Router-Aided Congestion Control

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Readings For the Last Two Lectures

From Peterson and Davie

- Reading for last lecture (i.e., TCP):
  - Read section 5 and focus on 5.2.1-5.2.6 (included)
- Reading for this lecture
  - Read 6.2-6.4 (included)

Outline

- No help from routers
  - DropTail
  - Problems with DropTail
- What can routers do?
- Examples
  - RED
  - XCP
  - Fair Queuing
  - Hop-by-hop congestion control

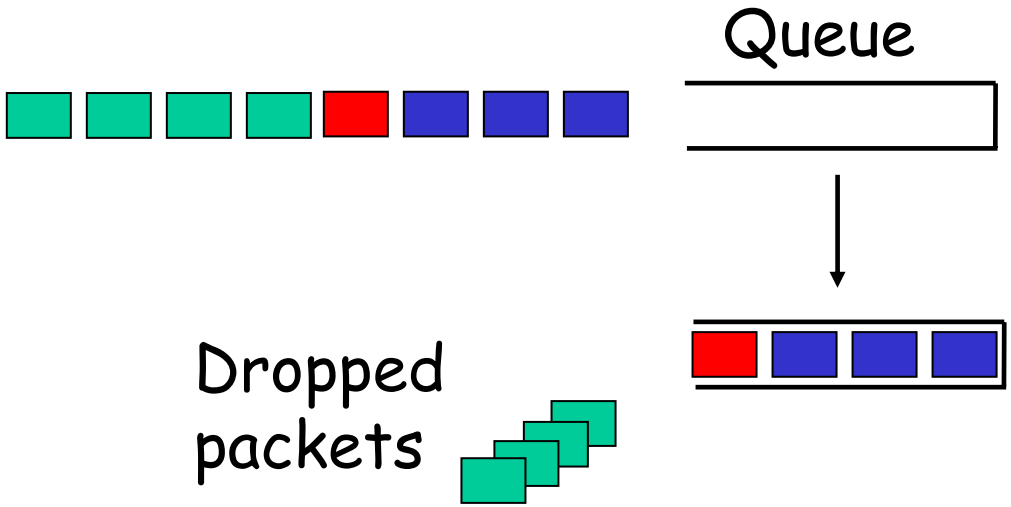
TCP + DropTail

- Most routers use DropTail
- Problems:
  - Large average queues
  - Bursty losses
  - Synchronization
  - No protection from misbehaving flows

Large Average Queues

- Queues are needed to absorb transient bursts
  - Yet avg. queue should stay low
- TCP fills the queue until a drop
  - Keeps avg. queue length high ☹

Bursty Losses



- Traffic from a single source comes in a burst
  - Packets are dropped in bursts
  - ⇒ Too many packets dropped from same cwnd
  - ⇒ Source can't use 3 dupacks to recover and has to wait for timeout ⇒ less efficient

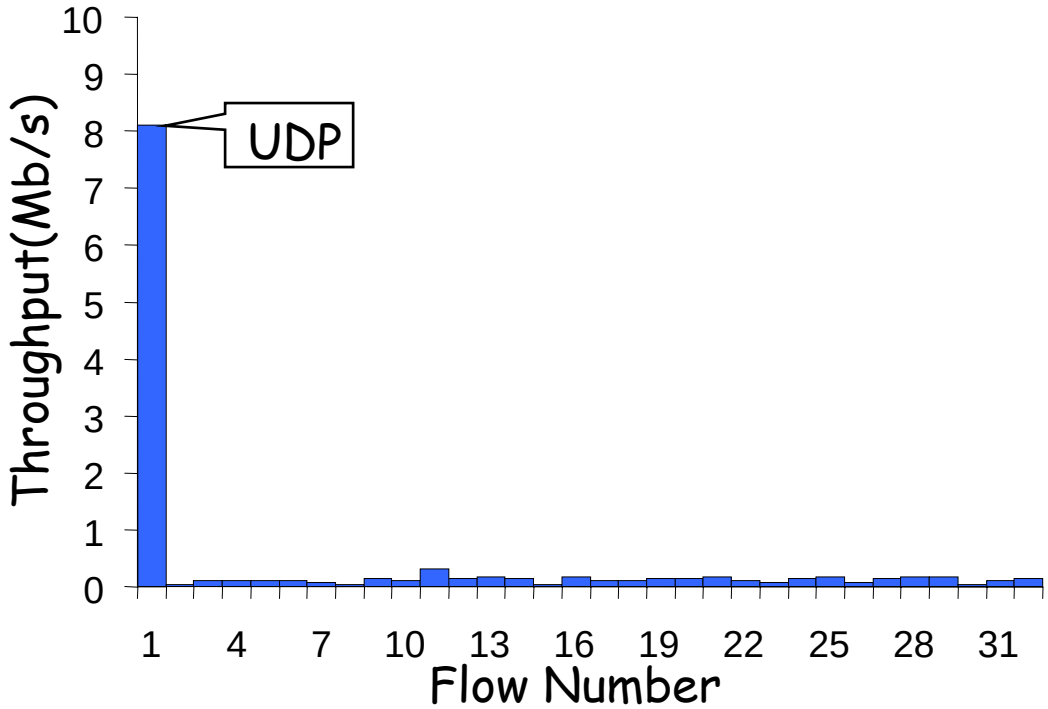
Synchronization

- All losses happen together when the queue overflows
- Sources decrease together $\Rightarrow$ potential underutilization
- Sources increase together until overflowing queue
- Cycle repeats…

Mainly caused by drops concentration at time of overflow

No Flow Protection

- No protection against misbehaving flows
- What happens if 1 UDP sending at 10 Mb/s shares a 10 Mb/s link with 30 TCPs?



How can routers help?

- Send an early and more explicit congestion feedback
  - Drops occur when queue overflows, but routers can send feedback earlier when queue starts forming
  - Spread the drops and desynchronize the senders
- Tell senders how much to increase or decrease
  - Routers can measure congestion by comparing input traffic to capacity and looking at the queue size
- Can provide protection against misbehaving senders
  - Routers can drop the packets of sources which send more traffic
- Scheduling: decide which packets in the queue go first
  - Give flows different quality of service (QoS)

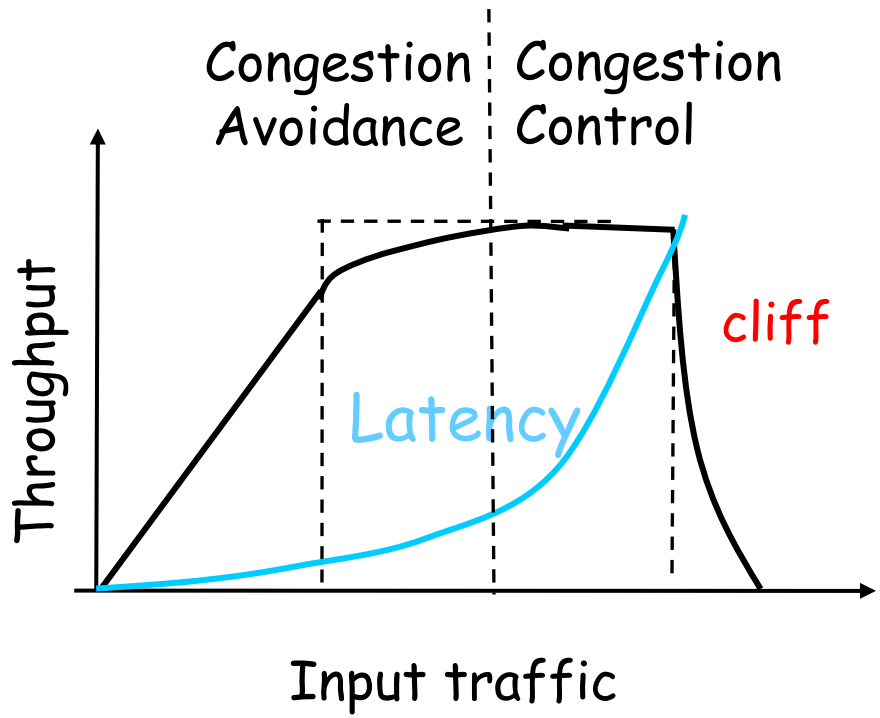
Pors & Cons of Routers' Participation in Cong. Cont.

- Pros
  - Who owns the resource should control it (why trust the senders)
  - Can do many useful things that we couldn't do otherwise:
    - better efficiency and fairness, QoS, protection, …
- Cons
  - Increase the complexity of the routers
  - Deployment is harder
    - It is hard to change the routers (convince ISPs)
    - Many schemes need to change a large number of routers together for the scheme to be effective

1. Random Early Detection (RED)

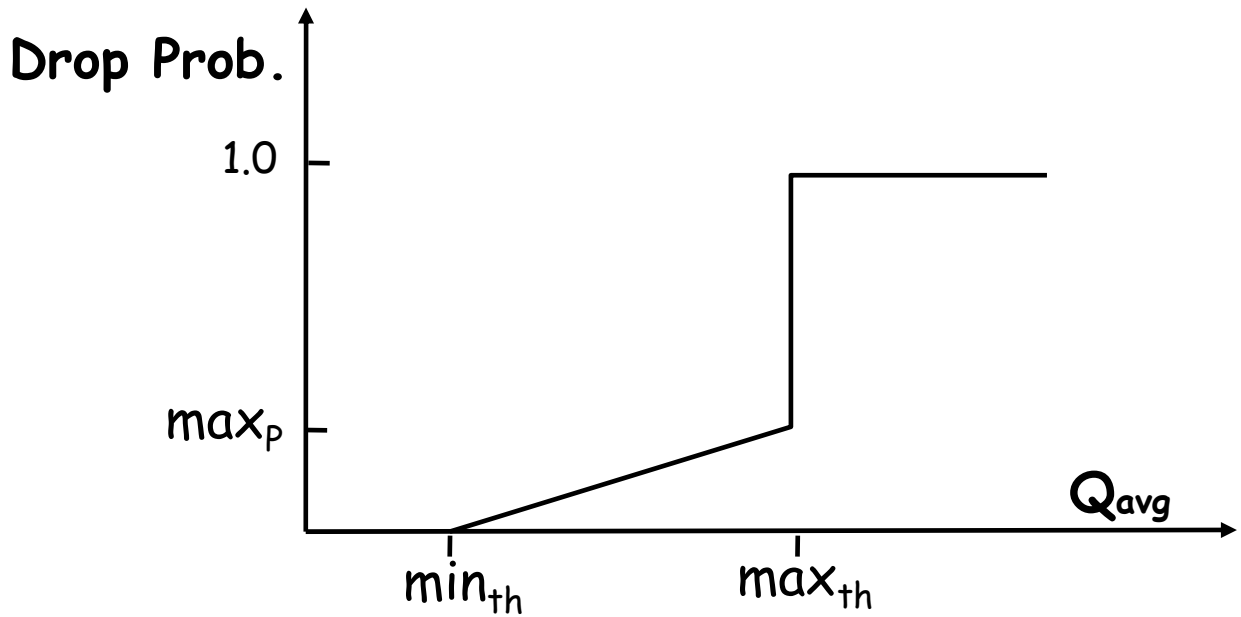
RED's objectives

- Operates at congestion avoidance
  - Keeps avg. queue low (low delay)
  - Safer
- Attempts to solve the synchronization and bursty drops problems



RED Algorithm

- Define 2 vars: min_thresh and max_thresh
  - Try to keep the queue between these two vars
- How? when a packet arrives:
  - Compute $Q_{avg} = w \times Q + (1-w) \times Q_{avg}$; $0 < w < 1$
  - Drop packet with probability $p=f(Q_{avg})$



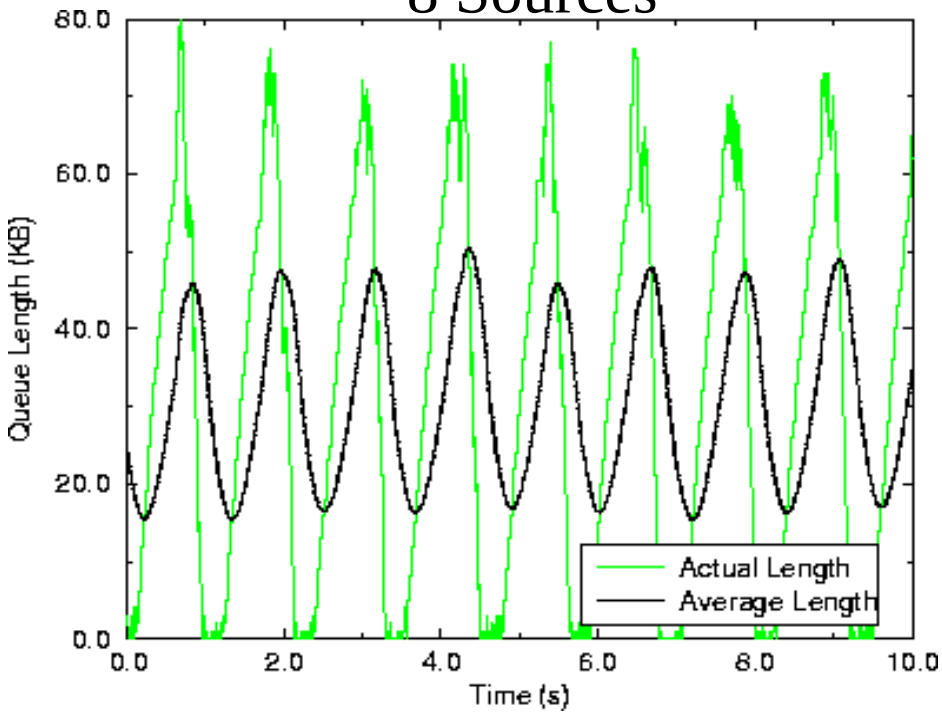
What Does RED Achieve?

- Less bias against bursty flows
  - Why?
- Smaller average queue size
  - Why?
- Reduces likelyhood of bursty drops
  - Why?
- Reduces likelihood of synchronization
  - Why?

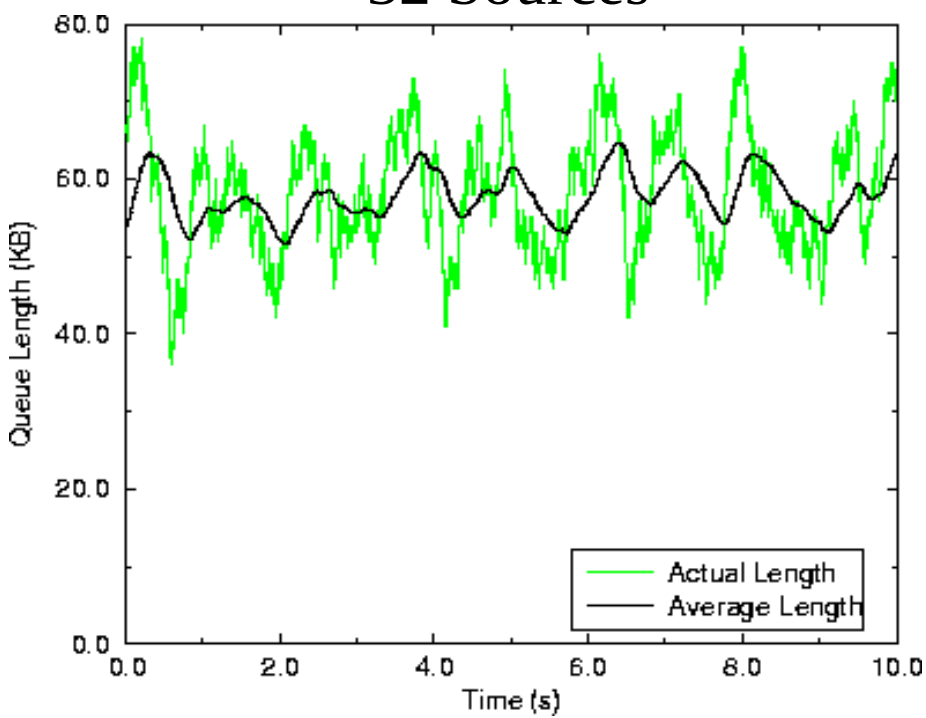
What Doesn't RED Achieve?

- No flow protection
  - Remember the UDP-TCP problem
- RED introduces its own problems
  - Hard to set parameters

8 Sources



32 Sources



ECN: Explicit Congestion Notification

- Mark packet instead of dropping it. Receiver has to relay this mark to the sender
  - Explicit feedback
- Advantages
  - In wireless environments drops are mainly caused by errors rather than congestion (ECN may help if widely deployed)
  - No wasting of resources on packets that will be dropped
- Cons
  - Deployment
  - No significant improvement in wired environments

2. Fair Queuing

Fair Queuing

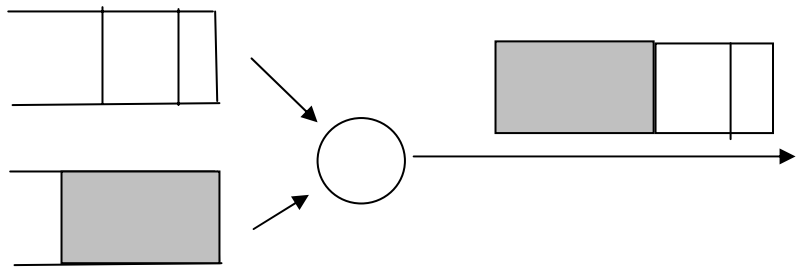
- Objective
  - Focuses on fairness
  - Protect a source from other sources that send a huge amount of traffic (fairness)

How does it work?

- Each Source has a separate queue
- To be really fair, you would like to do round robin between the queues and at each time send one bit from each queue
  - However we can't divide traffic to bits, we have to work with packets, and packets are not the same size
- For each packet compute the finishing time if the system sent bit by bit round robin
  - Imagine a clock that ticks each time a bit from all active flows is sent (i.e., each round);
  - $F_i = Max (F_{i-1}, A_i) + P_i$
    - F_i is finishing time; P_i is length; A_i is the arriving time
- Send packets according to their finishing time

How does it work?

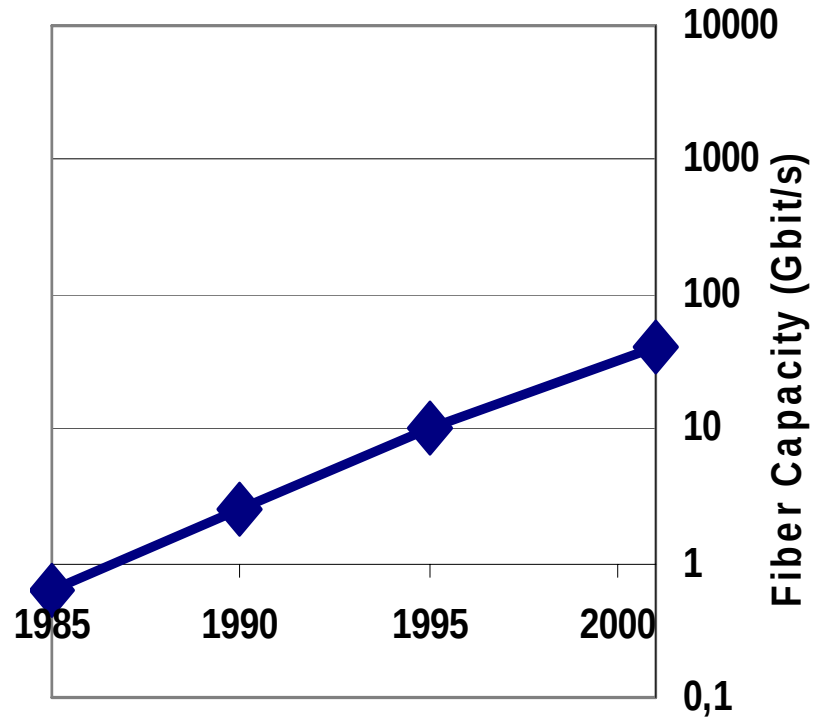
- Shorter packets are sent first
- Longer packets are not pre-empted
  - E.g, if the grey packet has started transmission before the two white packets arrive, then it finishes before them
- FQ is fair but not very scalable
  - Per flow state, and per-flow queuing



3. XCP: eXplicit Control Protocol

Problem

- Link bandwidth is increasing exponentially
- But, TCP can't maintain a very large throughput and can't benefit from the large increase in the per-flow bandwidth



For example,

- A TCP connection with a packet size 1500 byts and a steady-state throughput of 10Gb/s and RTT=100ms requires:
  - An average cwnd of 80,000 packets
  - 1 drop every 5,000,000,000 packets or more; I.e., one drop every 1 and 2/3 hours.

This is unrealistic!

Problem is caused by TCP's Lack of Fast Response

- TCP increases by 1 packet/RTT; takes forever in high-bandwidth environments
- Slow-start doesn't help much:
  - When a TCP starts, it increases exponentially

  ⇒ Too many drops

  ⇒ Flows halve cwnd

  ⇒ Flows ramp up by 1 packet/RTT, taking forever to grab the large spare bandwidth

What prevents TCP from increasing quickly?

- TCP Congestion feedback is binary (i.e., drop or no-drop) and indifferent to the degree of congestion
  - Source doesn't know whether spare bandwidth is 1 packet or 1000,000 packets. Increasing too quickly might cause congestion collapse.
  - Also, binary feedback causes oscillations

Solution

- Make increase proportional to spare bandwidth and decrease proportional to congestion

  $\Rightarrow$ Need more explicit congestion feedback from routers

XCP:

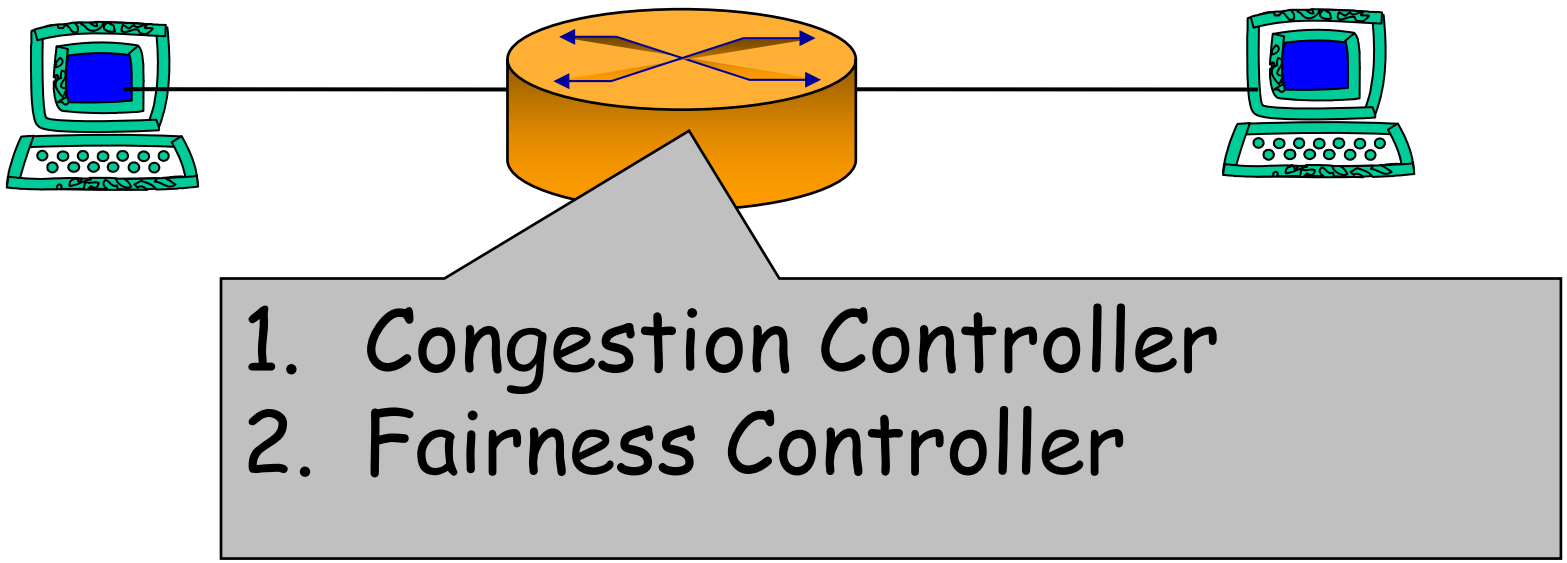
Decouple Congestion Control from Fairness

Coupled in TCP because a *single* mechanism, AIMD, controls both

How does decoupling solve the problem?

1. To control congestion: use MIMD which shows fast response
2. To control fairness: use AIMD which converges to fairness

XCP: An eXplicit Control Protocol



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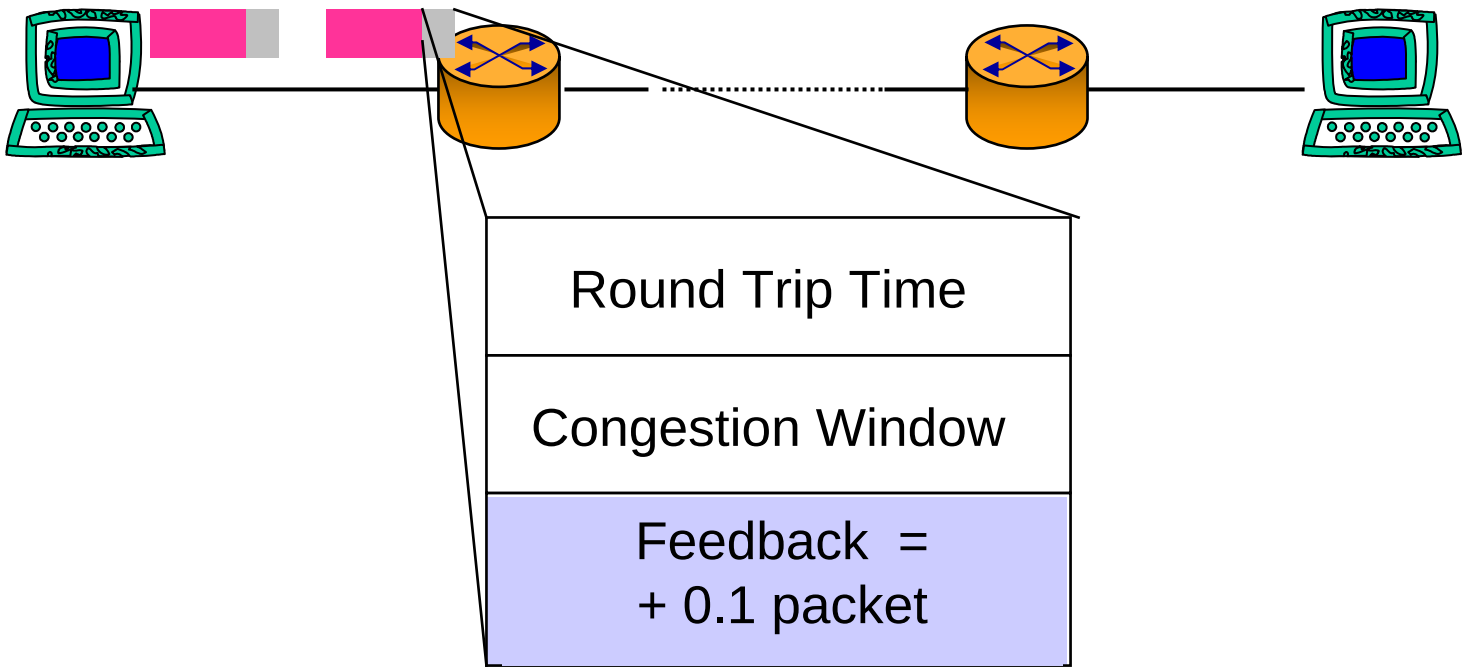

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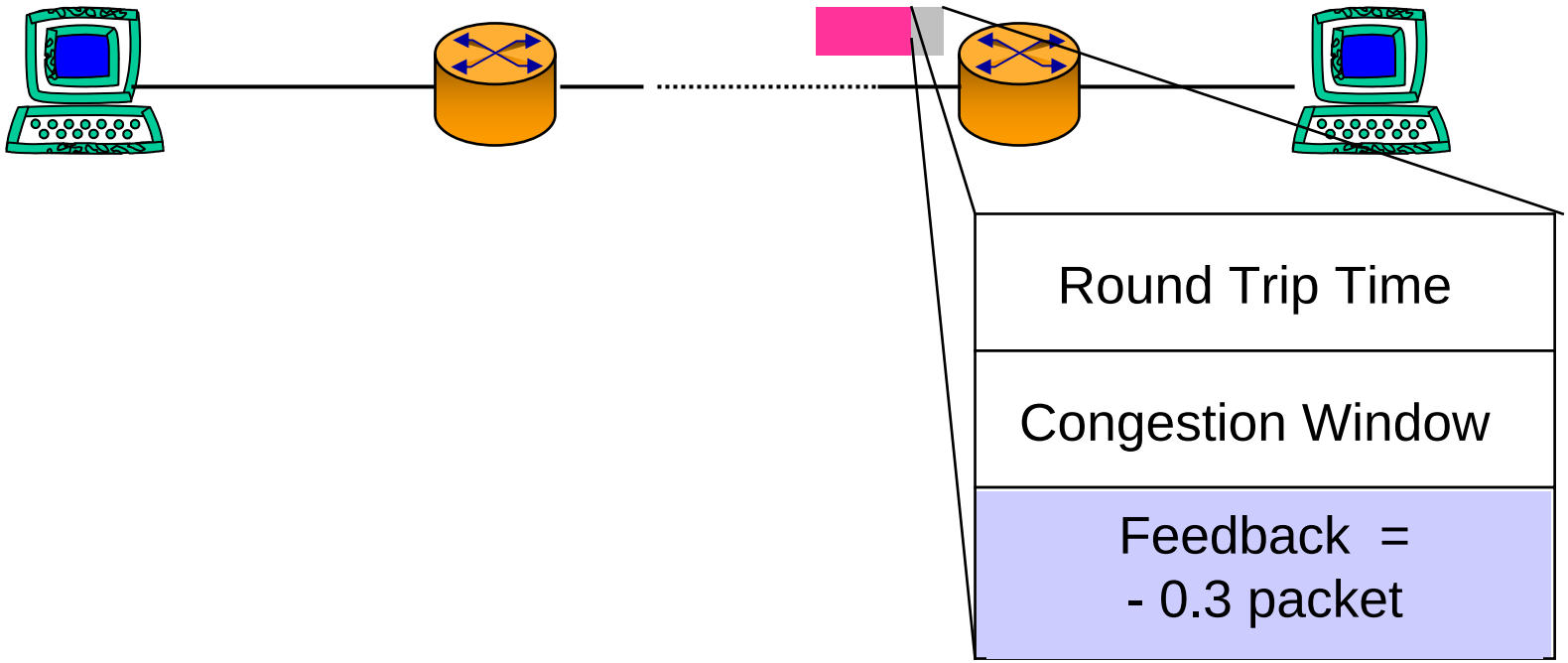

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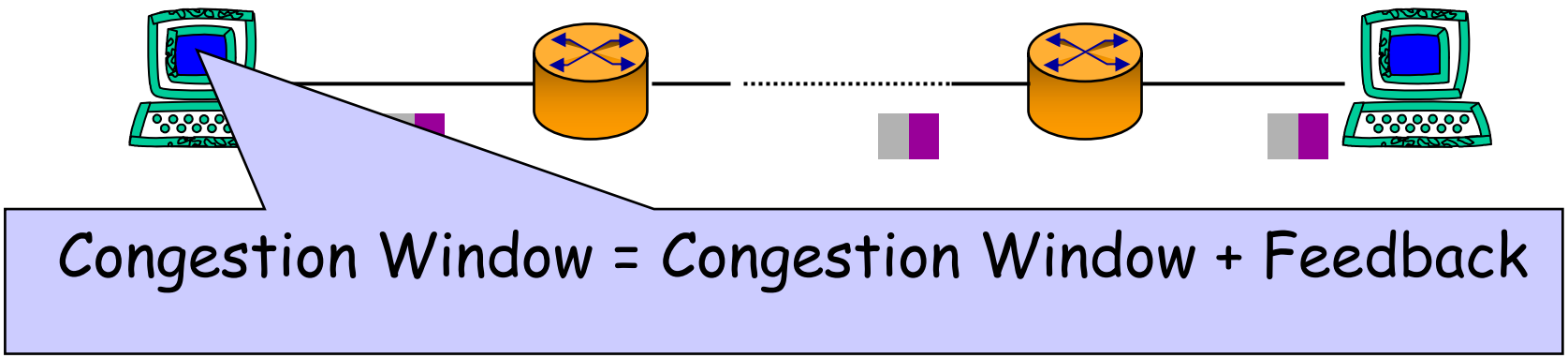


Note, every router can overwrite the feedback to decrease it but can never increase it

XCP extends ECN

How Does an XCP Router Compute the Feedback?

Congestion Controller

Goal: Matches input traffic to link capacity & drains the queue

Looks at aggregate traffic & queue

MIMD

Algorithm:

Aggregate traffic changes by Δ

$\Delta \sim$ Spare Bandwidth

$\Delta \sim -$ Queue Size

So, $\Delta = \alpha\, d_{avg}\, Spare - \beta\, Queue$

Fairness Controller

Goal: Divides Δ between flows to converge to fairness

Looks at a flow's state in Congestion Header

AIMD

Algorithm:

If $\Delta > 0 \Rightarrow$ Divide Δ so that flows increase their throughput equally

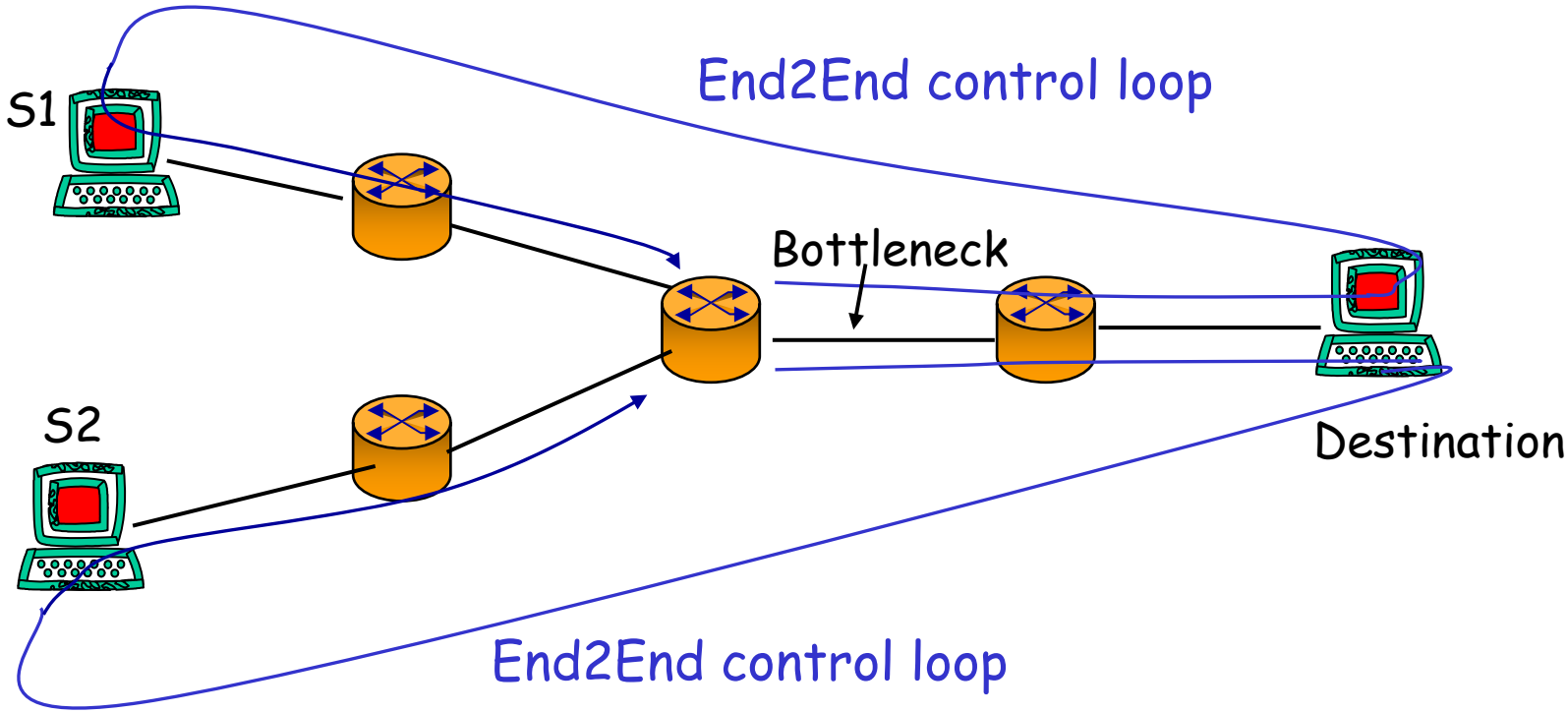
If $\Delta < 0 \Rightarrow$ Divide Δ between flows proportionally to their current rates

Reflections on XCP

- Pros
  - More efficient than TCP
    - Why?
  - Fairer than TCP
    - Why?
  - Can deal with large per-flow bandwidth well
    - Why?
- Cons
  - More work at routers
  - Deployment requires changing senders and routers
  - No flow protection (also true about TCP)

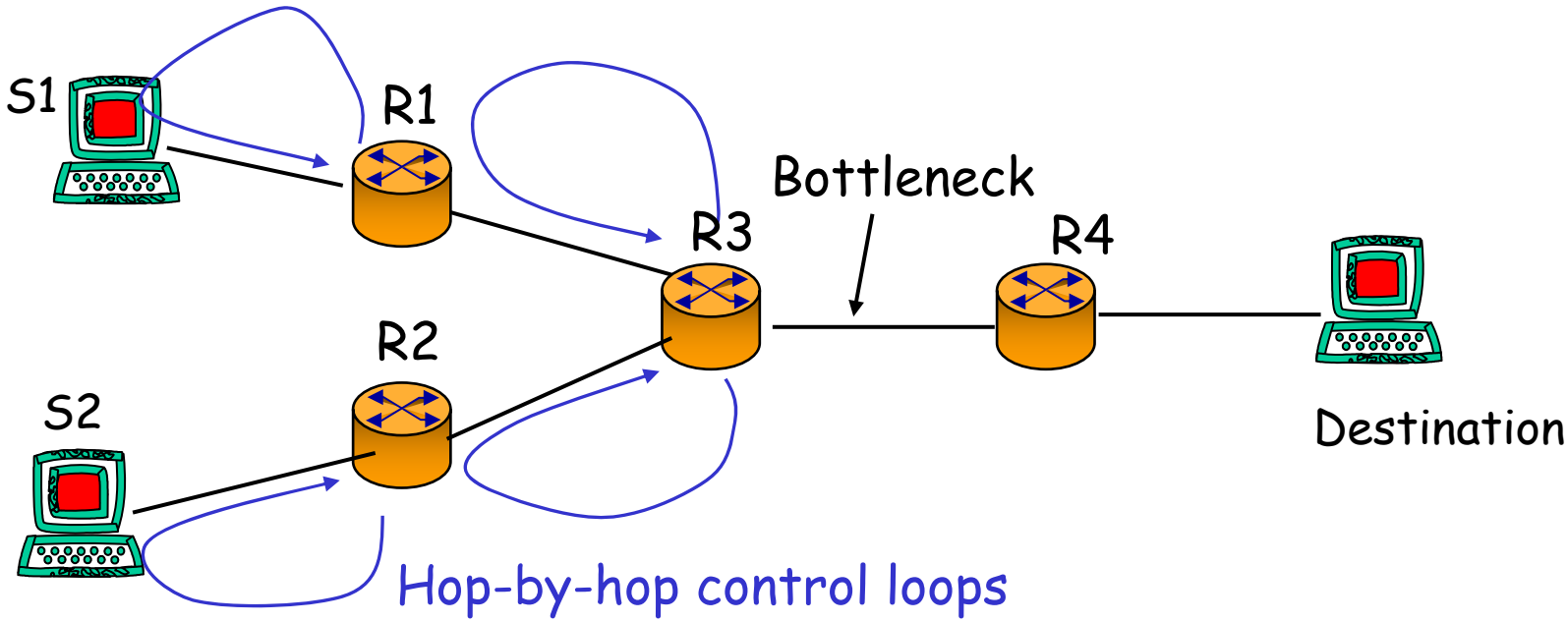
4. Hop-by-Hop Congestion Control

End2End vs. Hop-by-Hop



DropTail, RED and XCP use end2end cong. cont.

End2End vs. Hop-by-Hop



To make this a cong. cont. protocol, we need to specify how R1 and R2 slow down so that :

1) Bottleneck is not congested

2) fair to flows sharing R1 and R2

Evaluation of Hop-by-hop

- Pros
  - Does not involve links downstream a bottleneck
  - Works with short flows (i.e., messages)
  - Faster
  - Does it protect flows from misbehavior?
- Cons
  - Queue buildup at each hop → large delay
  - Deployment