CS 352
Network Service Guarantees

CS 352, Lecture 20.1

http://www.cs.rutgers.edu/~sn624/352

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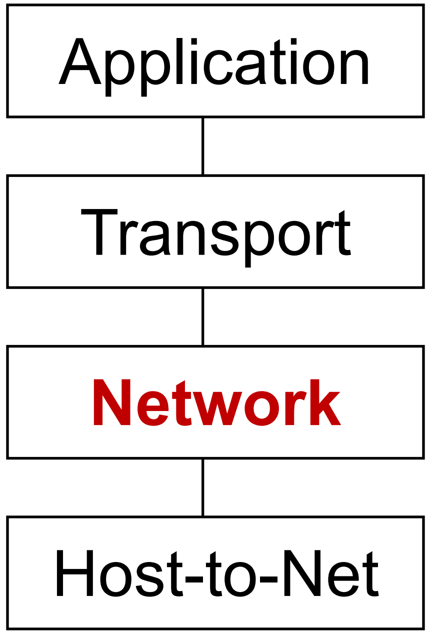
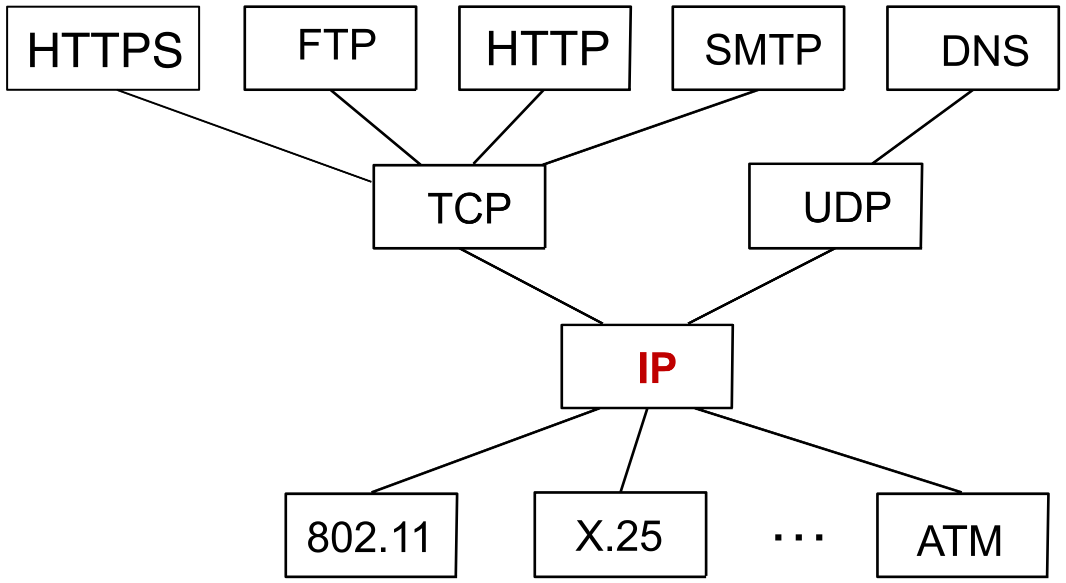
Network



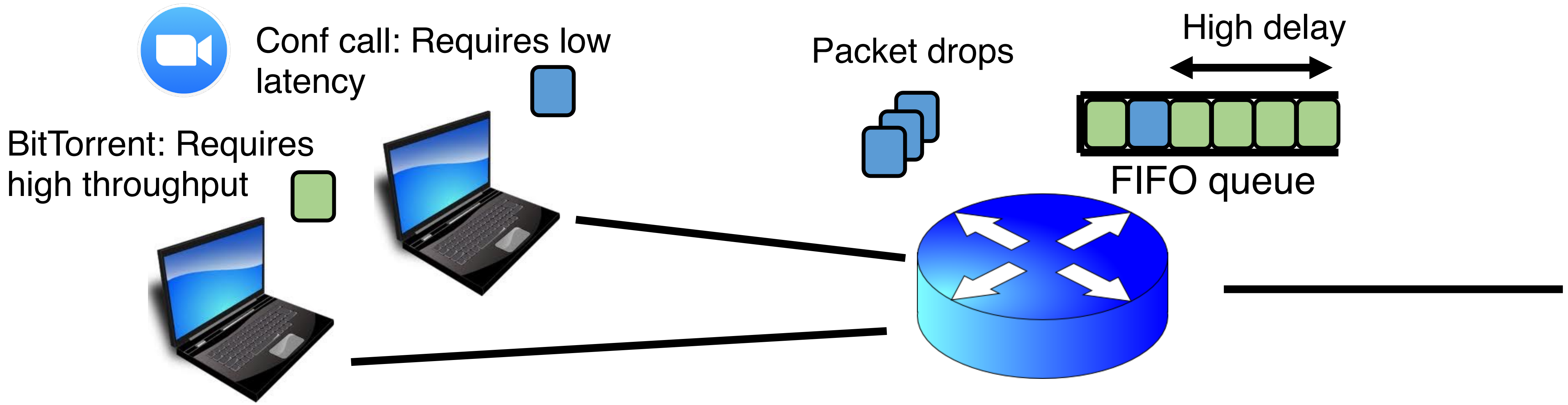


The network layer moves packets from one place to another.
The network will put in its best effort but makes no guarantees.

Network support for applications

- A best effort Internet architecture does not offer any guarantees on delay, bandwidth, and loss
    - Network may drop, reorder, corrupt packets
    - Network may treat traffic randomly regardless of their "importance"
- However, many apps require special treatment & guarantees
    - E.g., voice over IP (phone calls) require strict delay guarantees
    - E.g., HD video requires a reasonable minimum bandwidth
    - E.g., remote surgery with 3D-vision requires strict sync & latency
- Q: How to provide quality of service (QoS) for apps?

Why best effort isn't enough: Contention



Conf call: Requires low latency
BitTorrent: Requires high throughput
Packet drops
High delay
FIFO queue

- Resource contention occurs in the core of the network
- Congestion control will react, but may be too little & too late:
  - Congestion control can't prevent packet drops "now"
  - Congestion control won't prevent high-sending-rate flows from inflicting large delays or recurring drops

Can networks help improve the quality of service for applications?

Yes, but networks must become better than best-effort.

Approach 1: Provision more capacity

- If you're an ISP (e.g., AT&T), you might deploy enough capacity so that contention doesn't occur any more
  - Low complexity: can use current "best effort" network

- However, this approach incurs high costs (e.g., bandwidth)

- A key challenge: estimating how much bandwidth is enough
  - Need to estimate demand over time
  - Network operators can do this quite well usually
  - But there are exceptional circumstances: pandemics, Superbowl, etc.

Approach 2: Classes of service

- Have the network treat different traffic differently
  - Also called traffic differentiation

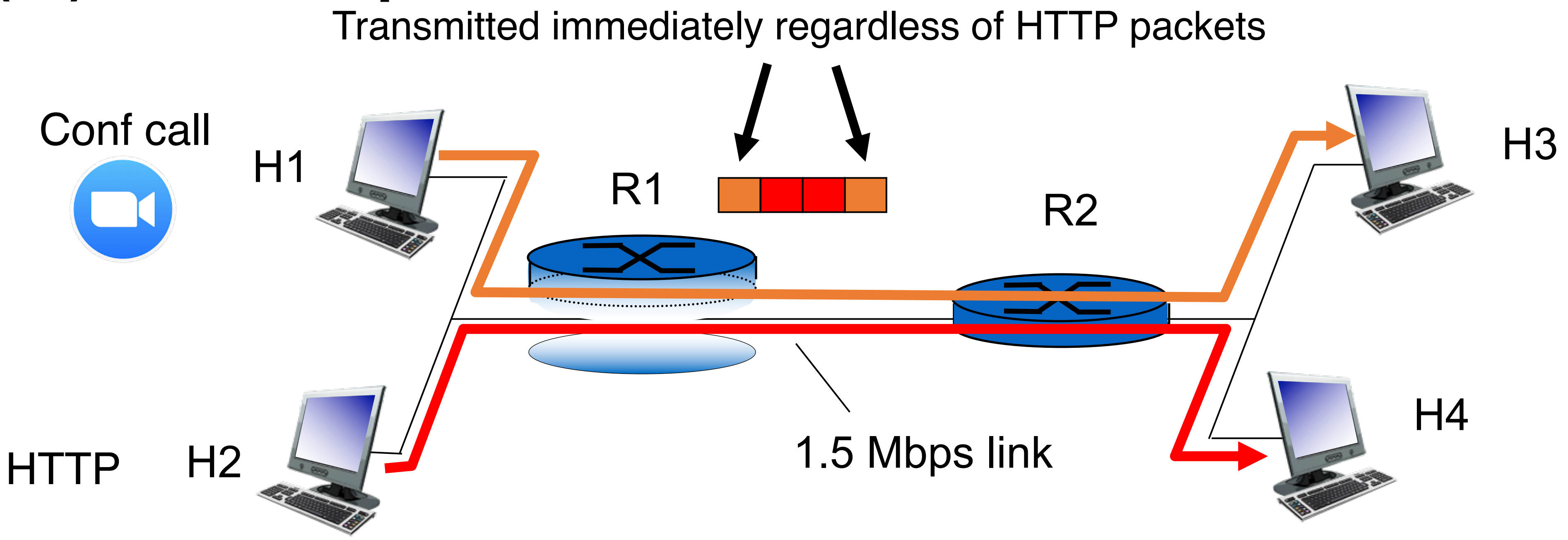
- Analogy: lines at an airport (e.g., first class vs. economy)

- Partition traffic into classes and offer service guarantees per class and across classes
  - Classes may be indicated using the IP type of service header bits
  - Classes may be inferred from IP & transport headers (e.g., src/dst/ports)

- Packet classification: assigning packets to classes
  - (Not in scope: we won't discuss packet classification)

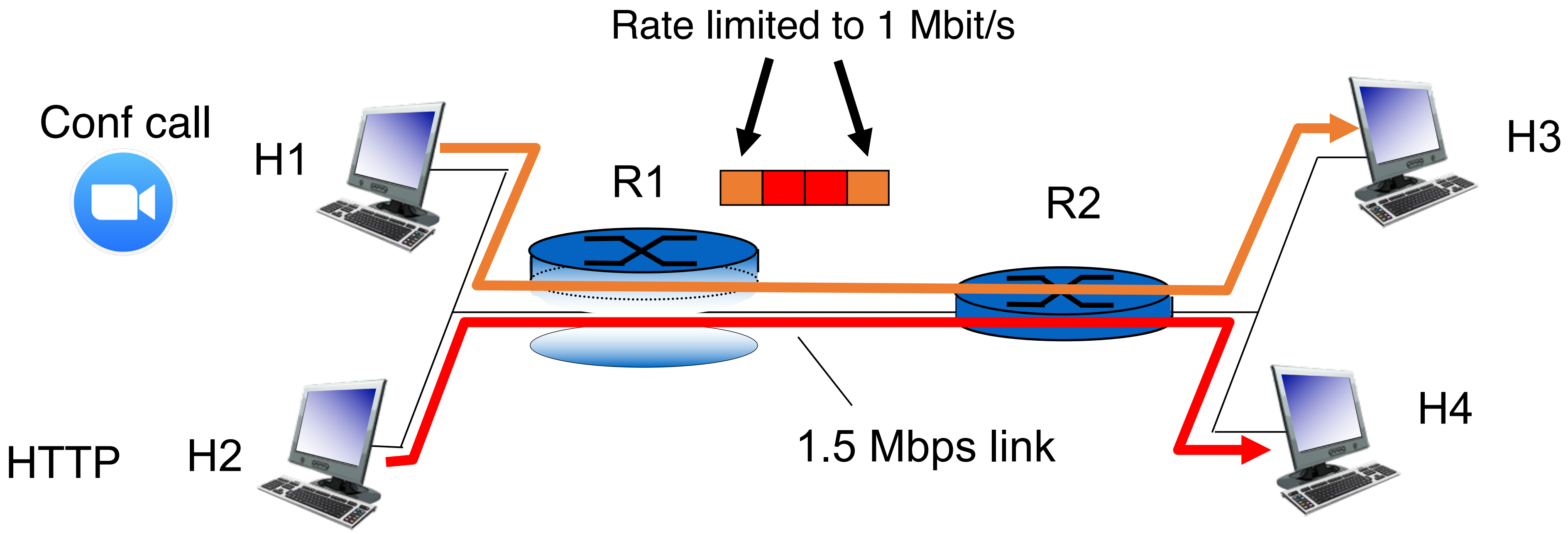
Kinds of Service Guarantees

(1) Strict prioritization



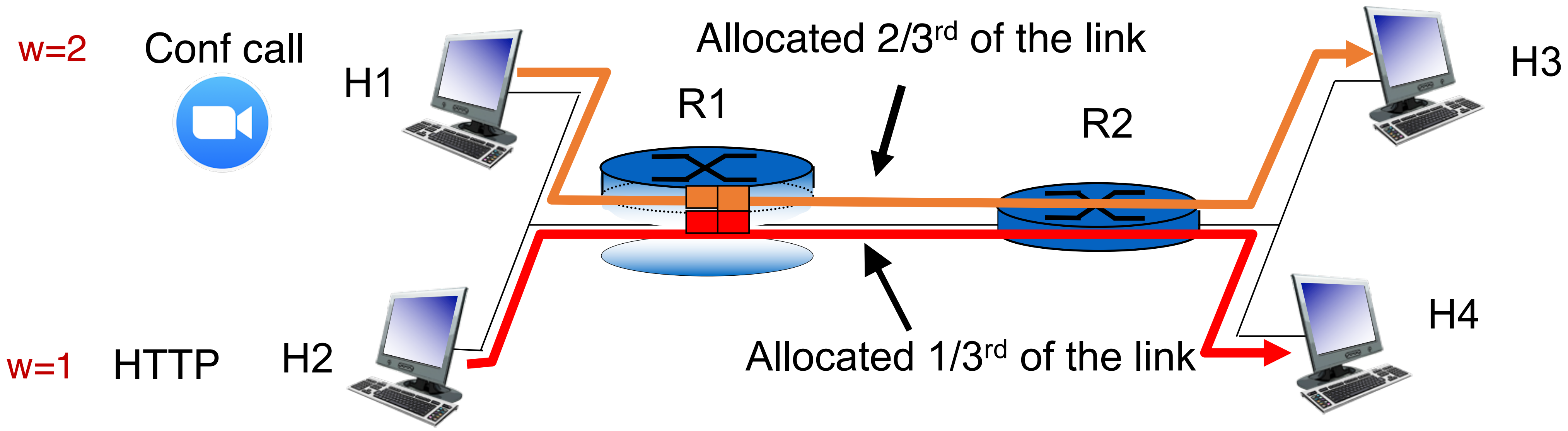
- Suppose a 1Mbps interactive flow and an HTTP connection share a 1.5 Mbps link.
- A network operator (e.g., Rutgers admin) might choose to prioritize the interactive app strictly over the HTTP flow.

(2) Rate limiting



- What if a flow doesn't respect its allocation?
  - Example: Say, conf call flow goes beyond 1 Mbit/s
  - Don't want to starve HTTP flow!
- An operator might want to limit a flow to a certain max rate
- Isolation: HTTP should not be impacted by the conf call

(3) Weighted fair sharing

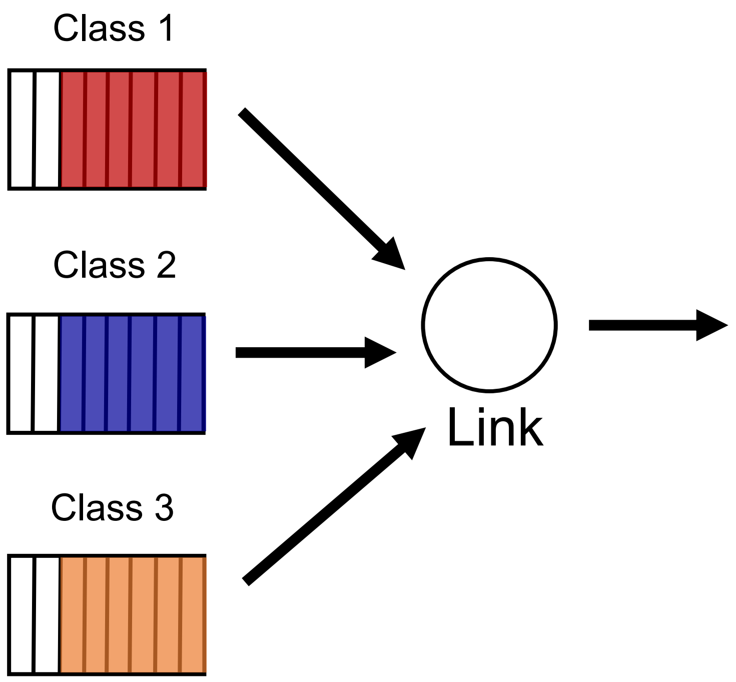


- An operator might want to partition the link’s rate C into separate allocations for each class
  - Partitions may have weights w (example: 2, 1)
- Usually, class i gets the illusion of traversing a logical link of rate

$$w_i * C / \sum_j w_j$$

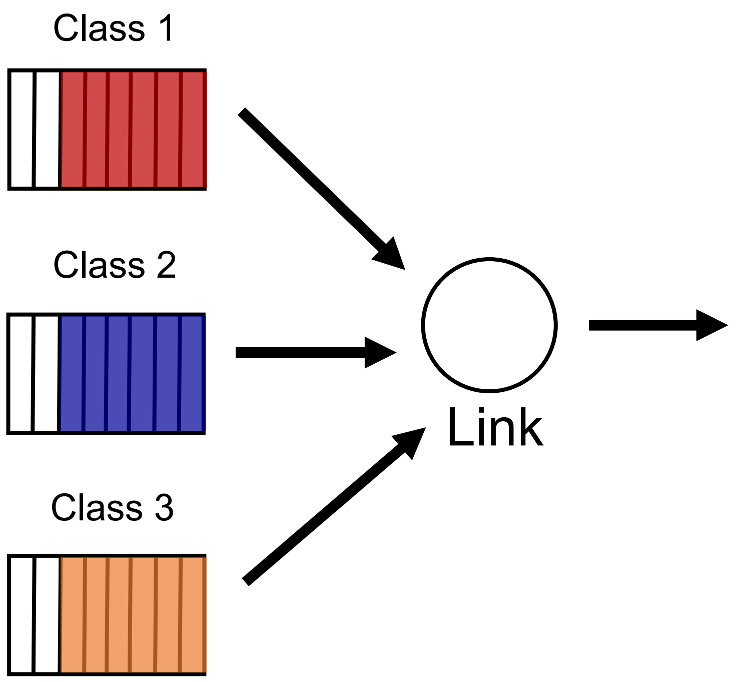
(3) Weighted fair sharing

- Customary to think of different classes as belonging to different queues
- For this reason, weighted fair sharing is also called weighted fair queueing (WFQ)
- Each queue is first-in-first-out (FIFO)
- The link multiplexes among these queues
- Intuitively, packets of one queue should not influence the behavior of other queues
- Hence, fair queueing is also a form of isolation across traffic classes



(3) Weighted fair sharing

- But what if one class doesn't use its share?
  - Can other classes use the spare capacity?
- Yes! WFQ is work-conserving: a router implementing WFQ will allow other classes to use the unused capacity
- Work conservation makes WFQ different from rate limits applied separately to each class
  - Class i's usage can exceed $w_i * C / \sum_j w_j$
  - (only if spare capacity is available, of course.)



Q: Where are guarantees enforced?

- We’ve seen three kinds of service guarantees: prioritization, rate limiting, and fair sharing
- Common goal: allocate the bottleneck link capacity across packets from traffic classes
- This allocation occurs in the packet scheduler in the bottleneck router
    - Recall: scheduling is the task of choosing the packet (among buffered packets) which is transmitted over the output link
- A router is said to implement packet scheduling policies

Why care about service guarantees?

- Influences how packets are treated at contentious resources in the core of the network
  - Regardless of the endpoint transport

Next lecture: a deeper look at mechanisms for one kind of service guarantee

- Service guarantees: prioritization, rate limiting, fair sharing

- Implementations of scheduling (QoS) within large networks have implications for debates on network neutrality

- Scheduling is a fundamental problem in computer networks

CS 352
Rate Limiting

CS 352, Lecture 20.2

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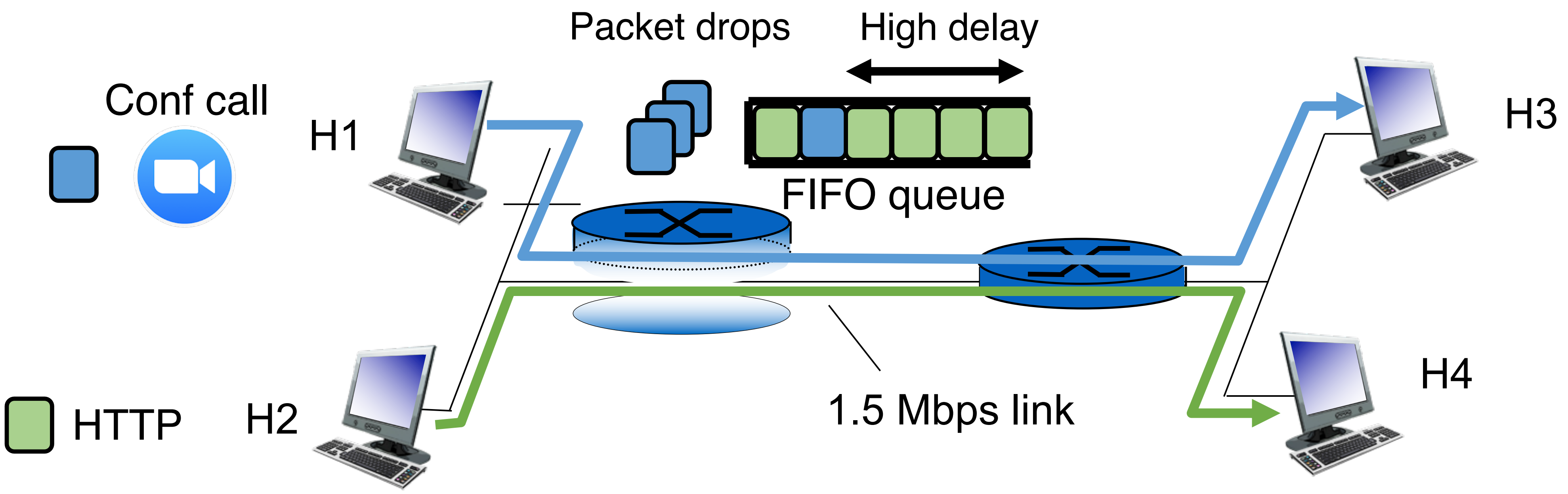
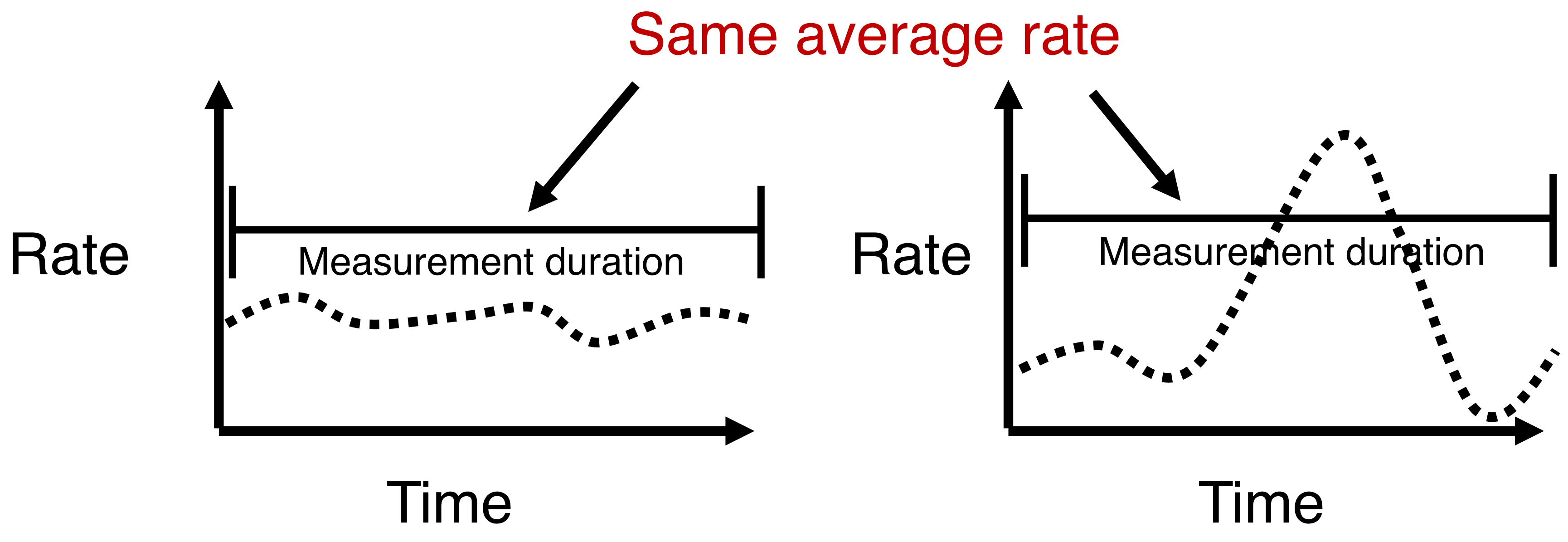
Review



- Best-effort network isn't enough
  - Applications might require more guarantees
- 3 mechanisms: prioritization, rate limiting, and fair sharing
- This module: implementation of rate limiting

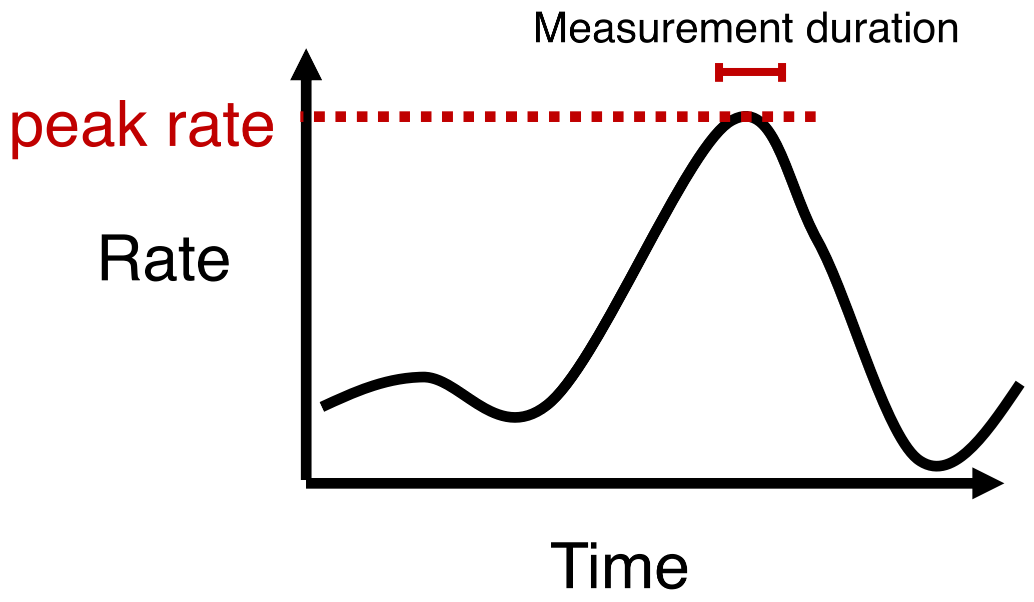
Measures of transmission rate

- Long-term/average rate: data rate transmitted per unit time, over a long period
  - Crucial question: what is the time interval over which rate is measured?
- Average and instantaneous behaviors can be very different



Measures of transmission rate

- Peak rate: largest instantaneous rate that is transmitted
  - Measurement duration is typically very small
- Burst size: maximum amount of data sent consecutively without any intervening idle periods



Rate enforcement

- There are two kinds of rate enforcement policies:
  - shaping and policing

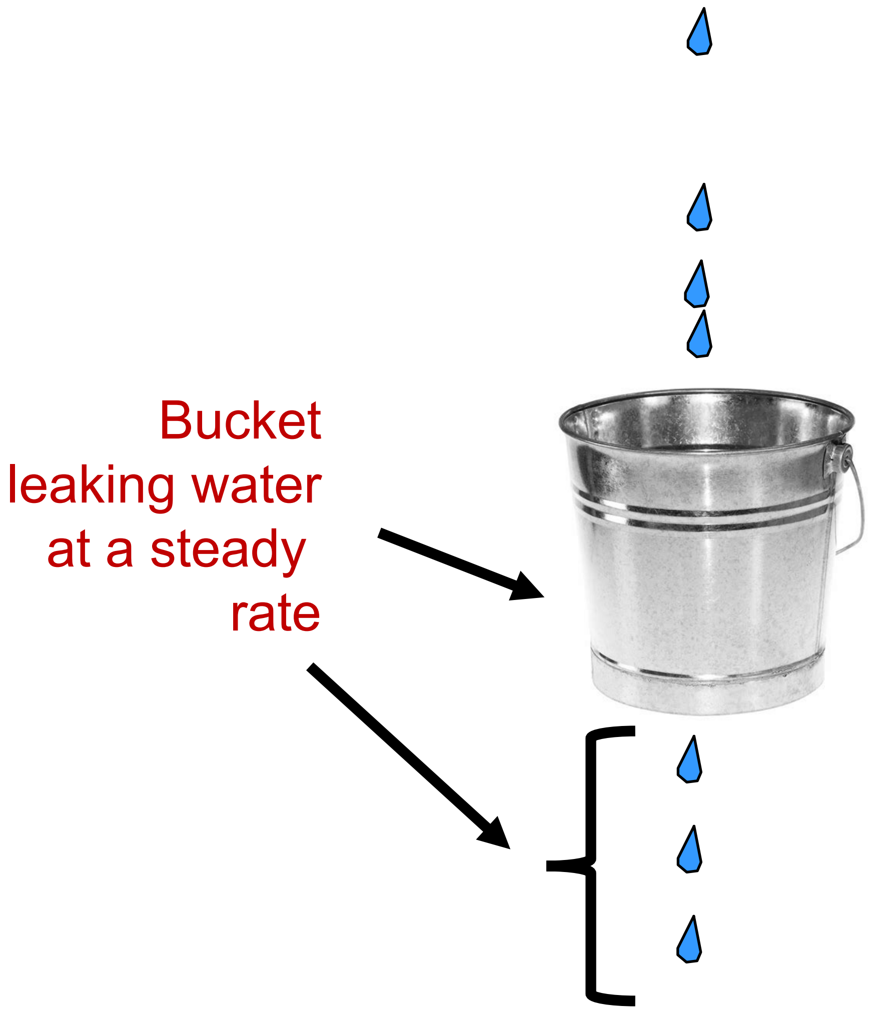
- Two specific mechanisms to implement those:
  - leaky buckets and token buckets

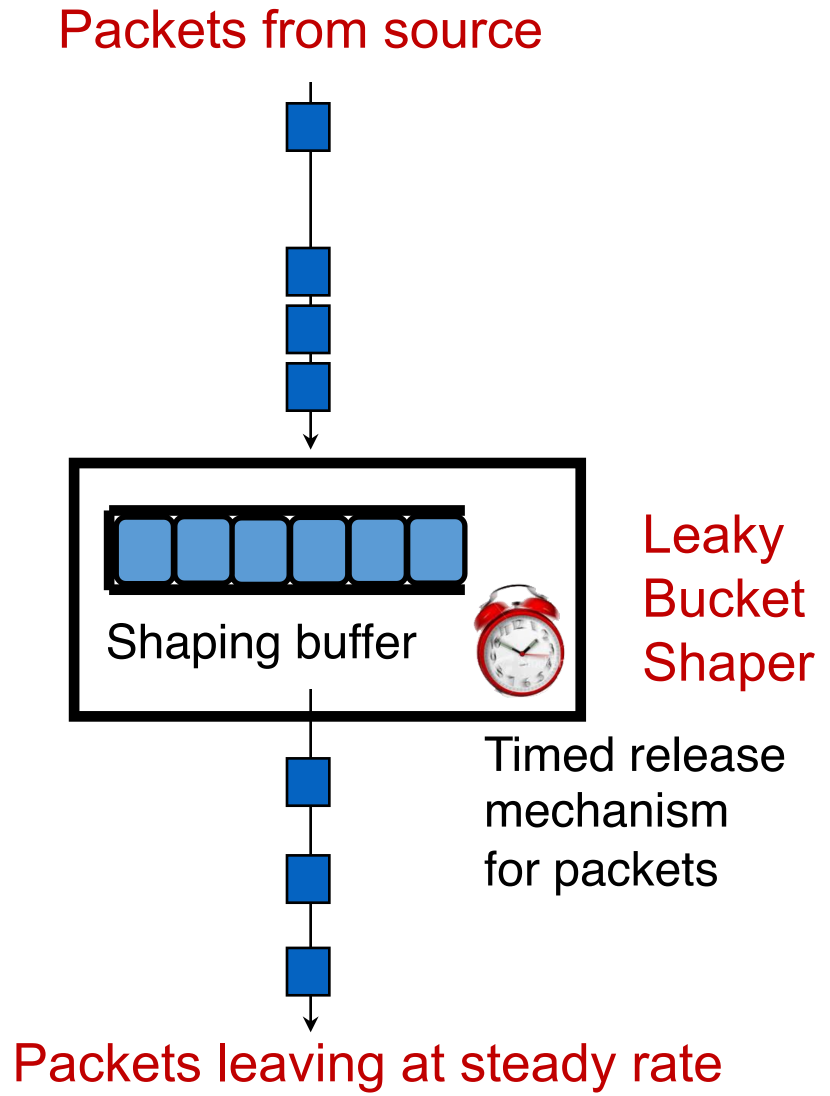
Shaping vs. Policing

Shaping	Policing
Enforces rate by queueing excess packets in a buffer • Drop only if buffer is full	Enforces rate by dropping excess packets immediately • Can result in high loss rates
Requires memory to buffer packets	Does not require a memory buffer
Can inflate round-trip time (queueing in shaping buffer)	No additional inflation in round-trip times

Leaky bucket shaper

Intuition: release packets at steady rate





Leaky Bucket Shaper

- Packets may enter in a bursty manner
- However, once they pass through the leaky bucket, they are evenly spaced
- The shaping buffer holds packets up to a certain point
  - If the buffer is full, packets are dropped (true of any shaper)
- Setting the rate is a policy concern
  - Assume an admin provides us the rate
- Shapers may be used in the core of a network to limit bandwidth use, or at the edge to pace packets entering the network in the first place

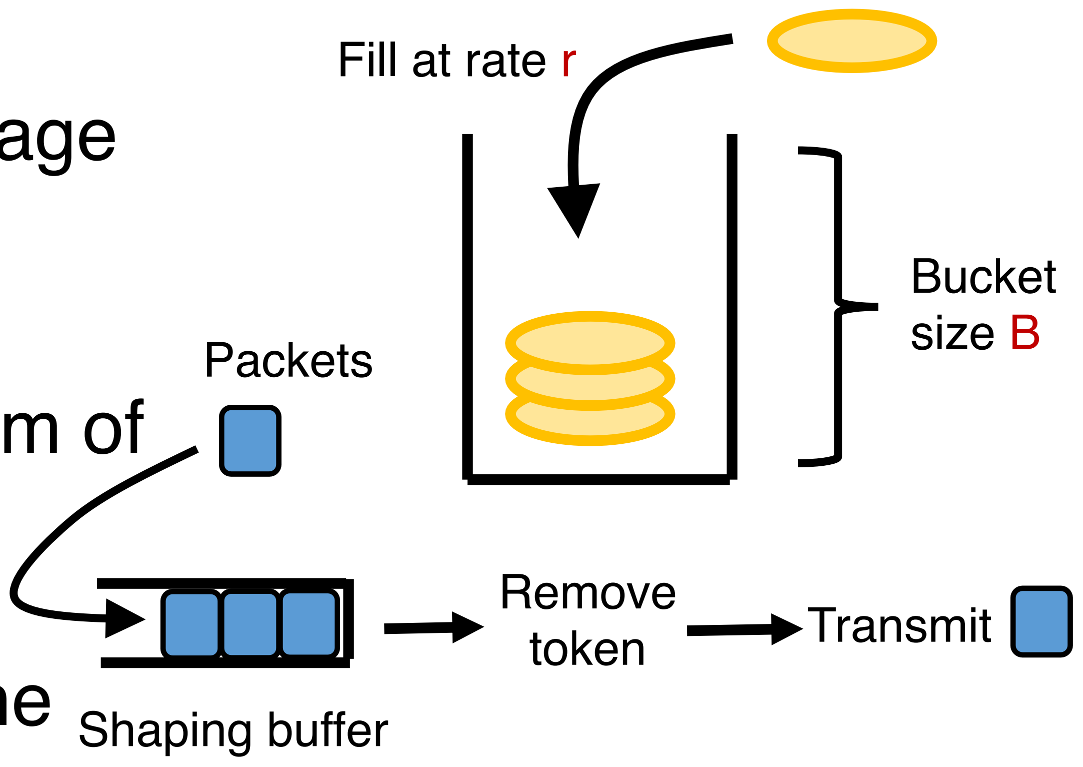
Leaky Bucket Shaper

- For a leaky bucket shaper, assume average rate == peak rate
- However, many Internet transfers just have a few packets
    - For example, web requests and responses
    - Enforcing rate limit for those can significantly delay completion
- We often wish to have peak rate higher than avg rate
    - If so, use a token bucket: burst-tolerant version of a leaky bucket

Token bucket shaper

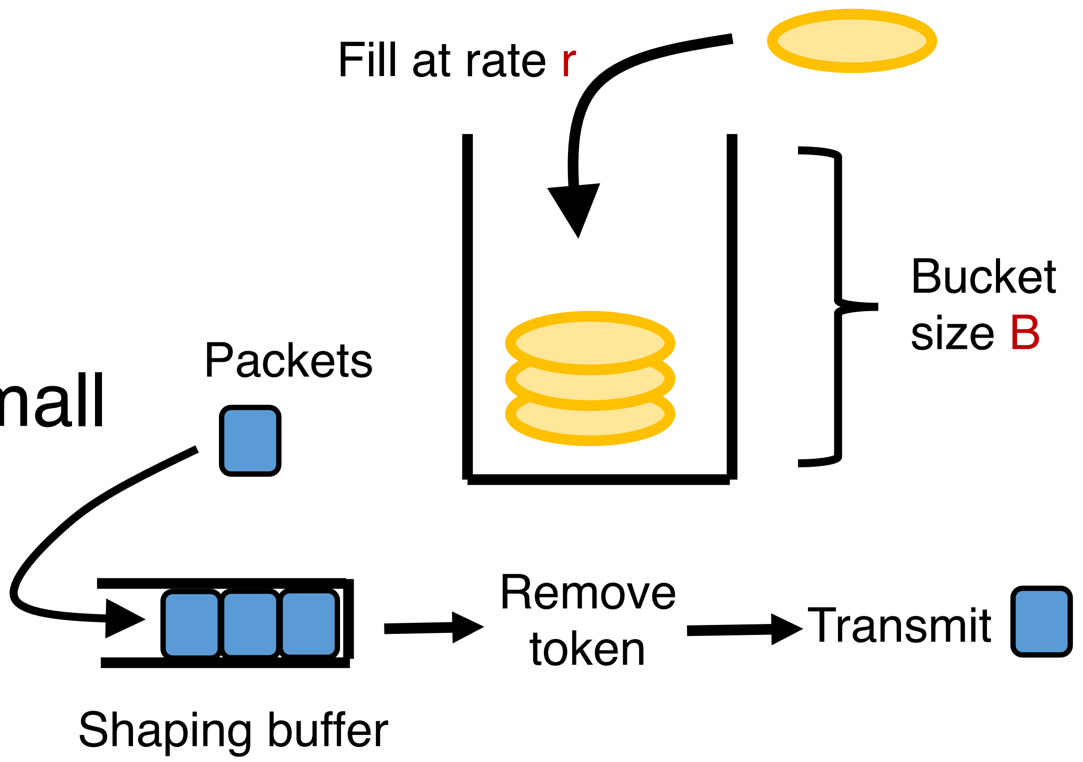
Token bucket shaper

- Limits traffic class to a specified average rate r and burst size B
- Tokens are filled in at rate r
- The token bucket can hold a maximum of B tokens. Further tokens dropped
    - Note: distinct from shaping buffer size
- Suppose a packet is at the head of the shaping buffer
- If a token exists in the bucket, remove token, and transmit the packet
    - If not, wait.



Token bucket shaper

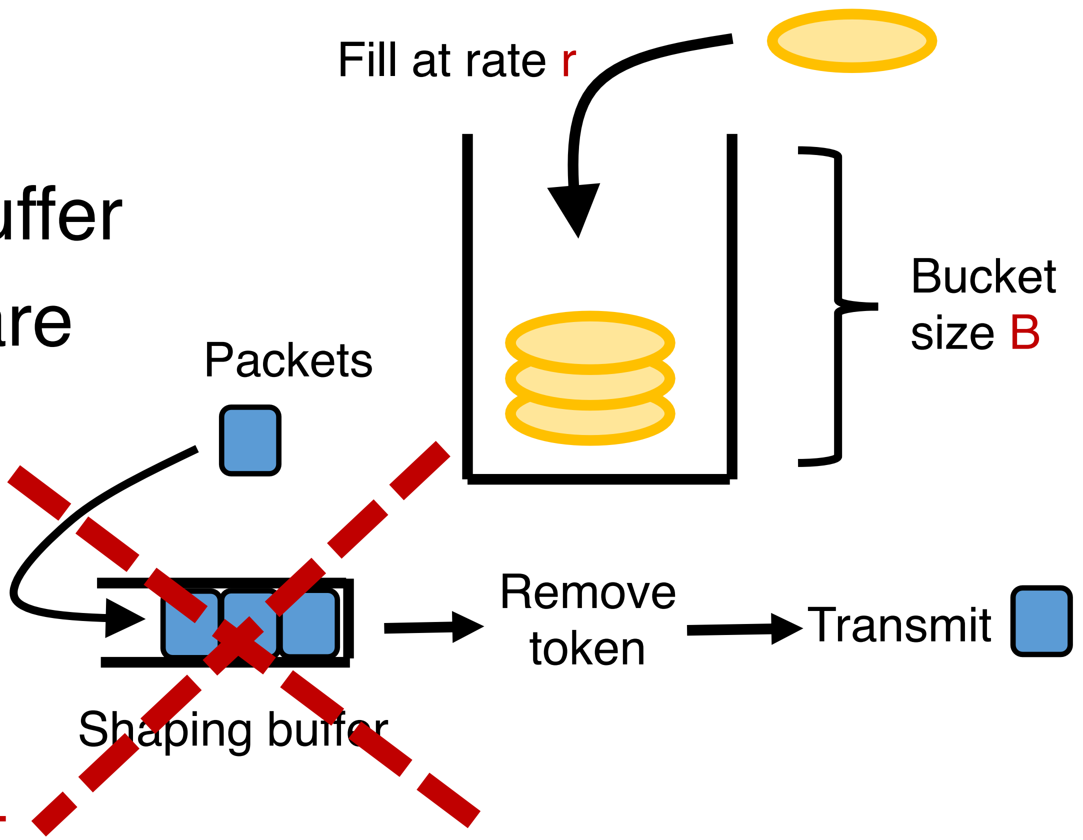
- In time t, the maximum number of packets that depart the shaper is (r * t) + B
- A full bucket of tokens would allow small flows to go through unaffected
  - A maximum burst of B packets
- Longer flows have average rate r
  - Bucket emptied initially, the rest of the flow must respect the token fill rate
  - As t → ∞, the average rate approaches r
  - That is, (1/t) * (r*t + B) → r



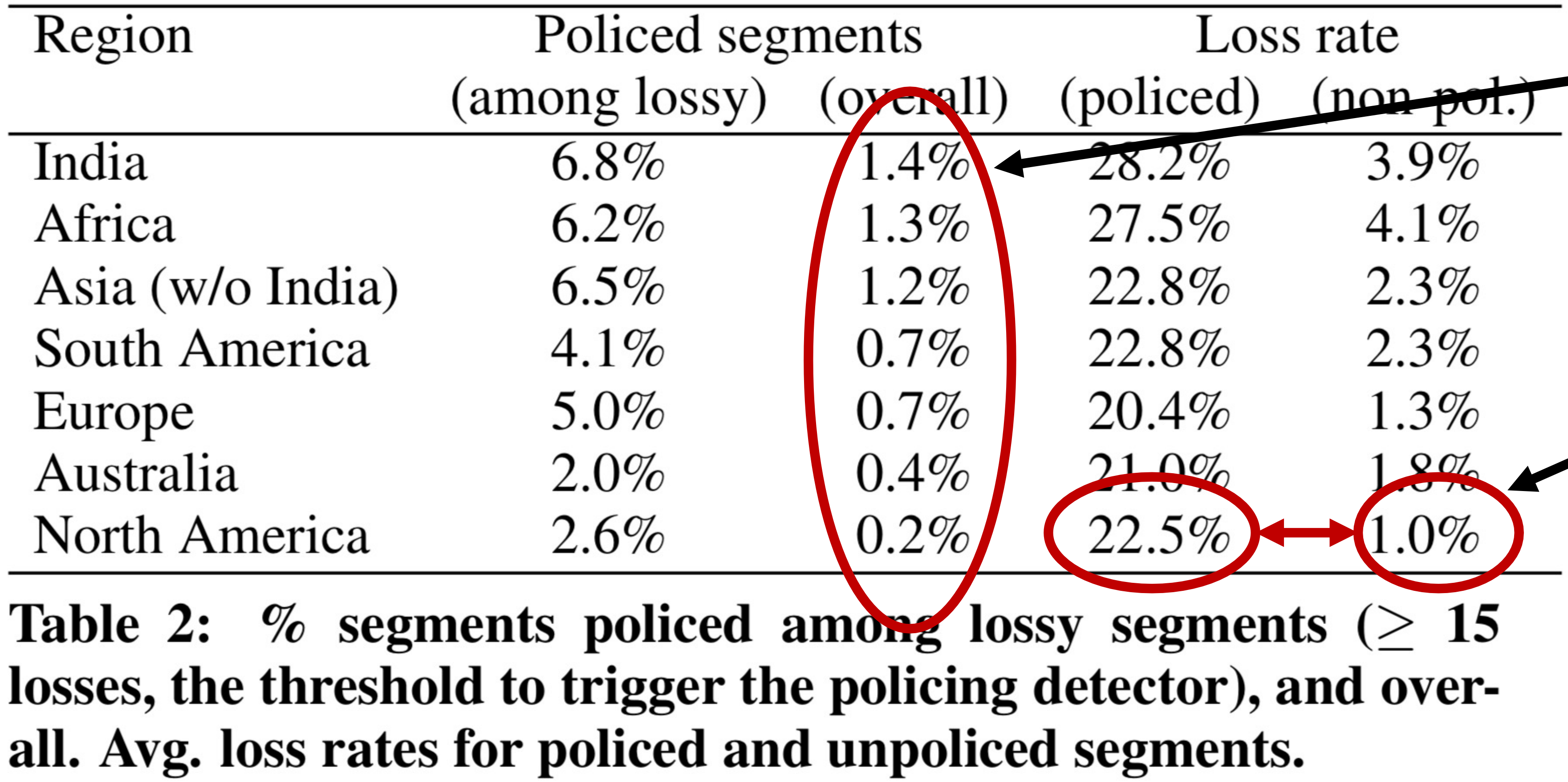
Token bucket policers

Token bucket policer

- A token bucket policer is just a token bucket shaper without the shaping buffer
- No place for packets to wait if there are no tokens
- If token exists, packet transmitted.
- If not, packet dropped
- Simple and efficient to implement.
- The internet has tons of token bucket policers



Google study from 2016



Region	Policed segments (among lossy)	Policed segments (overall)	Loss rate (policed)	Loss rate (non-pol.)
India	6.8%	1.4%	28.2%	3.9%
Africa	6.2%	1.3%	27.5%	4.1%
Asia (w/o India)	6.5%	1.2%	22.8%	2.3%
South America	4.1%	0.7%	22.8%	2.3%
Europe	5.0%	0.7%	20.4%	1.3%
Australia	2.0%	0.4%	21.0%	1.8%
North America	2.6%	0.2%	22.5%	1.0%

Table 2: % segments policed among lossy segments ($\geq$ 15 losses, the threshold to trigger the policing detector), and overall. Avg. loss rates for policed and unpoliced segments.

Small but non-trivial fraction of policed links

Significant impact on packet loss rate

Flach et al., An Internet-Wide Analysis of Traffic Policing, SIGCOMM 2016

Impact on TCP

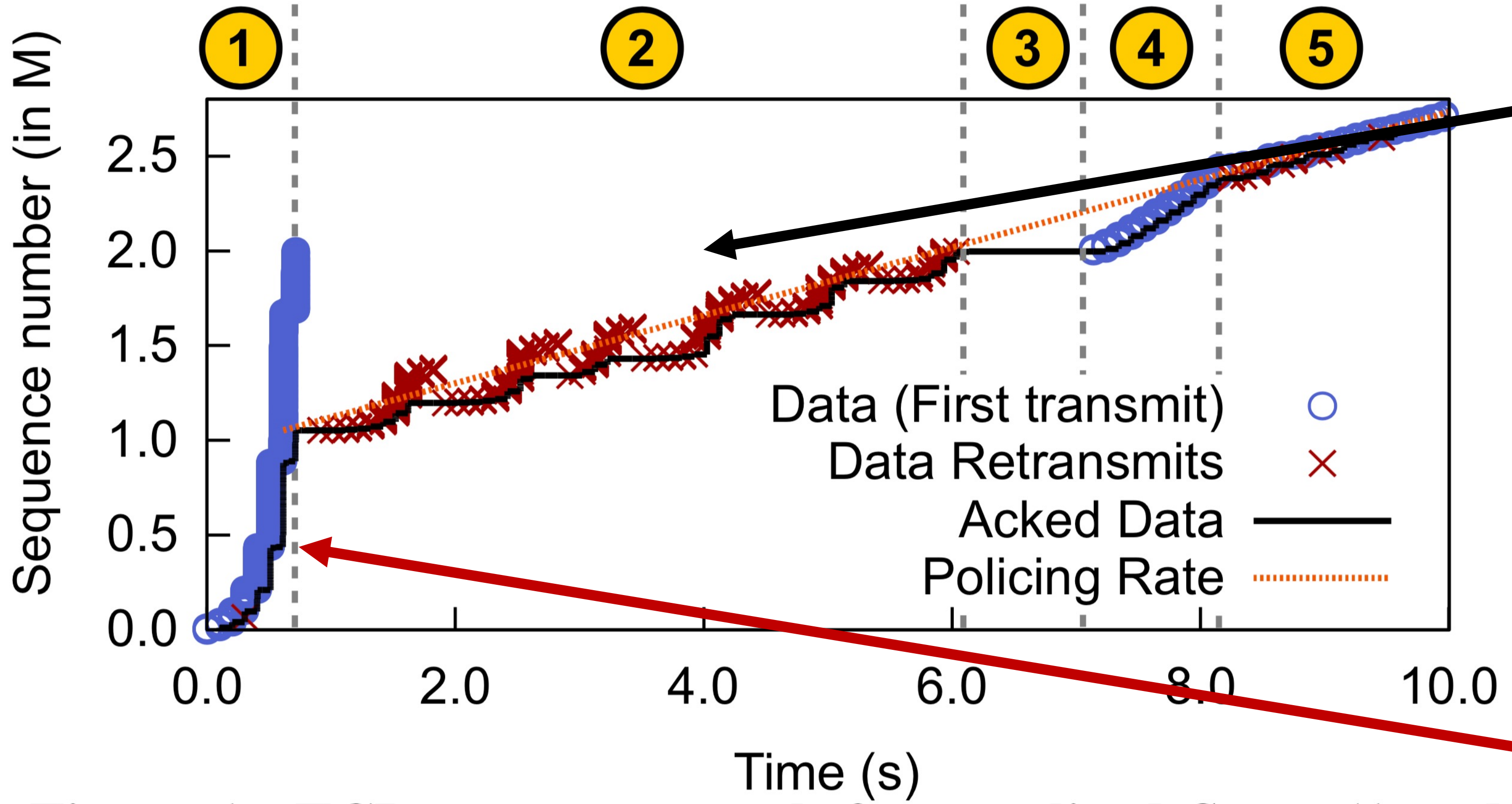


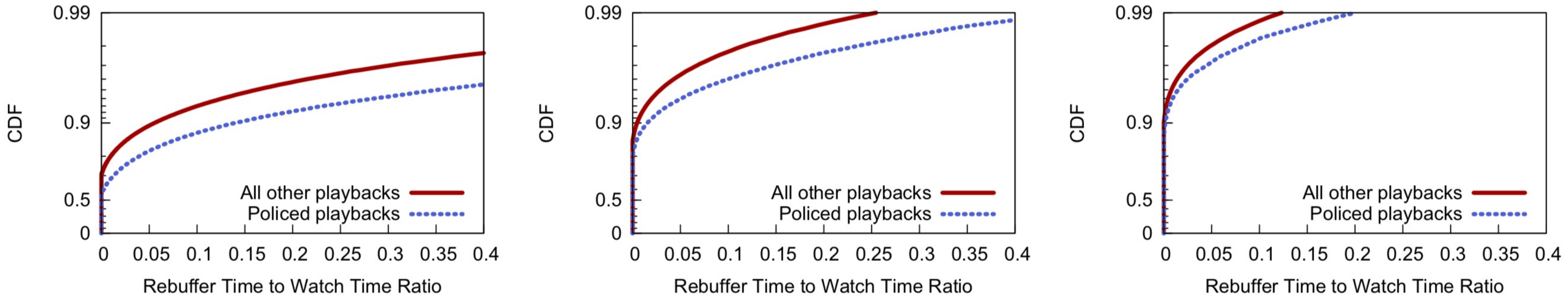
Figure 1: TCP sequence graph for a policed flow: (1 and 4) high throughput until token bucket empties, (2 and 5) multiple rounds of retransmissions to adjust to the policing rate, (3) idle period between chunks pushed by the application.

Policers drop multiple packets in a burst: causing RTOs and retransmissions after emptying of token bucket

Slow start period: burst allowed with a full bucket of tokens

Effect on actual apps: YouTube

- Video rebuffer rate: rebuffer time / overall watch time



(a) 300 kbps (b) 1.5 Mbps (c) 3 Mbps

Figure 9: Rebuffer to watch time ratios for video playbacks. Each had at least one chunk with a goodput of 300 kbps, 1.5 Mbps, or 3 Mbps ($\pm 15\%$).

Summary of rate limiting

- Rate limiting is a useful mechanism to isolate traffic classes from each other

- Two strategies: policing and shaping

- Leaky bucket and token bucket

- The Internet has a lot of token bucket policers, causing real impact on TCP connections and app performance