Effects on Traffic



Network Effects on Traffic



Network Effect on Delay

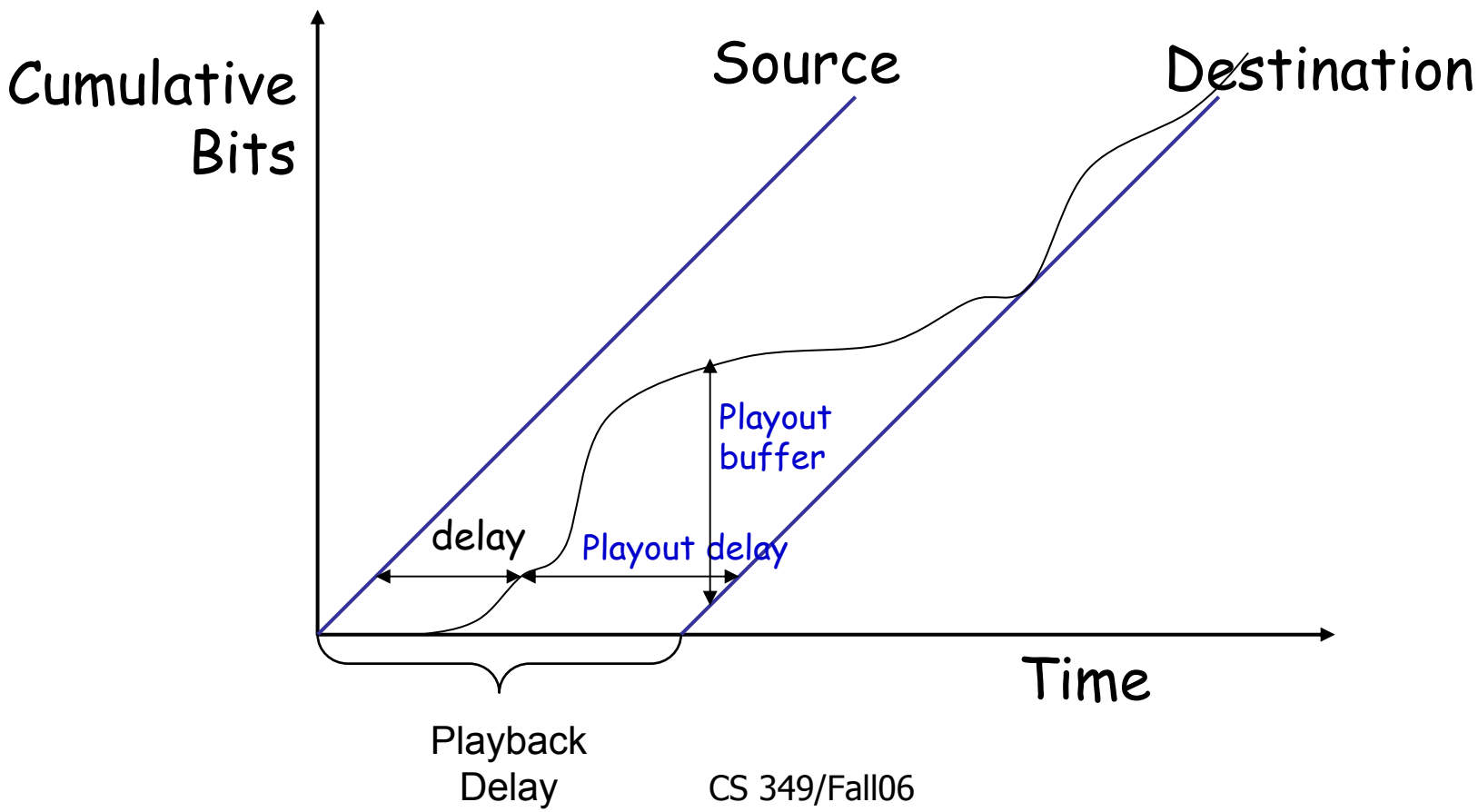


Choices

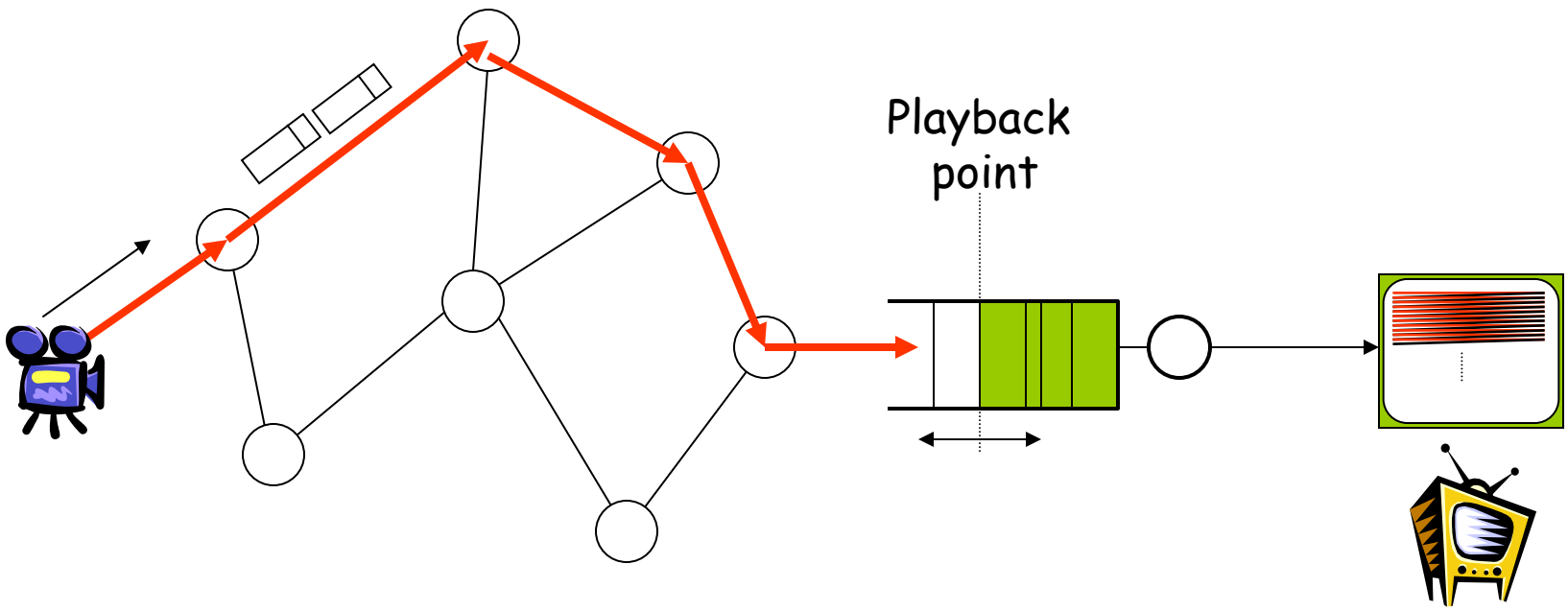
- Play back data upon arrival
  - distorted signal
- Buffer data for a while (playback buffer)
  - extra delay, less distortion
- Tradeoff depends on application (and use)
  - noninteractive: absorb delay, eliminate all distortion
  - interactive: absorb only a little delay, eliminate some distortion

Playback Buffer

Play back data a fixed time interval after it was sent



Playback Point



Nick Mckeown

Adaptation

- Can move playback point as delays vary
- Moving playback point:
  - increases distortion
  - but allows lower delays

Application Taxonomy (Oversimplified and Fanciful)

- Elastic versus "real-time"
  - traditional data apps are elastic
  - streaming media are real-time
- RT intolerant versus RT tolerant
  - intolerant applications need all data
- Tolerant nonadaptive versus tolerant adaptive
  - not clear why any tolerant app couldn't adapt
- Rate-adaptive versus delay-adaptive (or both)

Key Points

- Some apps don't need to know maximal delay, just need it to be controlled
  - tolerant, delay-adaptive applications will move playback point to reduce delay
  - can absorb occasional outliers
- Some apps need to know maximal delay
  - can't tolerate loss or distortion
  - need to fix playback point and so need a priori knowledge of delay bound
  - bound is typically much worse than actual delays

Two Service Classes

- Controlled Load
  - keep delays under control, but no bound
- Guaranteed Service
  - explicit delay bound

Process

- Flow requests service from network
  - service request specification (RSpec)
    - controlled load: nothing
    - guaranteed: service rate (can calculate delay)
  - traffic specification (TSpec) (next slide)
- Routers decide if they can support request
  - admission control
- If so, traffic is classified and scheduled at routers based on per-flow information

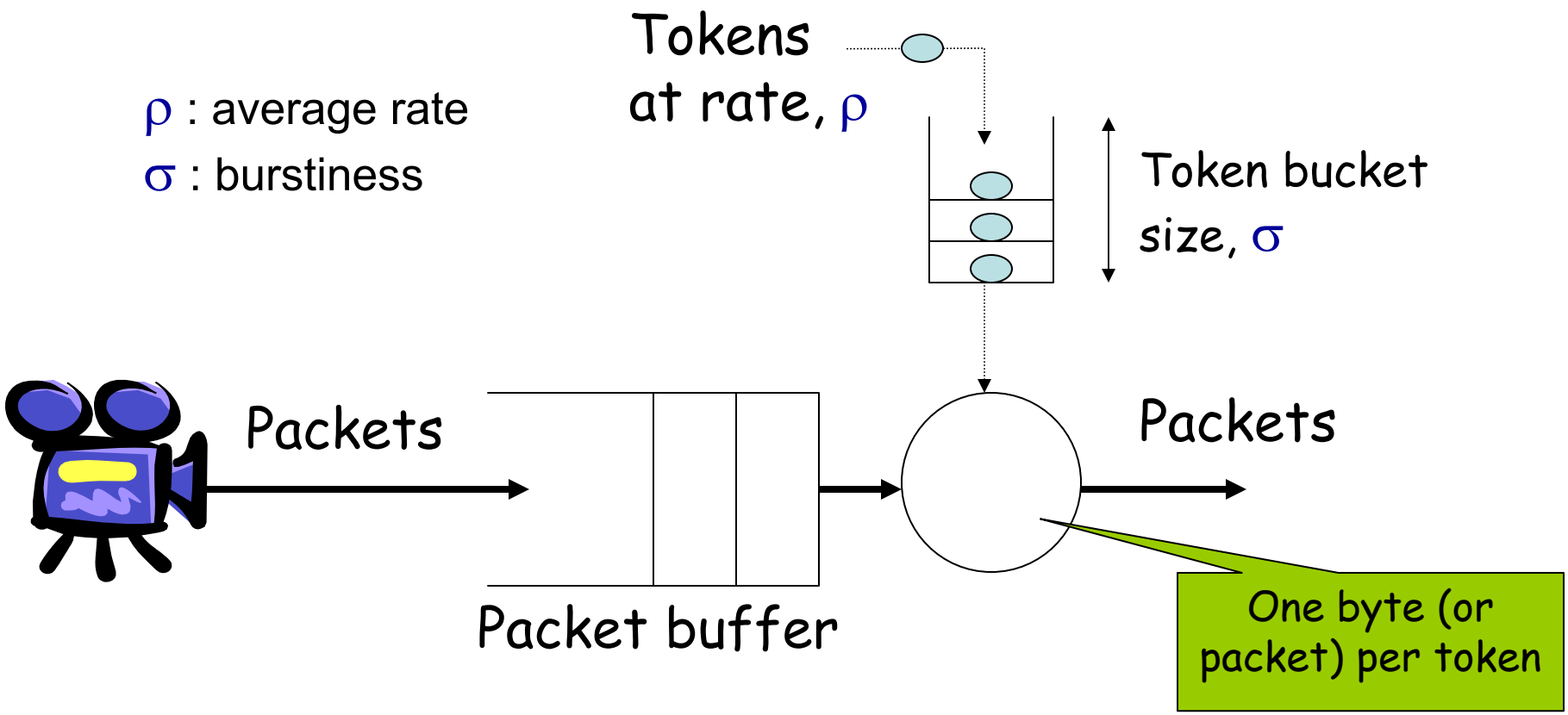
Problem

- How do you describe bursty traffic?
- Network needs some description of traffic
- But video source is bursty (due to coding)
  - can't predict in advance the exact behavior
- Describe "envelope" of traffic: rate and burstiness
- Bits sent between times s and t: $A(s,t) \leq \sigma + \rho(t-s)$

TSpec: The Token Bucket

ρ : average rate

σ : burstiness



Bits sent between times s and t: $A(s,t) \leq \sigma + \rho(t-s)$

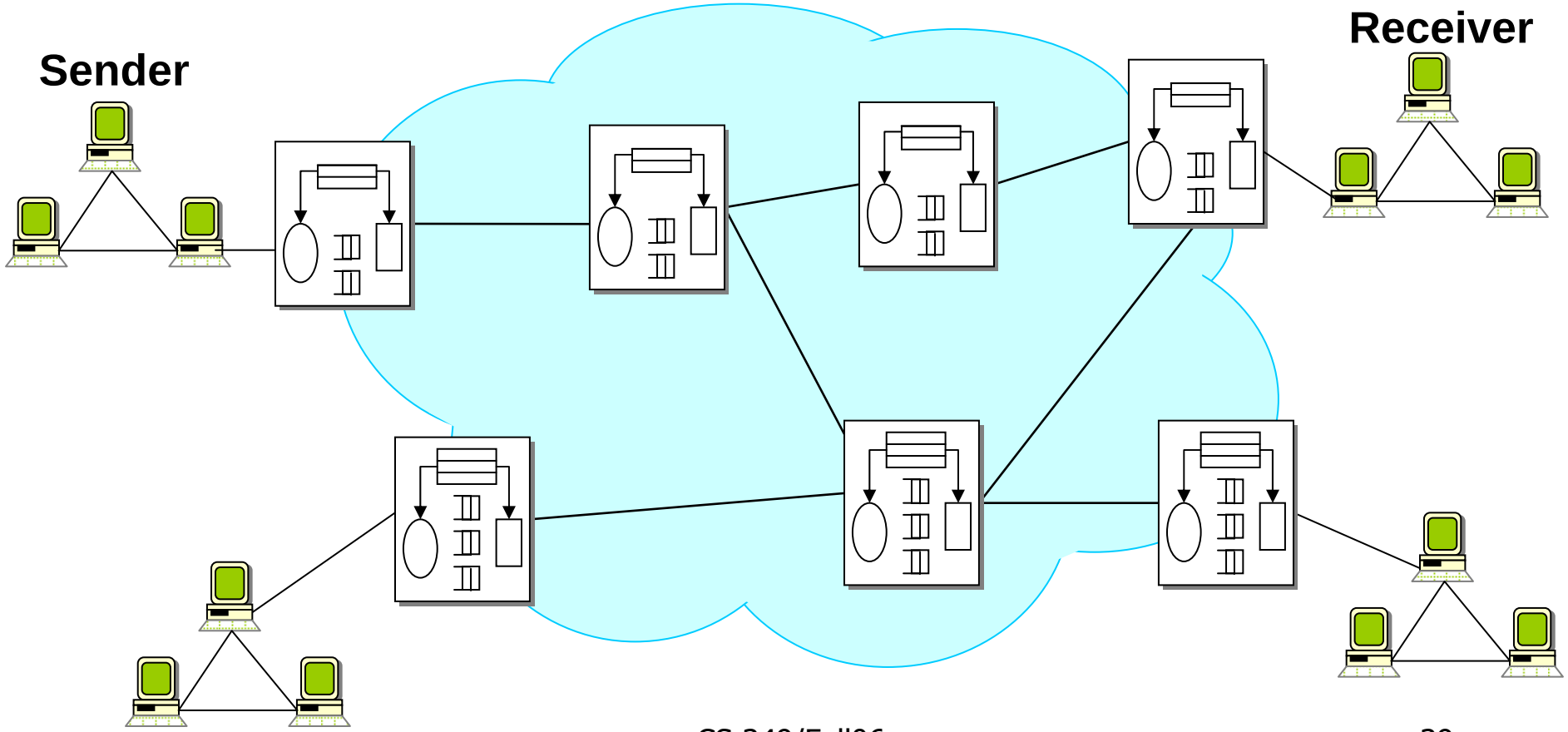
Required Elements

- Reservation Protocol
  - how service request gets from host to network
- Admission control algorithm
  - how network decides if it can accept flow
- Packet scheduling algorithms (next lecture)
  - so routers can deliver service

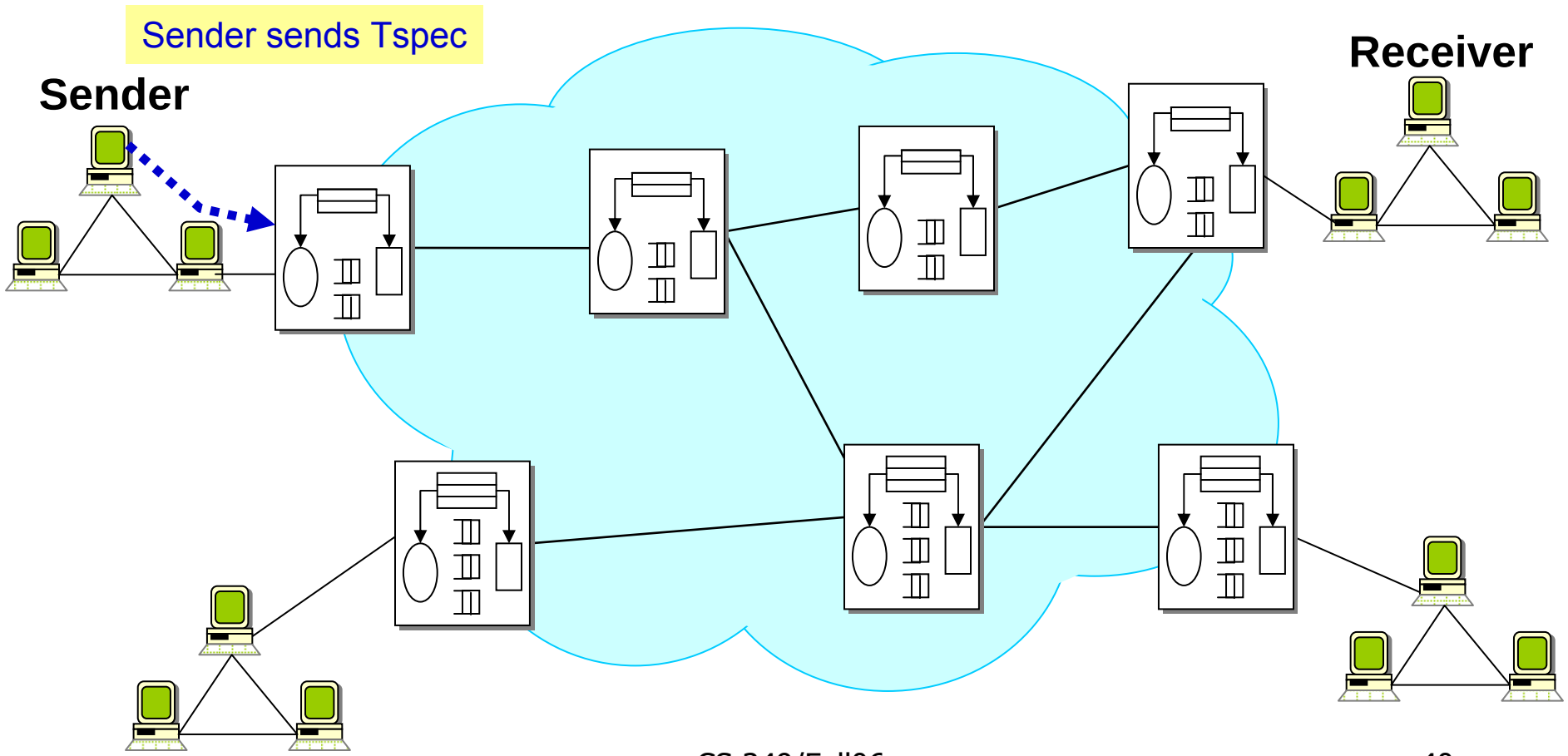
Control Plane versus Data Plane

- Plane as in geometry, not airplane
- Control plane:
  - how information gets to routers
- Data plane:
  - what routers do with that information to data packets

Control Plane: Resource Reservation



Control Plane: Resource Reservation



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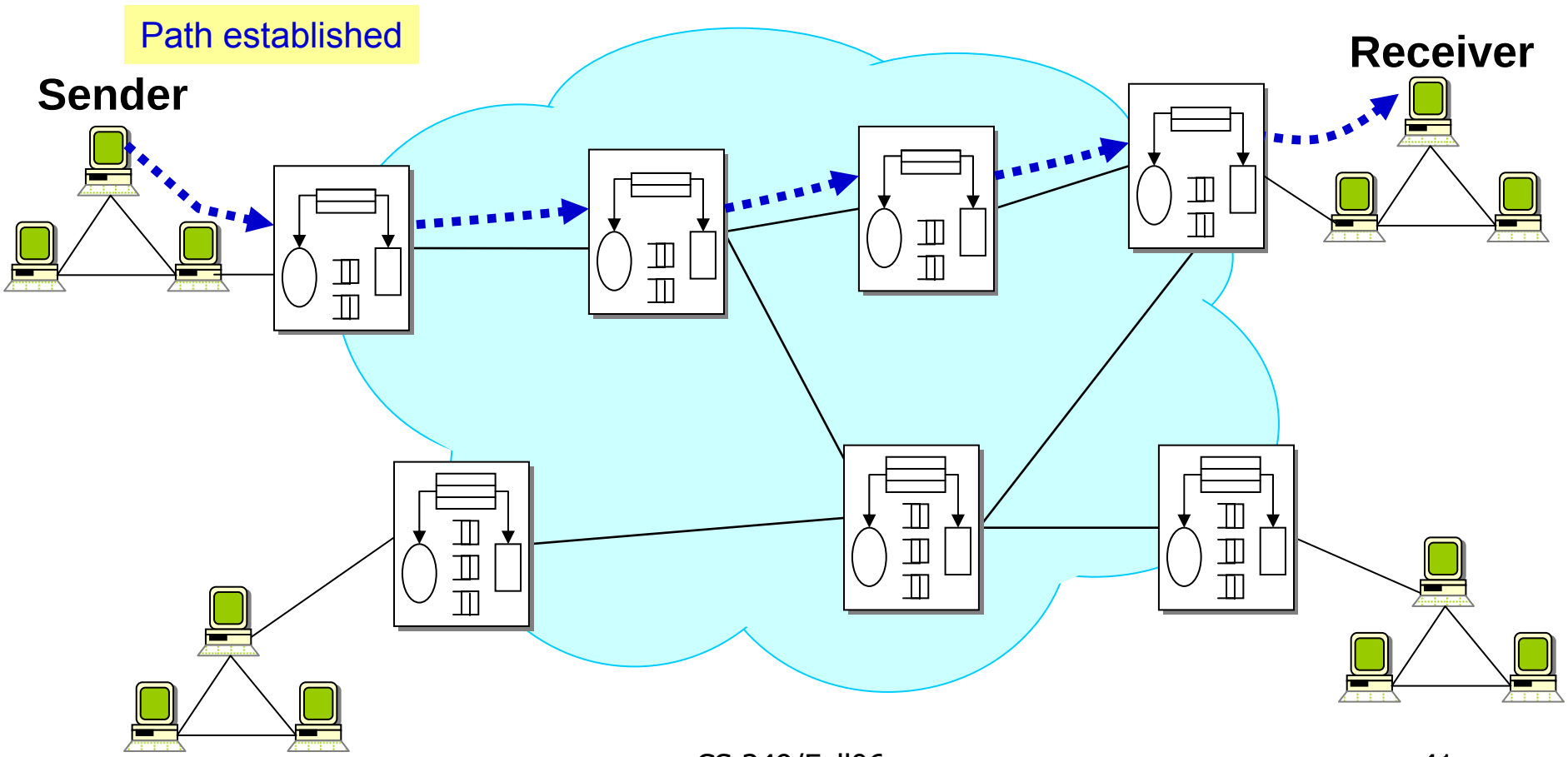

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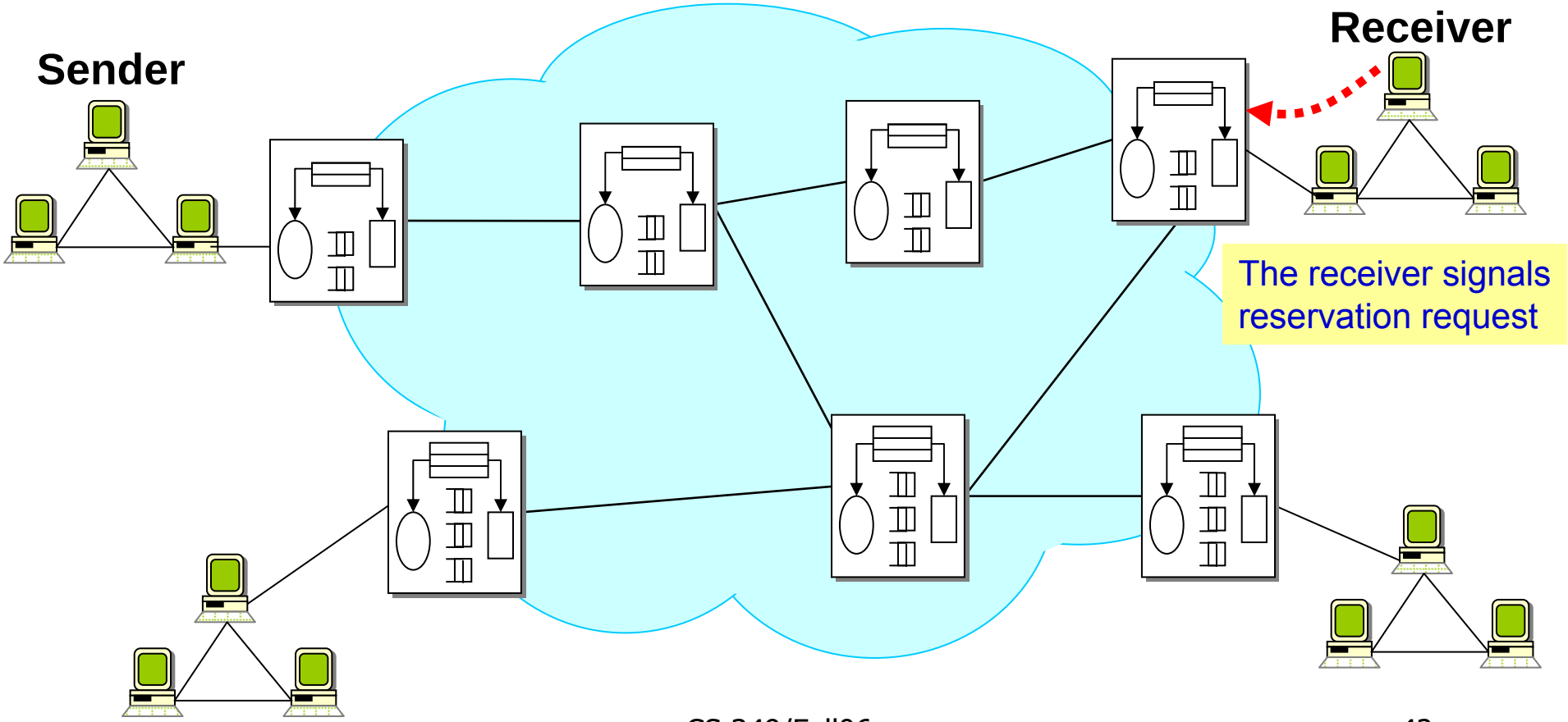
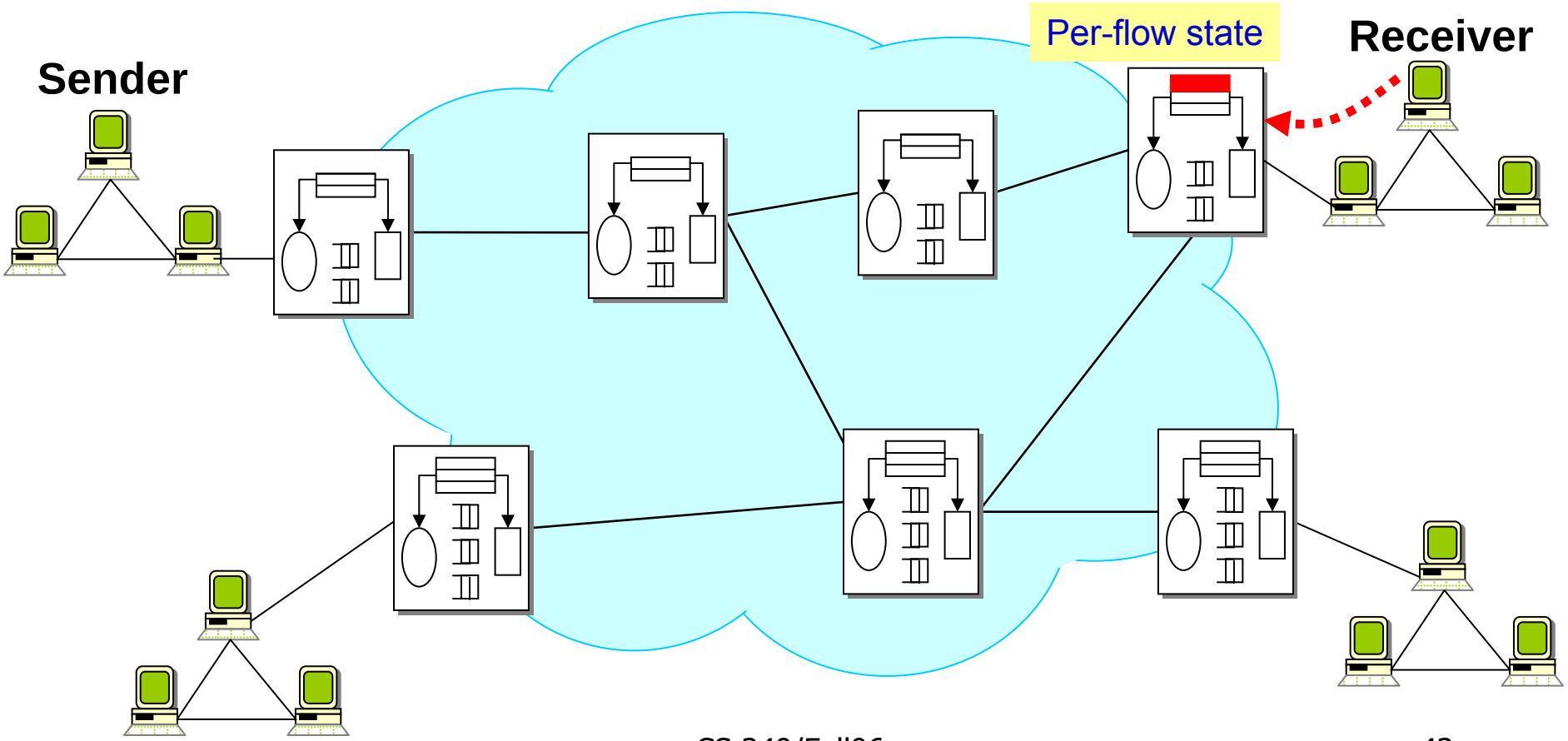
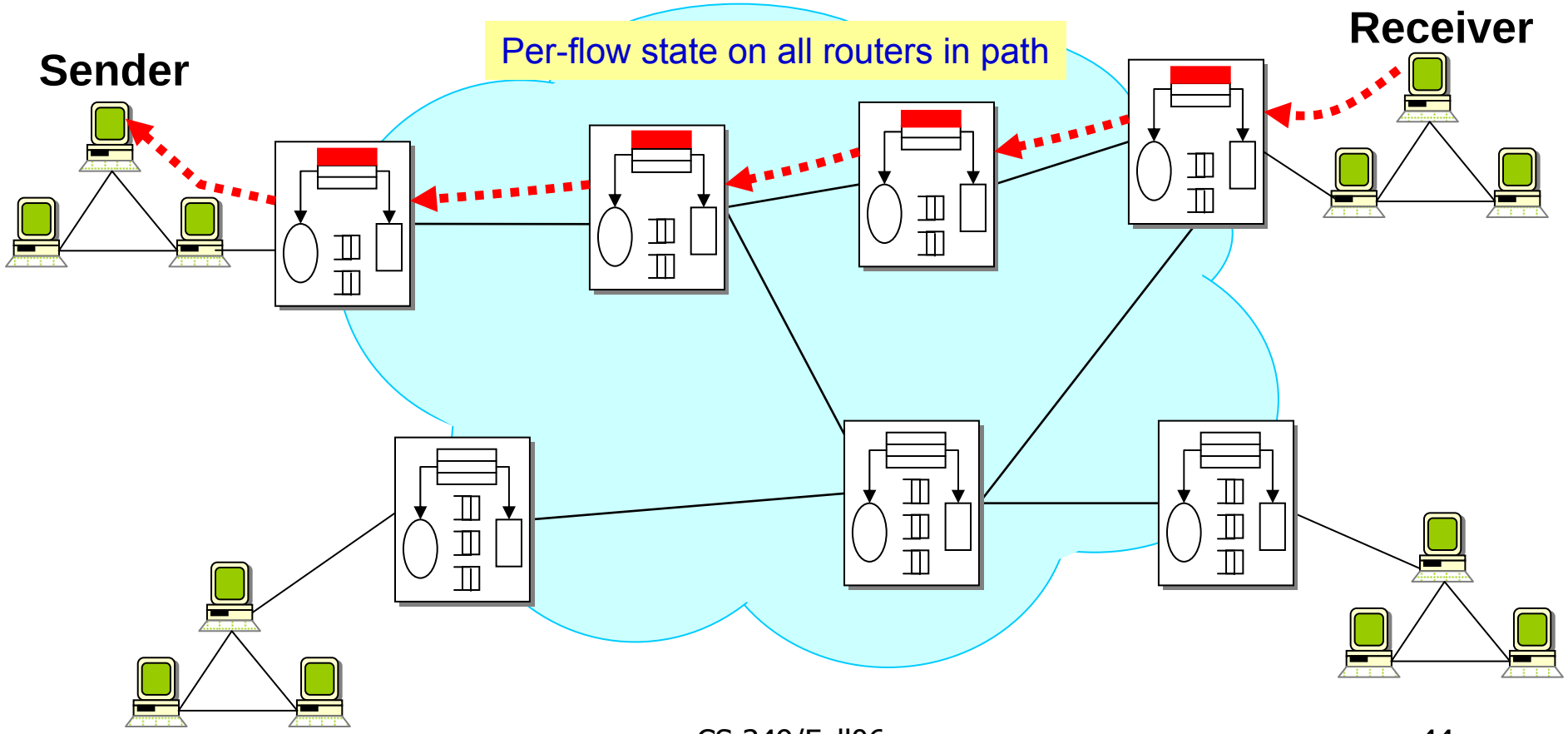


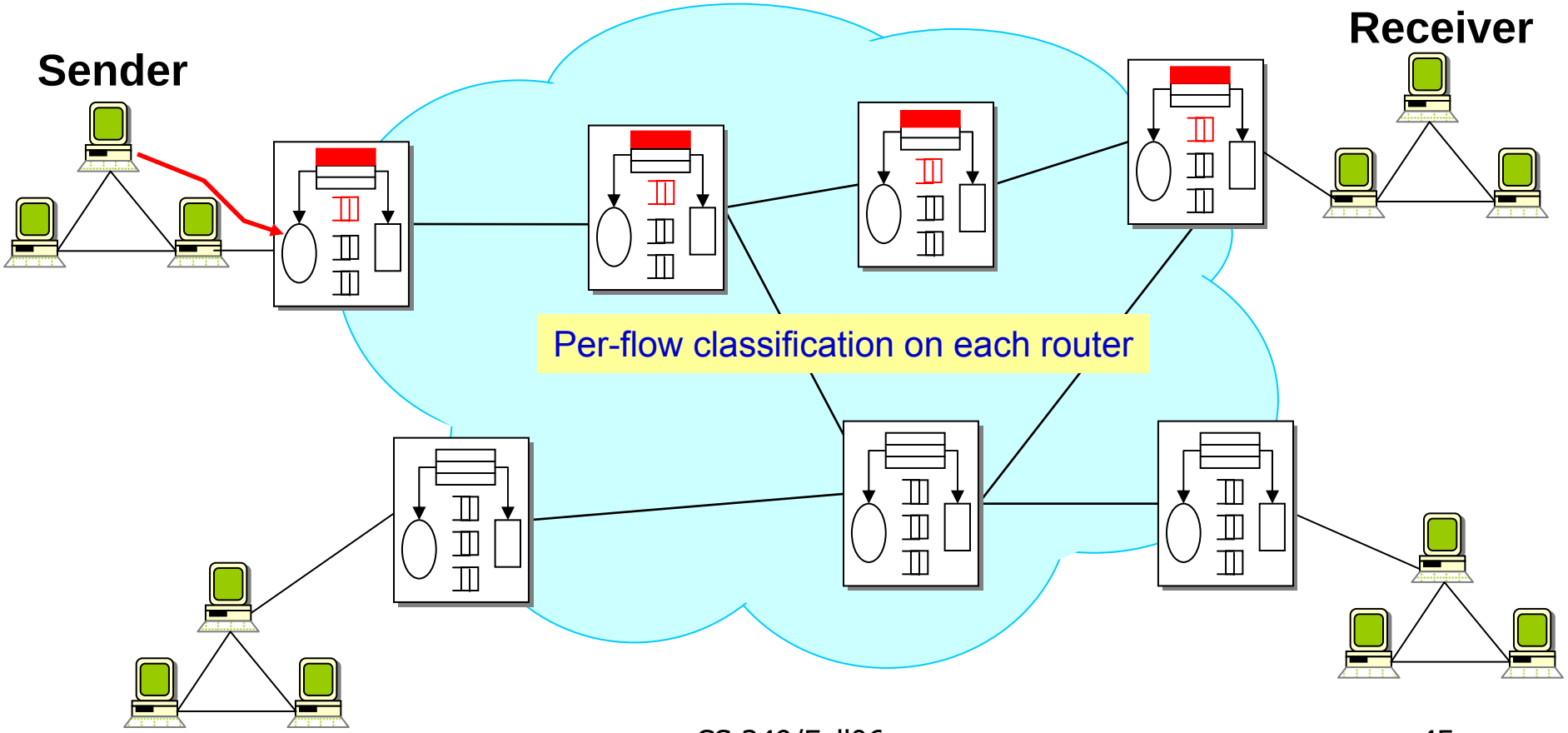
Control Plane: Admission Control



Control Plane: Admission Control



Data Plane



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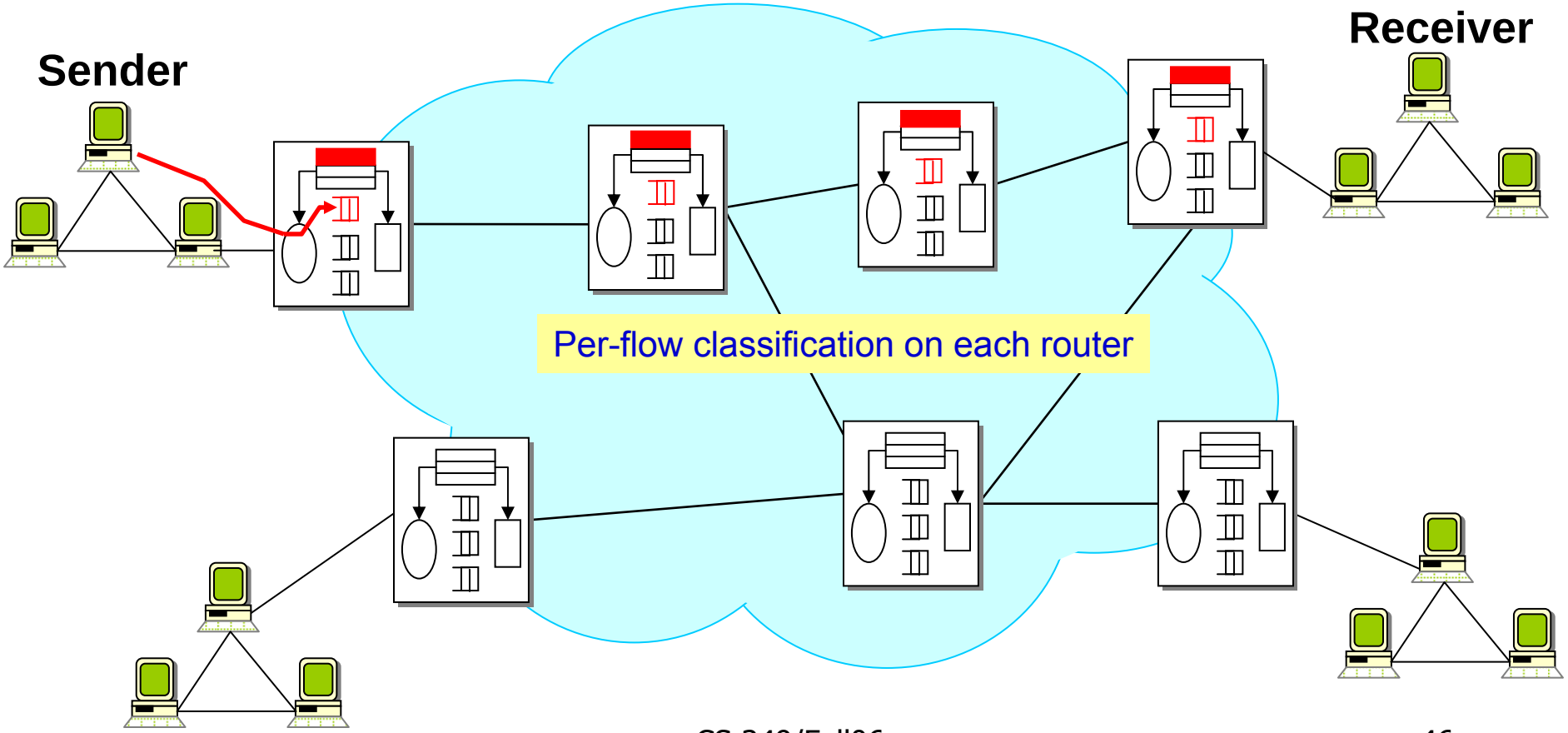
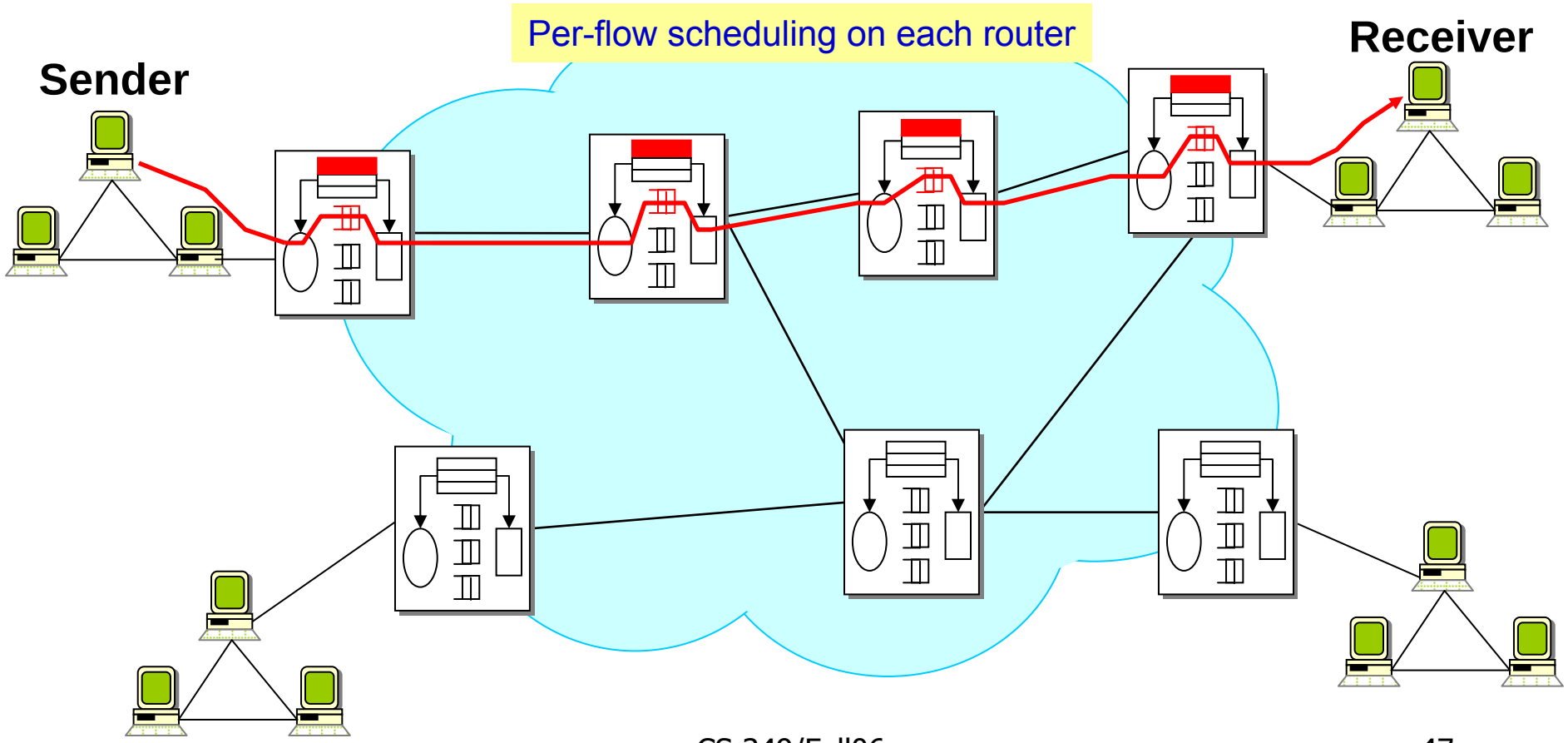


Data Plane



Resource Reservation Protocol: RSVP

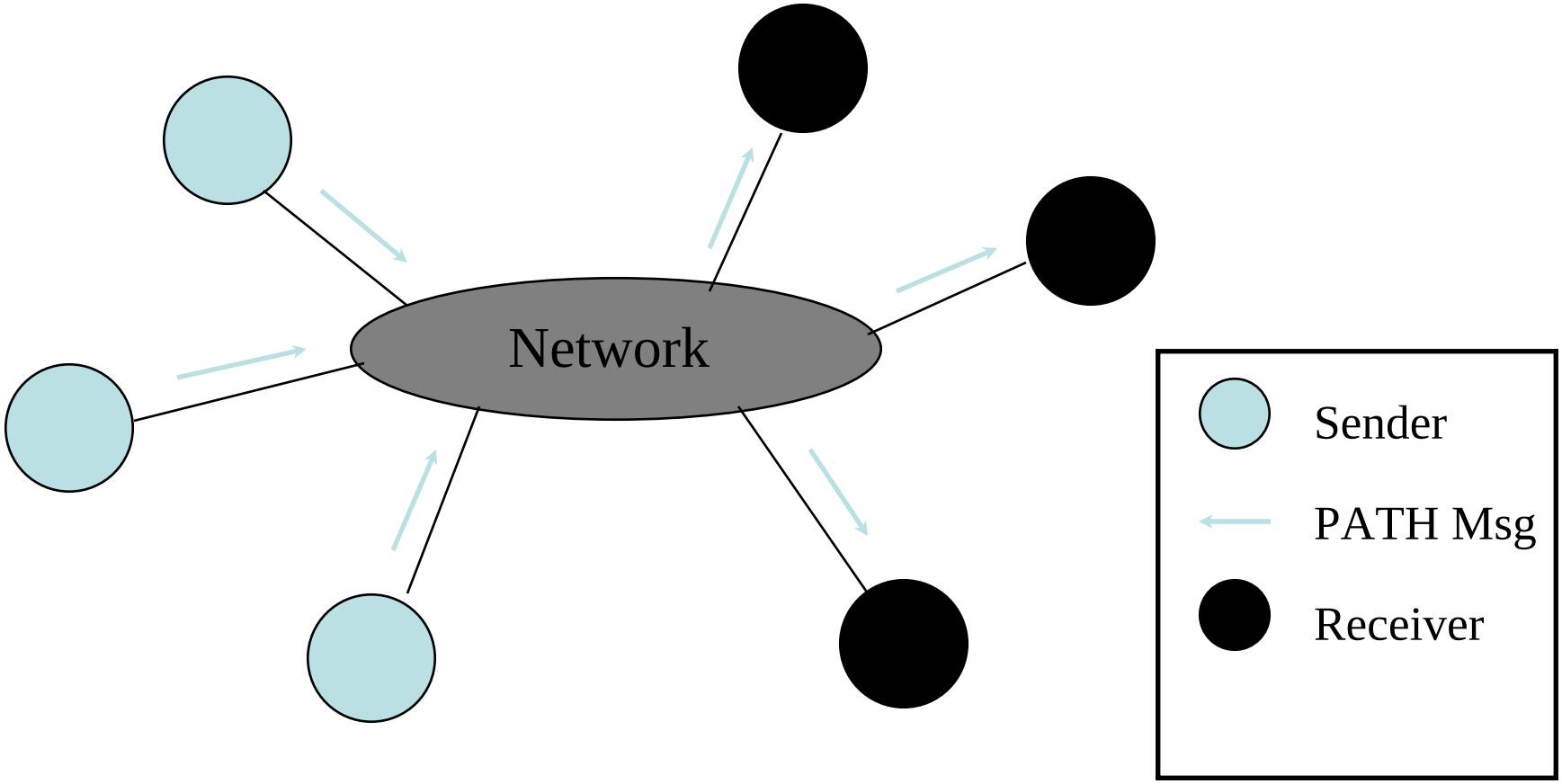
- Establishes end-to-end reservations over a datagram network
- Designed for multicast (which will be covered later in course).

- Sources: send TSpec
- Receivers: respond with RSpec Network
- Network: responds to reservation requests

PATH and RESV Messages

- Sender sends PATH messages
  - TSPEC: use token bucket
  - Set up the path state on each router including the address of previous hop (route pinning)
  - Collect path information (for guaranteed service)
- Receiver sends RESV message on the reverse path
  - Specify RSpec and TSpec
  - Sets up the reservation state at each router

The Big Picture



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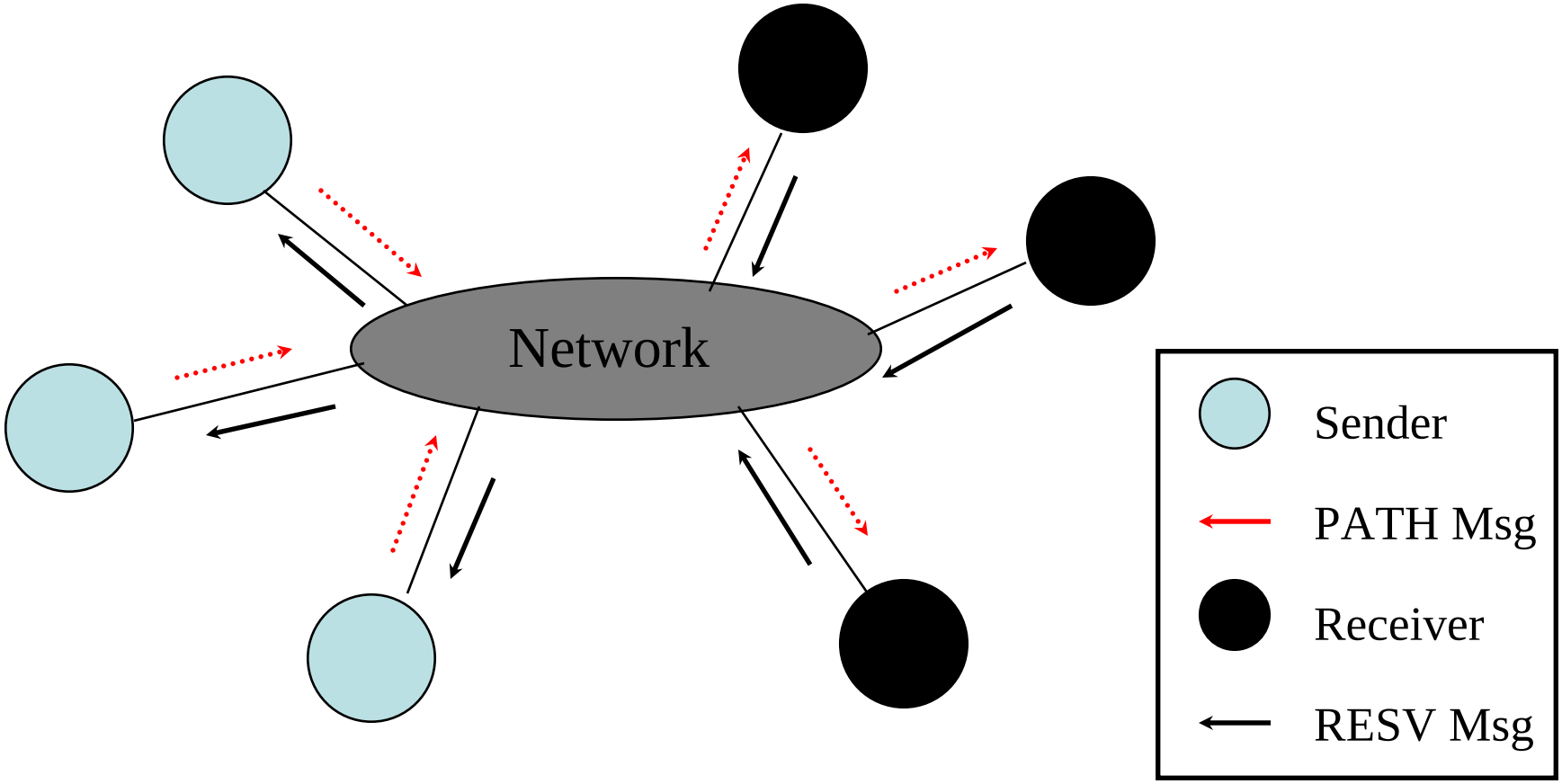
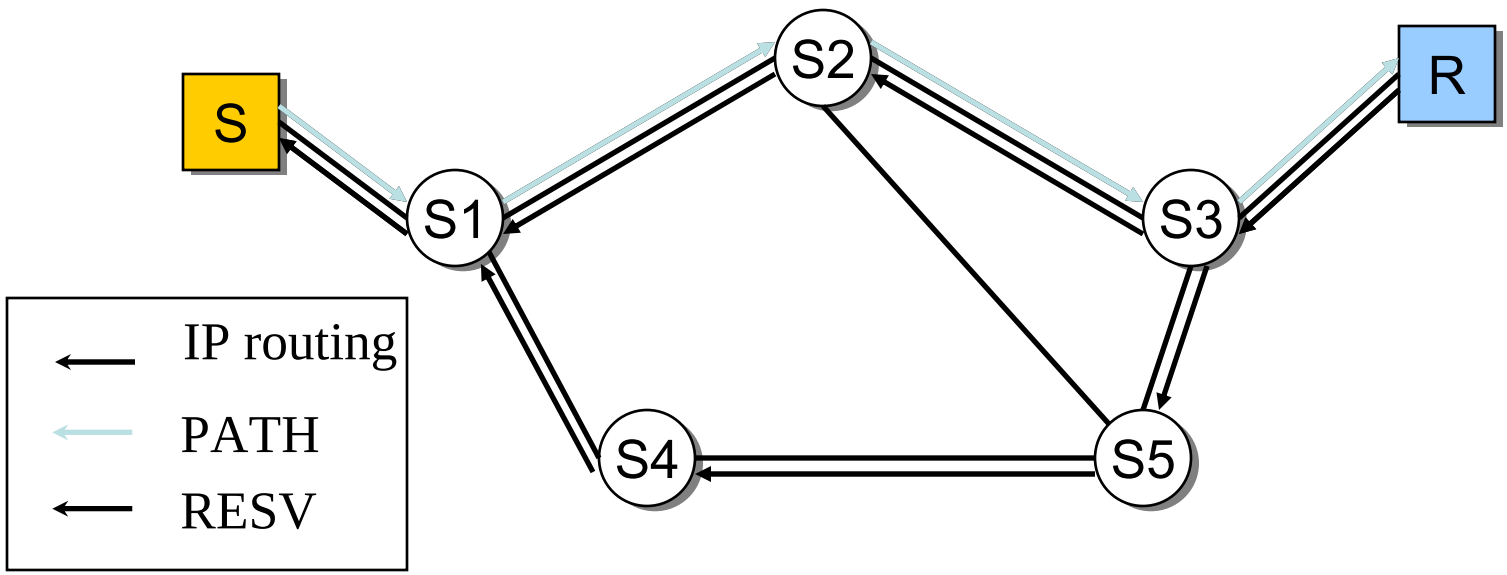


Soft State

- Per session state has a timer associated with it
  - Path state, reservation state
- State deleted when timer expires
- Sender/Receiver periodically refreshes the state, resends PATH/RESV messages, resets timer
- Advantages:
  - No need to clean up dangling state after failure
  - Can tolerate lost signaling packets
  - Easy to adapt to route changes

Route Pinning

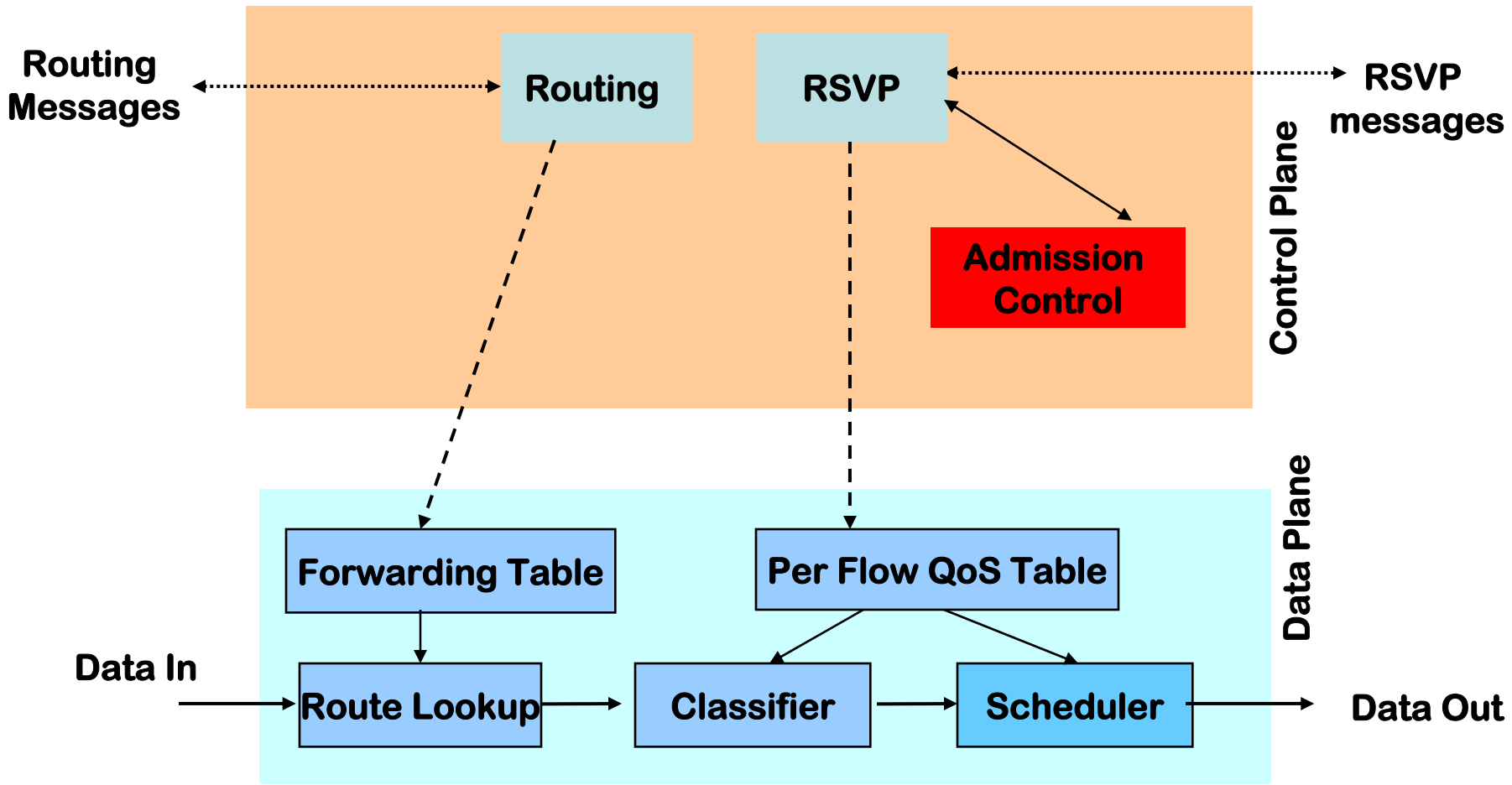
- Problem: asymmetric routes
  - You may reserve resources on R→S3→S5→S4→S1→S, but data travels on S→S1→S2→S3→R !
- Solution: use PATH to remember direct path from S to R, i.e., perform route pinning



Admission Control

- Parameter-based: worst cast analysis
  - guaranteed service
  - low utilization
- Measurement-based: measure current traffic
  - controlled load service
  - higher utilization
- Remember that best-effort service co-exists
  - no need for IntServ traffic to achieve high utilization

IntServ Node Architecture



Advantages of IntServ

- Precise QoS delivered at flow granularities
  - good service, given exactly to who needs it
- Decisions made by hosts
  - who know what they need
  - not by organizations, egress/ingress points, etc.
- Fits multicast and unicast traffic equally well

Disadvantages of IntServ

- Scalability: per-flow state, classification, etc.
  - we goofed, bigtime
  - aggregation/encapsulation techniques can help
  - can overprovision big links, per-flow ok on small links
  - scalability can be fixed, but no second chance
- Economic arrangements:
  - need sophisticated settlements between ISPs
  - right now, settlements are primitive (barter)
- User charging mechanisms: need QoS pricing

Differentiated Services

- Some traffic should get better treatment
  - application requirements: interactive vs bulk transfer
  - economic arrangements: first-class versus coach
- What kind of better service could you give?
  - measured by drops, or delay (and drops)
- How do you know which packets to give better service to?
  - bits in packet header

Traffic Limitations

- Can't give all traffic better service!
- Must limit the amount of traffic that gets better service
- Service Level Agreements (SLA)
  - source agrees to limit amount of traffic in given class
  - network agrees to give that traffic "better" service
    - for a price!
  - economics play an important (fatal?) role in QoS

DiffServ "Code Points"

- Use six of the ToS bits in IP packet header
- Define various "code points"
- Each code point defines a desired per-hop behavior
  - a description of the service the packet should get
  - not a description of the router implementation of that service

"Expedited Forwarding"

- Give packet minimal delay and loss service
  - e.g., put EF packets in high priority queue
- To make this a true "absolute" service,
  - all SLAs must sum to less than the link speed
  - unlikely
- More likely, a way to assure relatively low delay

Is Delay the Problem?

- With RED, most queues are small
- Packets are dropped when queue starts to grow
- Thus, delays are mostly speed-of-light latency
- Service quality is mostly expressed by drop-rate
- Want to give traffic different levels of dropping

"Assured Forwarding"

- Packets are all serviced in order
  - makes TCP implementations perform well
- But some packets can be marked as low-drop and others as high-drop
  - think of it as priority levels for dropping
- Can be implemented using variations of RED
  - different drop probabilities for different classes

Example

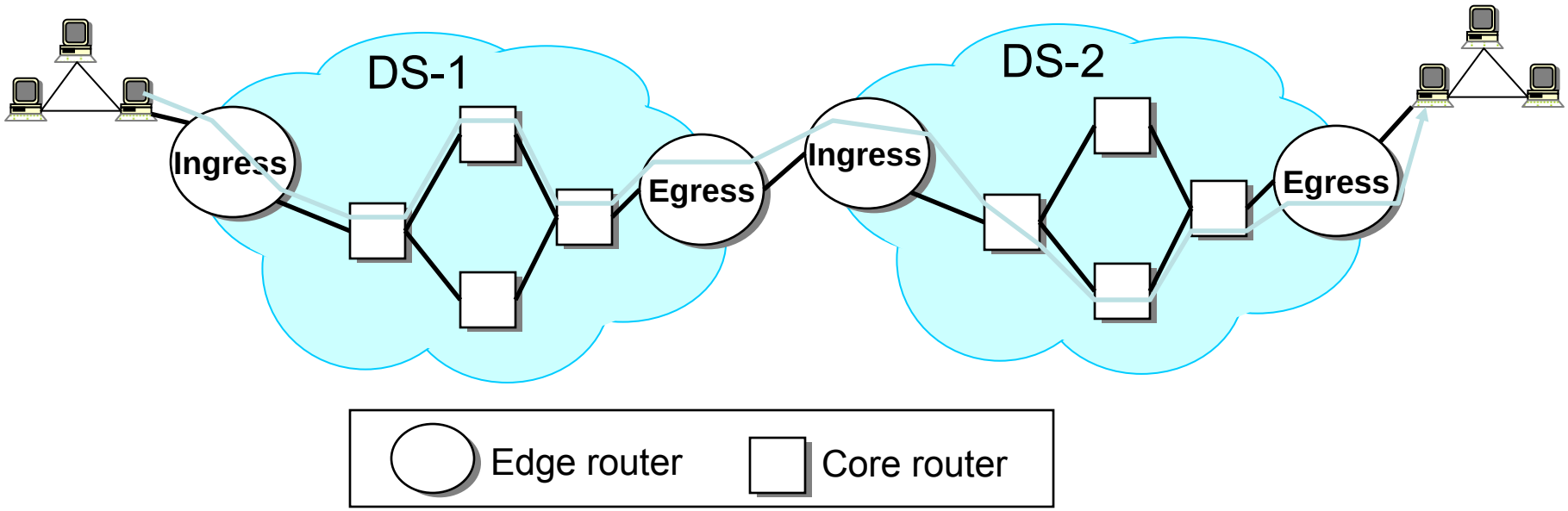
- 10% premium traffic, 90% ordinary traffic
- Overall drop rate is 5%
- Can give premium traffic 0% drops, and ordinary traffic a 5.55% drop rate
- Can get a large improvement in service for the small class of traffic without imposing much of a penalty on the other traffic
  - count on SLAs to control premium traffic

Advantages of DiffServ

- Very simple to implement
- Can be applied to different granularities
  - flows
  - institutions
  - traffic types
- Marking can be done at edges or by hosts
- Allows easy peering (bilateral SLAs)

DiffServ Peering

- Ingress routers
  - Police/shape traffic
  - Set Differentiated Service Code Point (DSCP) in DiffServ (DS) field
- Core routers
  - Implement Per Hop Behavior (PHB) for each DSCP
  - Process packets based on DSCP



Disadvantages of DiffServ

- Service is still "best effort", just a better class of best effort
  - except for EF, which has terrible efficiency
  - all traffic accepted (within SLAs)
- Some applications need better than this
  - certainly some apps need better service than today's Internet delivers
  - but perhaps if DiffServ were widely deployed premium traffic would get great service (recall example)
  - nonetheless, let's plunge ahead....

What You Need to Know

- Three kinds of QoS approaches
  - Link sharing, DiffServ, IntServ
- Some basic concepts:
  - differentiated dropping versus service priority
  - per-flow QoS (IntServ) versus per-aggregate QoS (DiffServ)
  - Admission control: parameter versus measurement
  - control plane versus data plane
  - controlled load versus guaranteed service
  - codepoints versus explicit signaling
- Various mechanisms:
  - playback points
  - token bucket
  - RSVP PATH/RESV messages

Factors Limiting QoS Deployment

- Prevalence of overprovisioning
  - if all links are only at 40% utilization, why do you need QoS?
  - lore says that inter-ISP links are not overprovisioned
- Primitive inter-ISP financial arrangements
  - QoS requires financial incentives to enforce tradeoffs
  - Current peering arrangements are not able to carry these incentives through in a meaningful way
    - must agree on pricing and service
    - currently agree on neither!
- End-users not used to pricing/performance options

QoS Debates

- Is overprovisioning enough?
  - if so, is this only because access links are slow?
  - what about Korea, Japan, and other countries with fast access links?
  - Disconnect: ISPs overprovision, users get bad service
- Is differentiated services enough?
  - can one really deliver reliable service just using relative priorities?
  - is EF service a viable option?
- It all depends on adaptability of applications