CS144
An Introduction to Computer Networks

Packet Switching

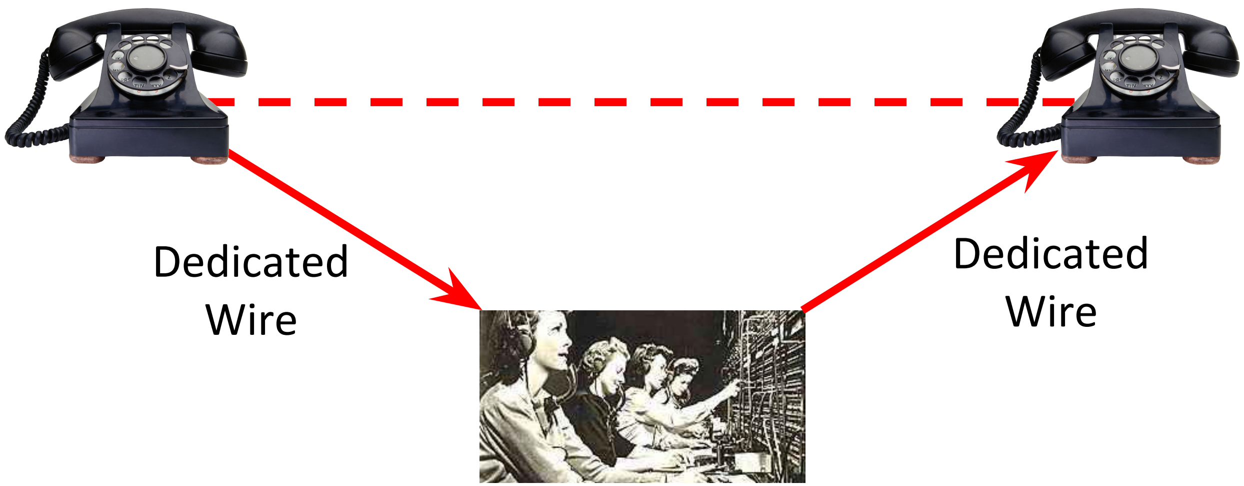
What is packet switching?

~~Nick McKeown~~ Stephen Ibanez
Professor of Electrical Engineering
and Computer Science, Stanford University

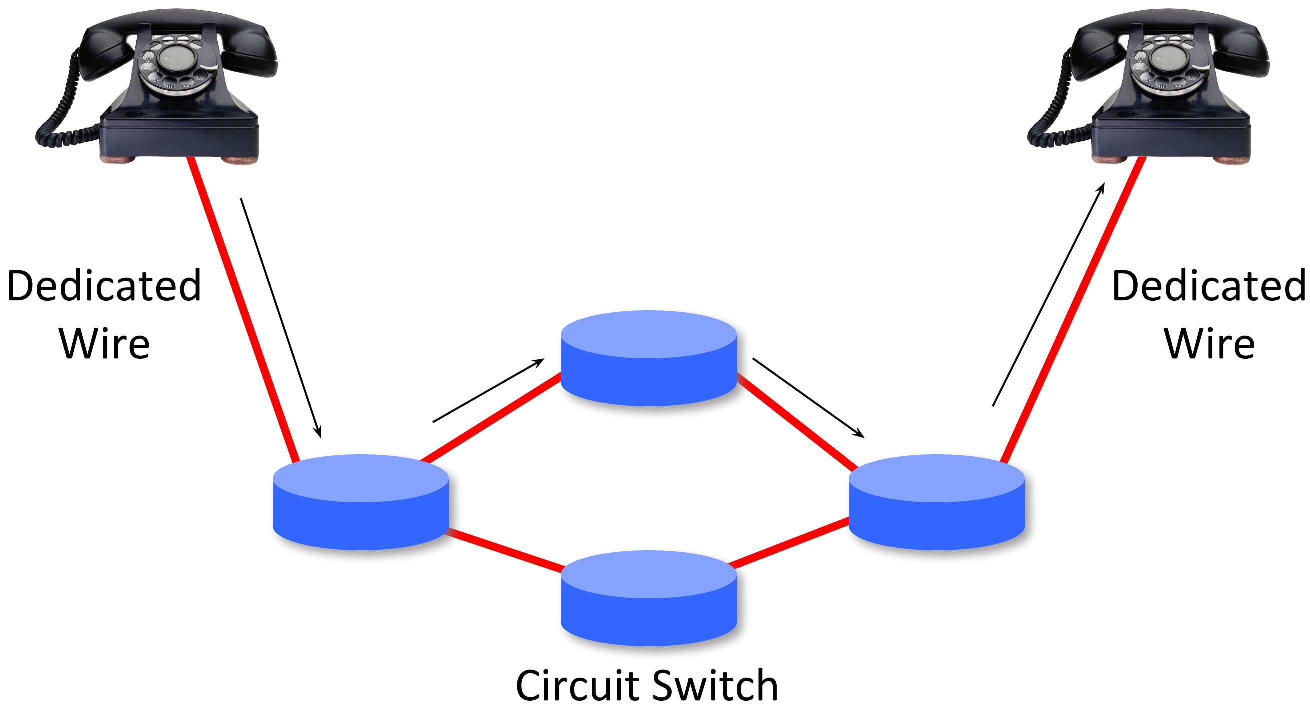
Outline

1. What is Circuit Switching?
2. What is Packet Switching?
3. Why does the Internet use Packet Switching?

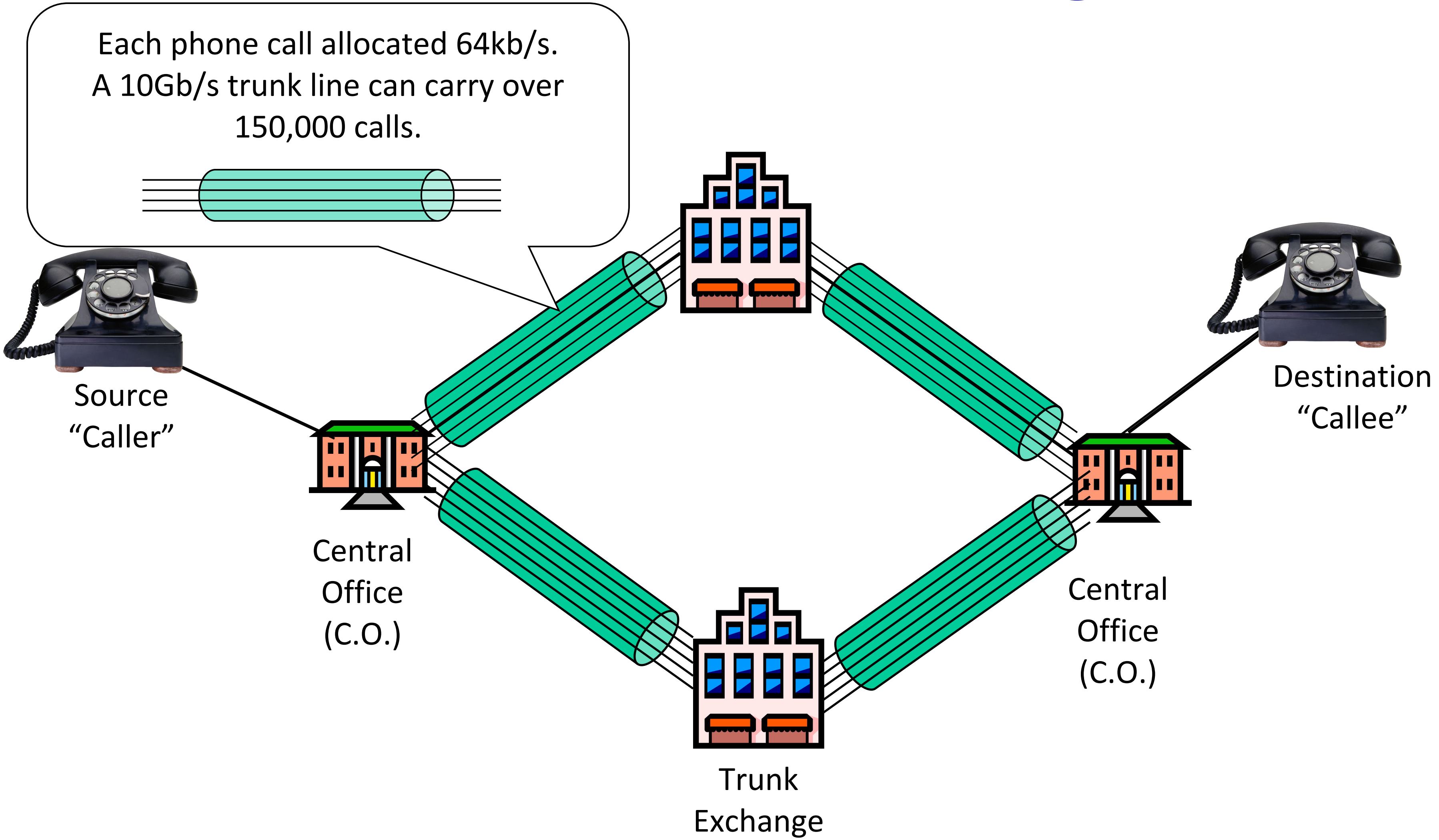
Circuit Switching



Circuit Switching



Circuit Switching



Circuit Switching

- Each call has its own private, guaranteed, isolated data rate from end-to-end.
- A call has three phases:
  1. Establish circuit from end-to-end ("dialing")
  2. Communicate
  3. Close circuit ("tear down")
- Originally, a circuit was an end-to-end physical wire.
- Nowadays, a circuit is like a virtual private wire.

Problems

1. **Inefficient**. Computer communication tends to be very bursty. *e.g*. typing over an ssh connection, or viewing a sequence of web pages. If each communication has a dedicated circuit, it will be used very inefficiently.
2. **Diverse Rates**. Computers communicate at many different rates. *e.g.* a web server streaming video at 6Mb/s, or me typing at 1 character per second. A fixed rate circuit will not be much use.
3. **State Management**. Circuit switches maintain per-communication state, which must be managed.

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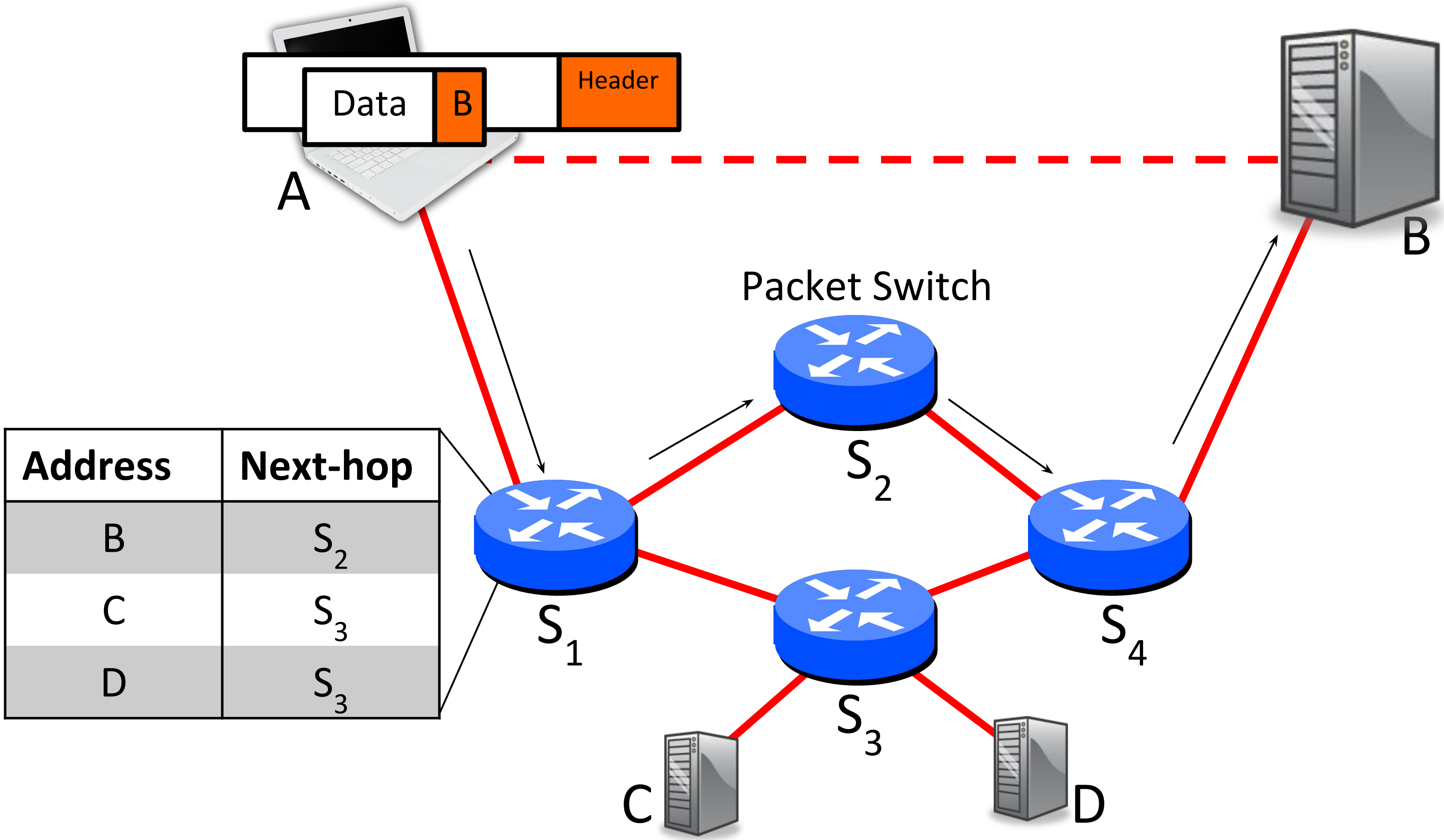
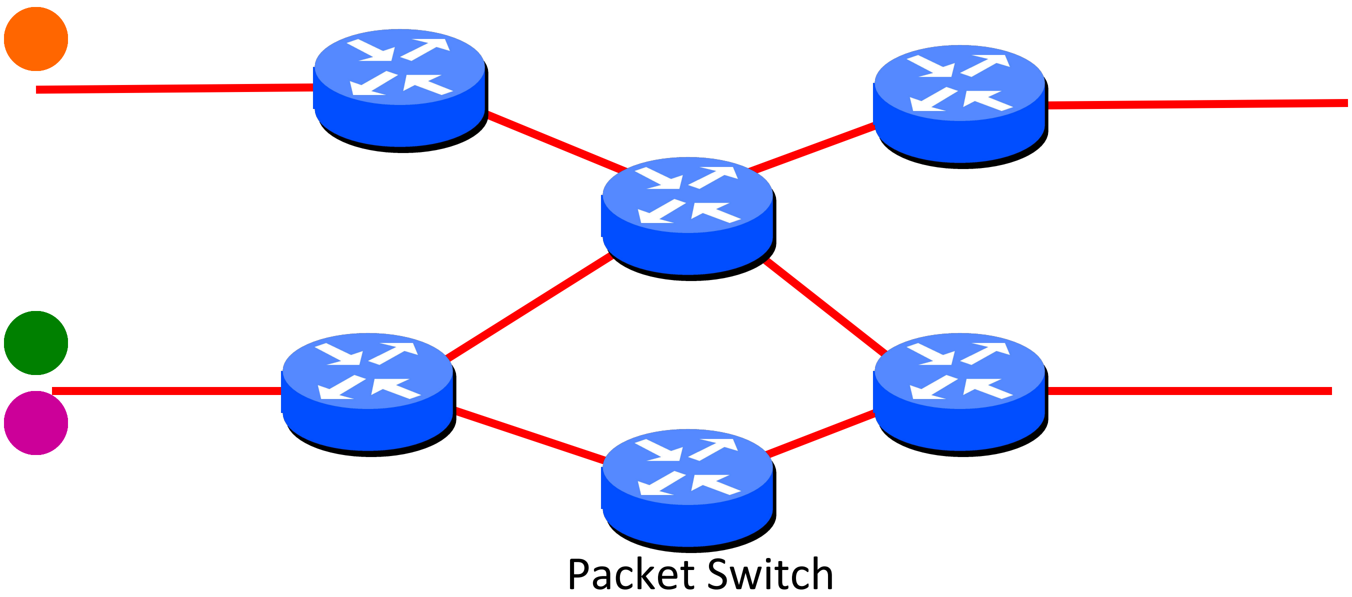
Packet Switching

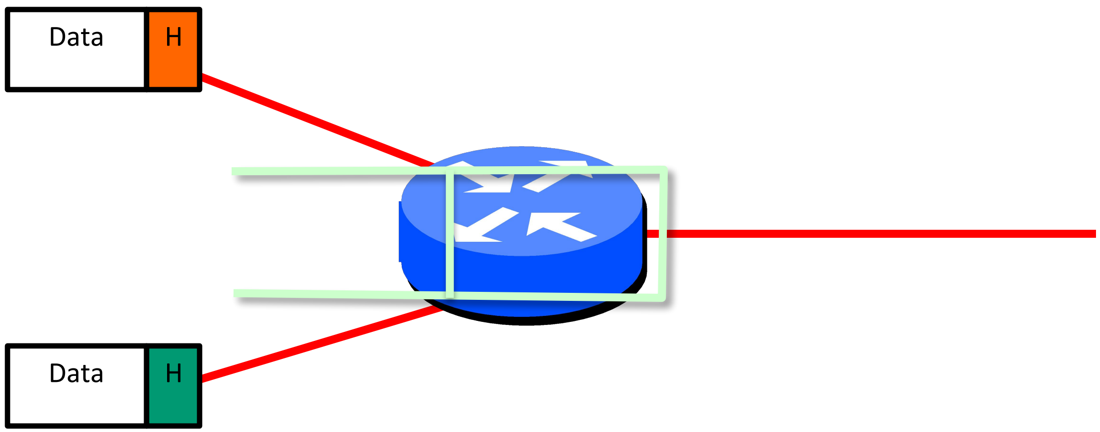


Address	Next-hop
B	S_2
C	S_3
D	S_3

Packet Switching



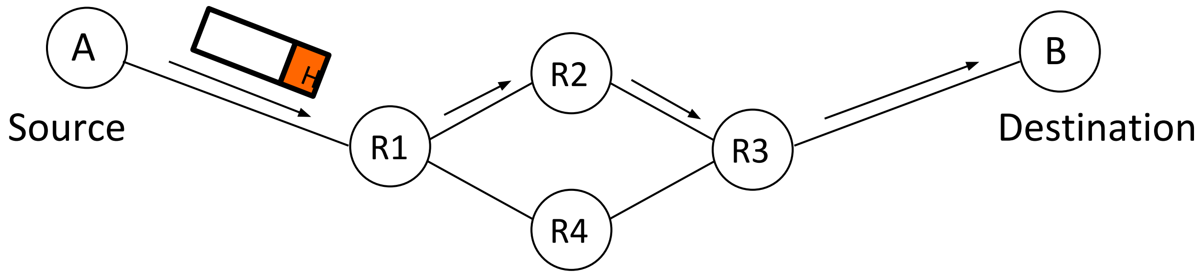
Packet switches have buffers



Buffers hold packets:

- When two or more packets arrive at the same time
- During periods of congestion

Packet Switching



- Packets are routed individually, by looking up address in router's local table.
- All packets share the full capacity of a link.
- The routers maintain no per-communication state.

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Efficient use of expensive links

- Links were assumed to be expensive and scarce.
- Packet switching allows many, bursty flows to share the same link efficiently.
- "Circuit switching is rarely used for data networks, ... because of very inefficient use of the links" – Bertsekas/*Gallager*

Resilience to failure of links & routers

- "For high reliability, ... [the Internet] was to be a datagram subnet, so if some lines and [routers] were destroyed, messages could be ... rerouted" - *Tanenbaum*

Summary

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2. What is Packet Switching?
3. Why does the Internet use Packet Switching?

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Packet Switching

End to End Delay

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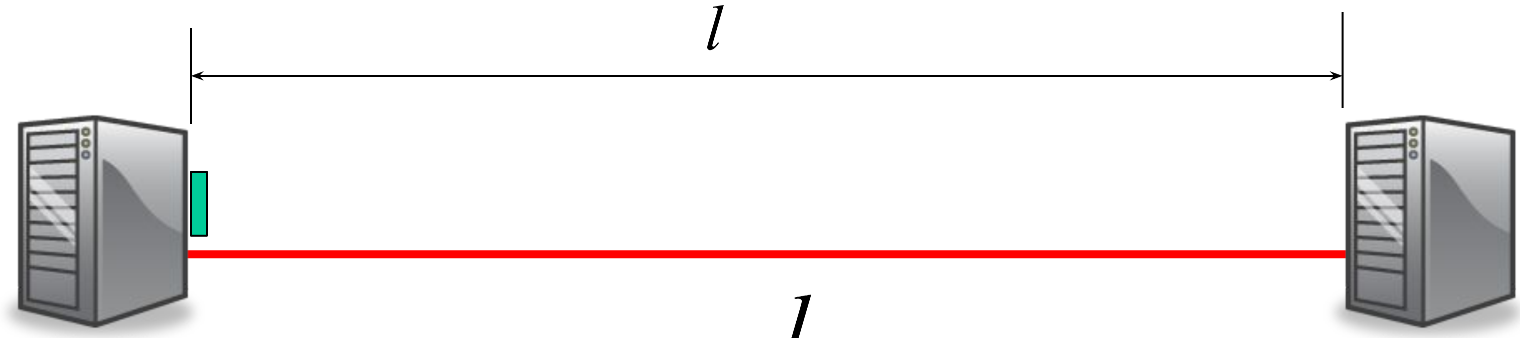
and Computer Science, Stanford University

Outline

1. Useful definitions
2. End-to-end delay
3. Queueing delay

Propagation Delay, t_l: The time it takes a single bit to travel over a link at propagation speed c.



$$t_l = \frac{l}{c}$$

<u>Example</u>: A bit takes 5ms to travel 1,000km in an optical fiber with propagation speed 2 x 10^8 m/s.

Packetization Delay, t_p: The time from when the first to the last bit of a packet is transmitted.

$$t_p = \frac{p}{r}$$

Example 1: A 64byte packet takes 5.12μs to be transmitted onto a 100Mb/s link.
Example 2: A 1kbit packet takes 1.024s to be transmitted onto a 1kb/s link.

Note: Packetization delay is sometimes called "serialization" delay because it's the time it takes to serialize a packet onto the link.

Outline

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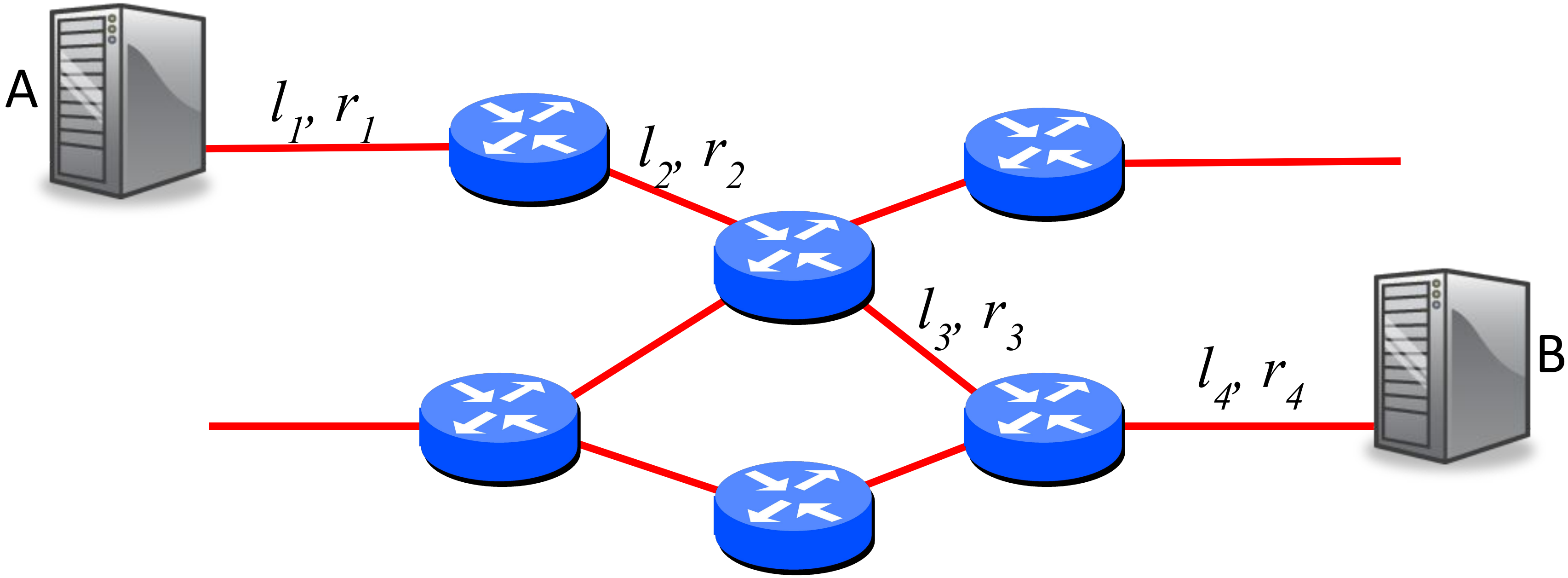
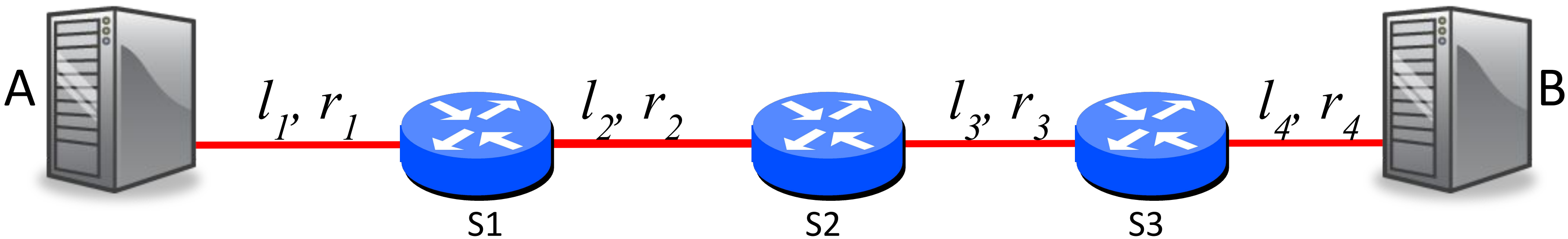
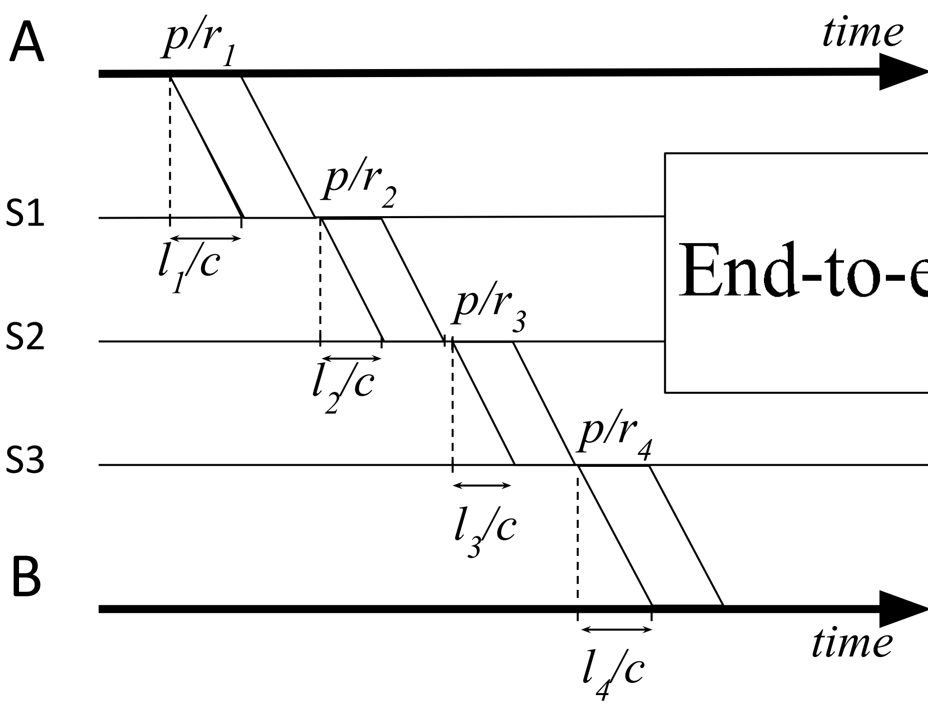
End-to-end delay



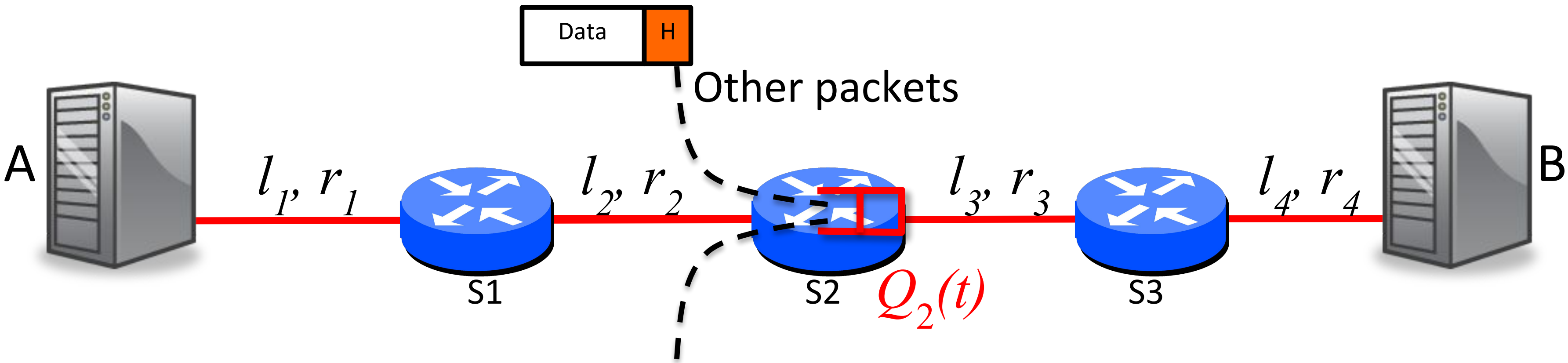
<u>Example</u>: How long will it take a packet of length p to travel from A to B, from when the 1st bit is sent, until the last bit arrives? Assume the switches *store-and-forward* packets along the path.

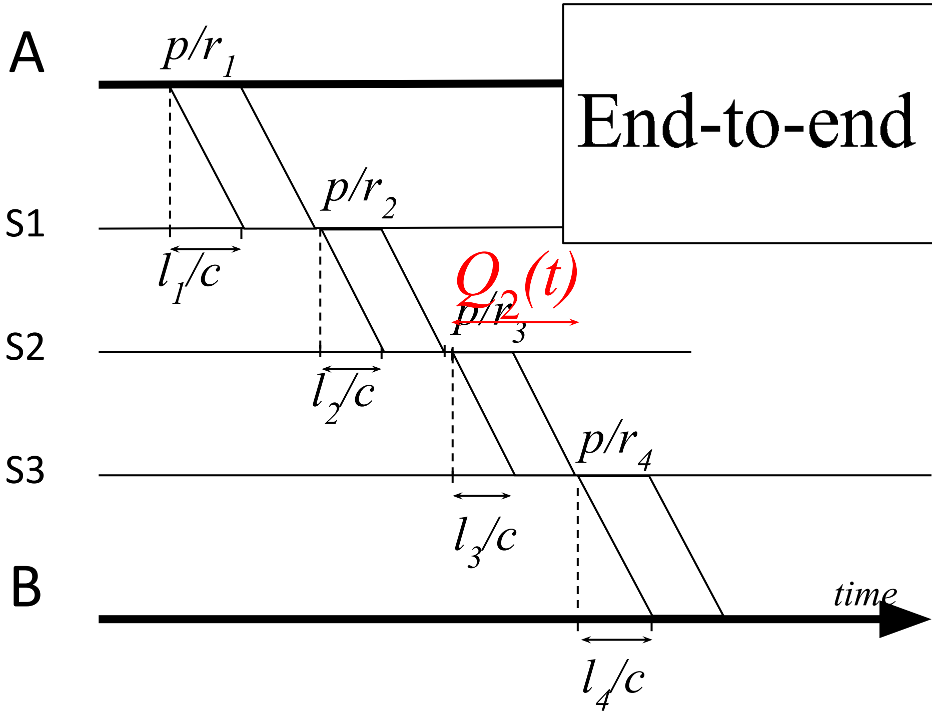
$$\text{End-to-end delay, } t = \sum_i \left(\frac{p}{r_i} + \frac{l_i}{c} \right)$$





End-to-end delay, $t = \sum_i \left(\frac{p}{r_i} + \frac{l_i}{c} \right)$



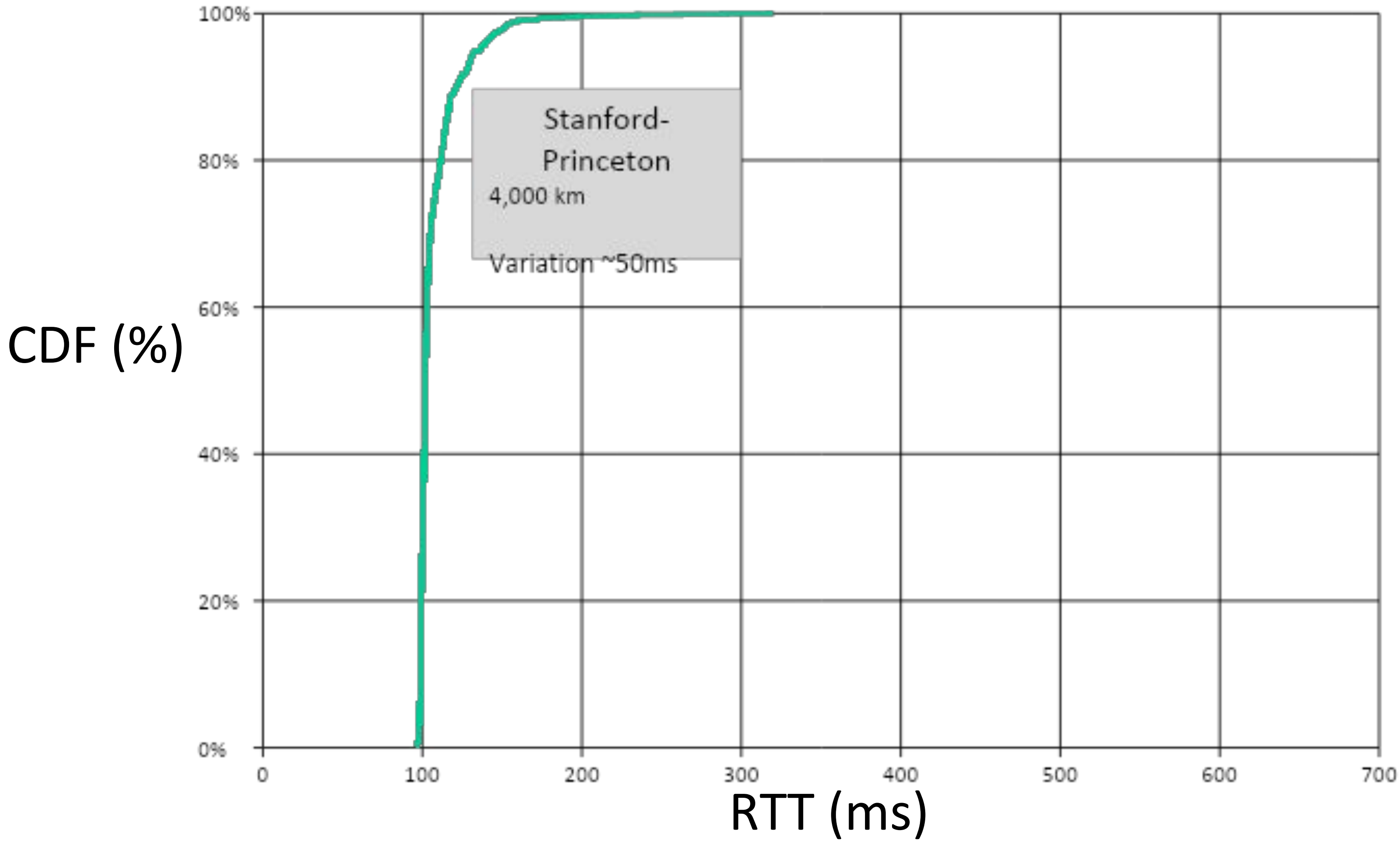


$$\text{End-to-end delay, } t = \sum_i \left(\frac{p}{r_i} + \frac{l_i}{c} + Q_i(t) \right)$$

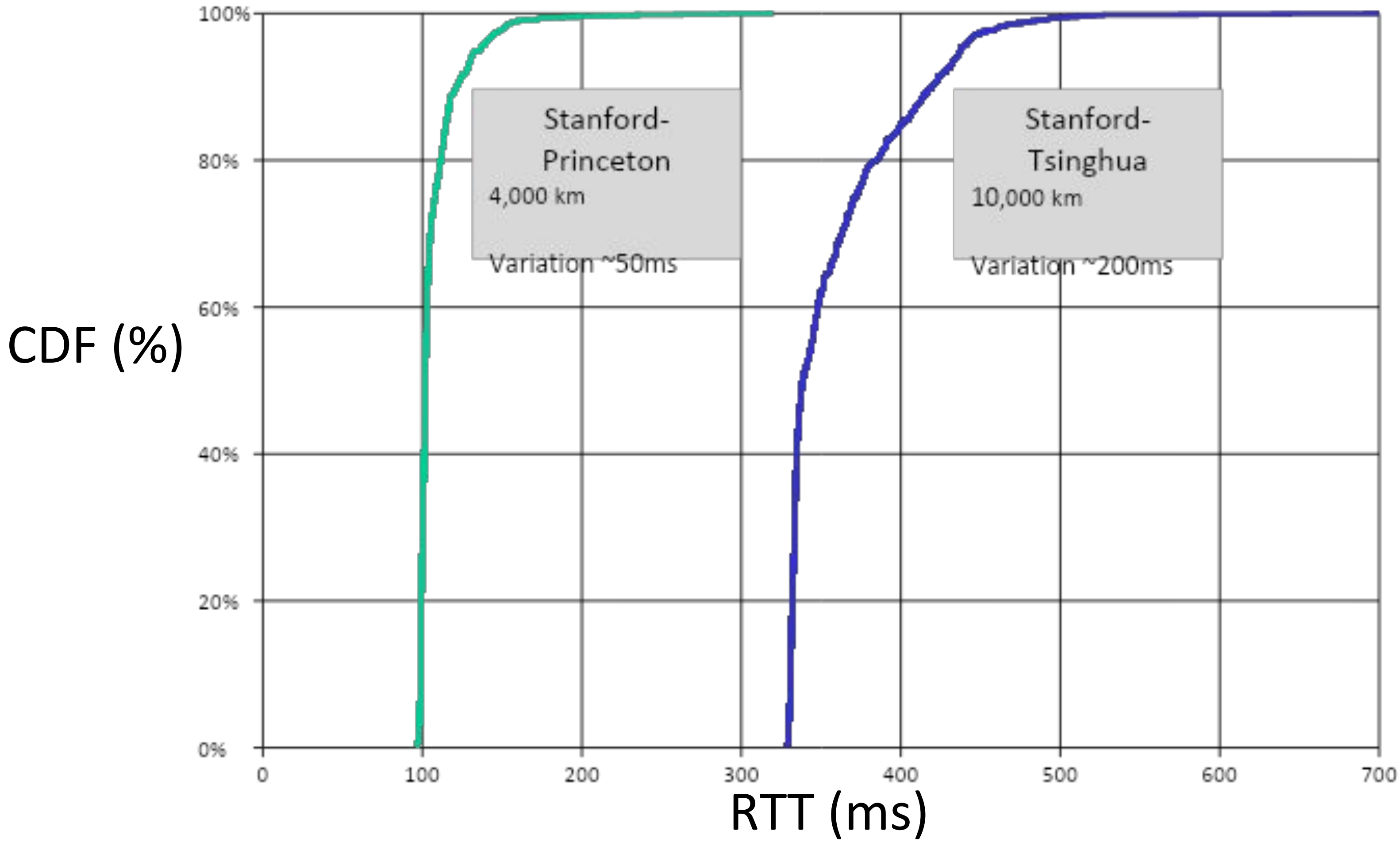
*Queueing = UK spelling, adopted by Kleinrock at UCLA in 1960s.
Queueing and queuing (US spelling) are both widely used.

Insert the “ping” video here.

Packet delay variation



Packet delay variation



Summary

End to end delay is made up of three main components:

- Propagation delay along the links (fixed)
- Packetization delay to place packets onto links (fixed)
- Queueing delay in the packet buffers of the routers (variable)

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Playback Buffers

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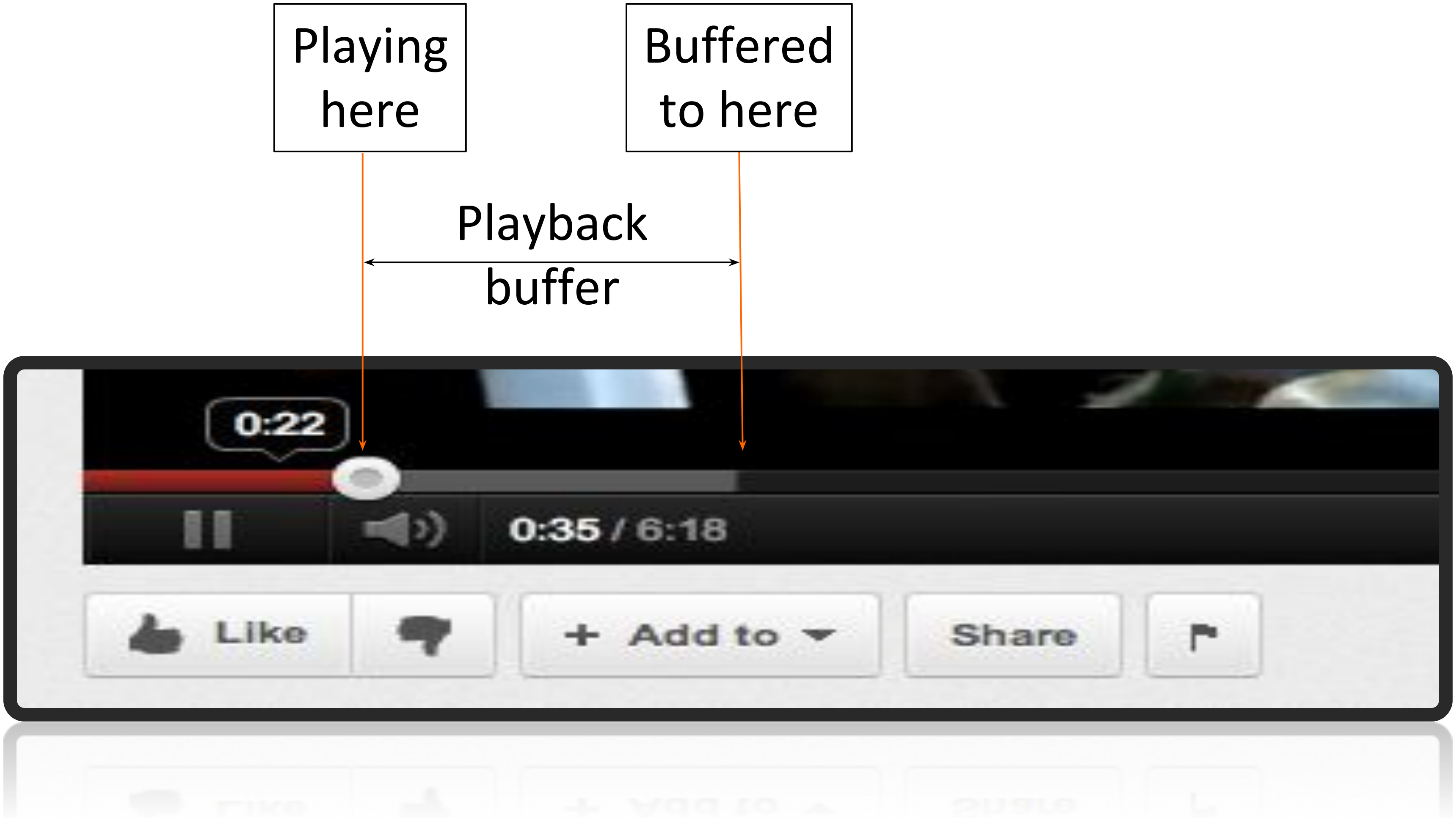
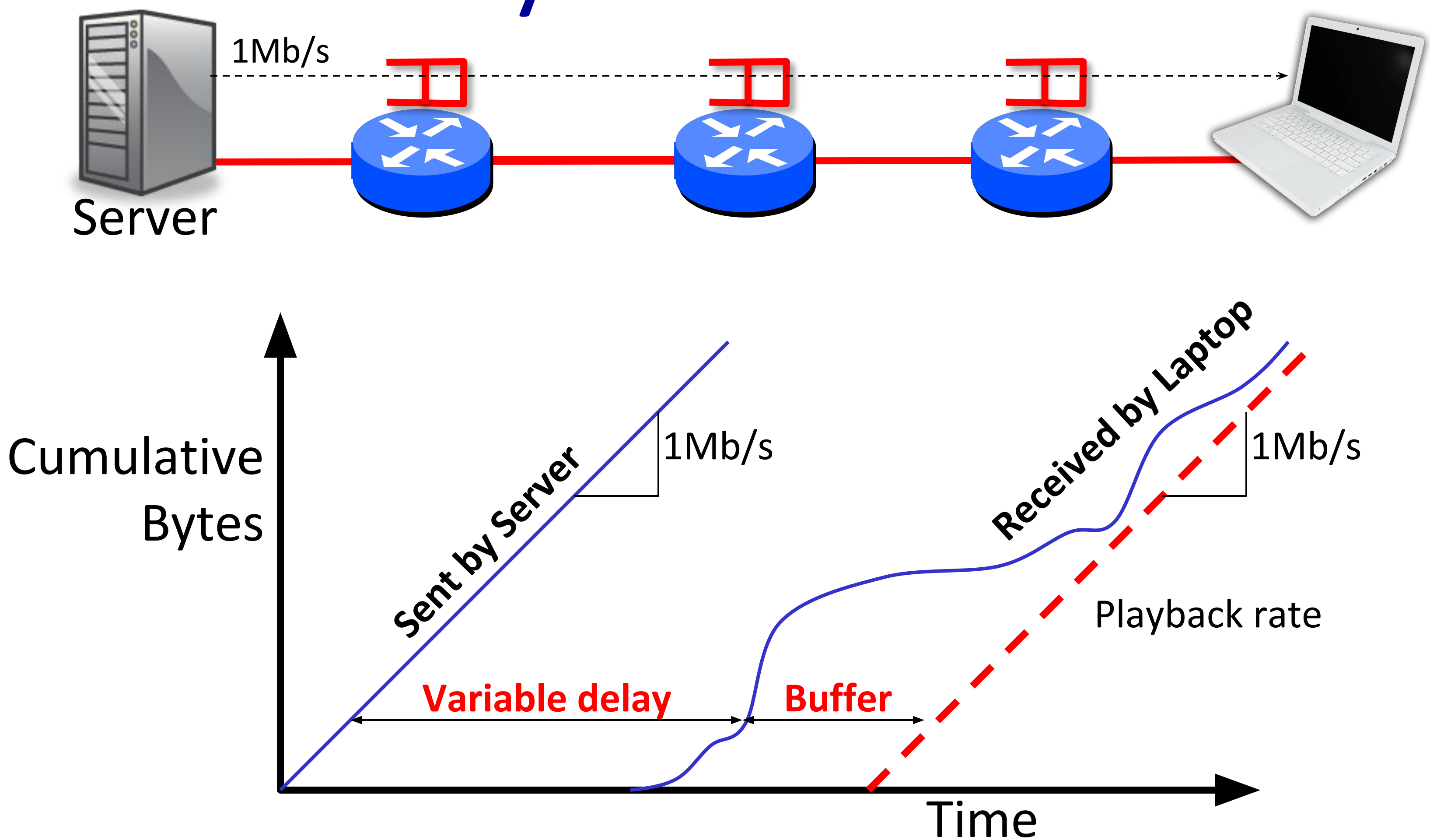
Real-time applications (e.g. YouTube and Skype) have to cope with variable queueing delay

Playback buffers

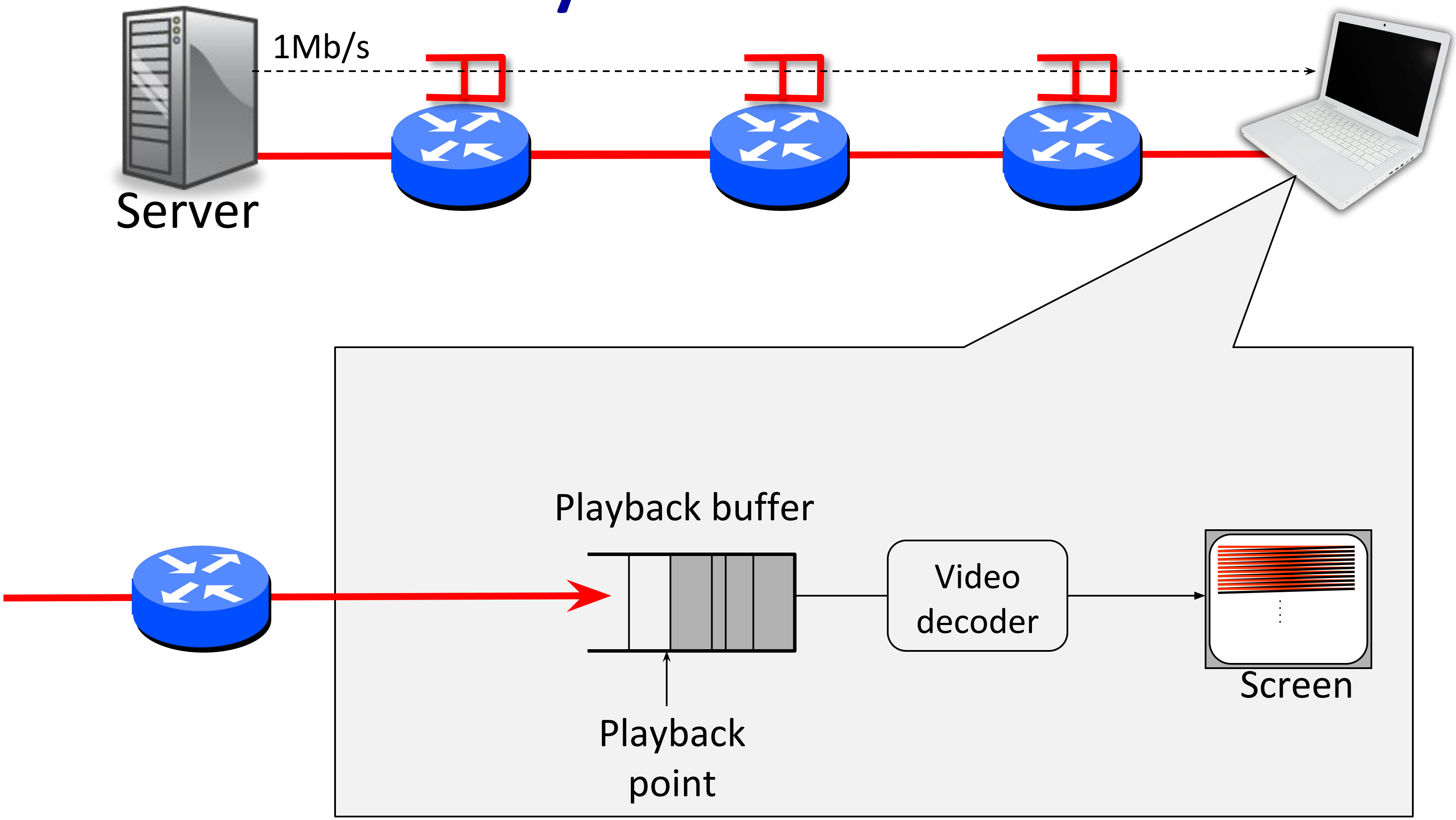


From: youtube.com

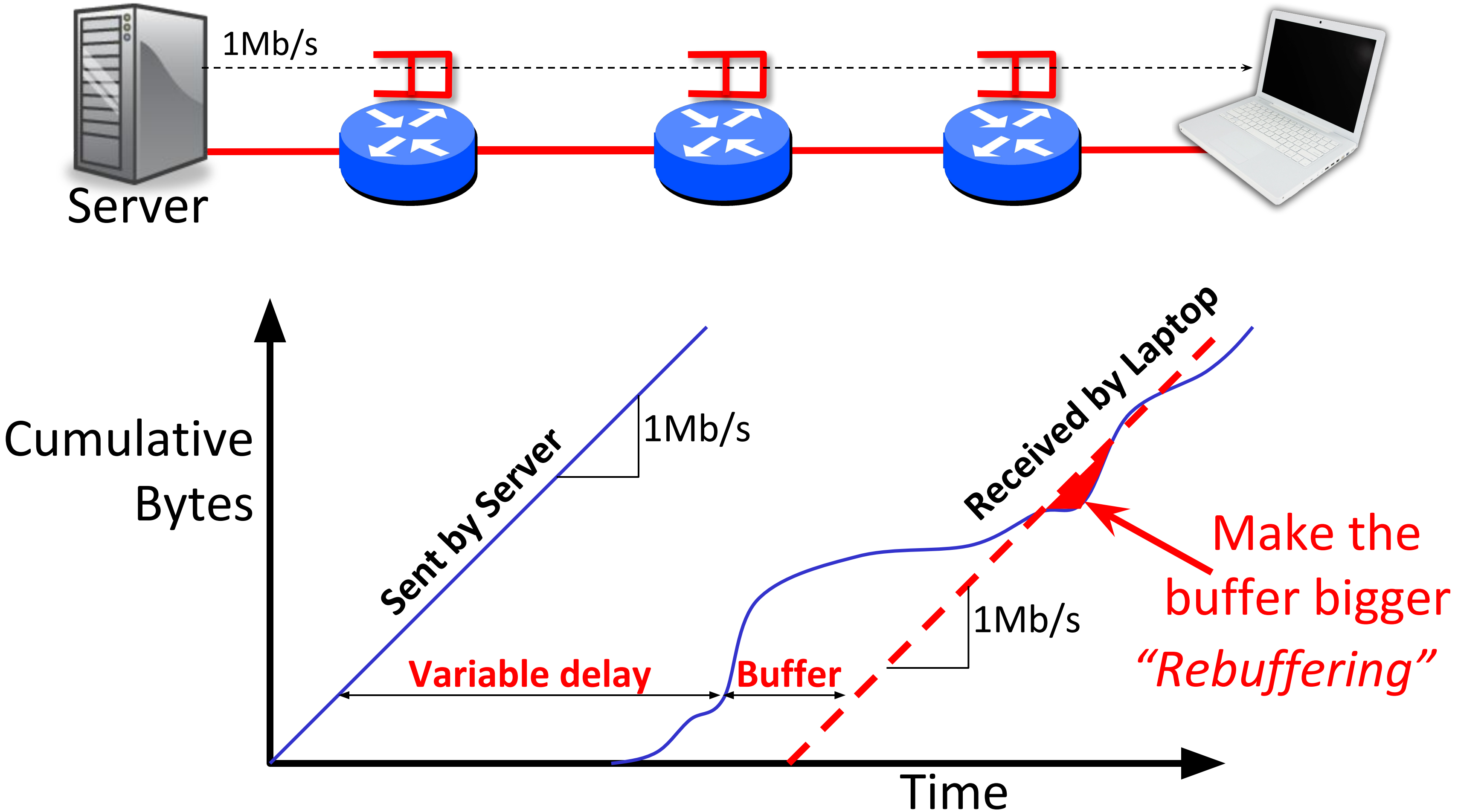
Playback buffers



Playback buffers



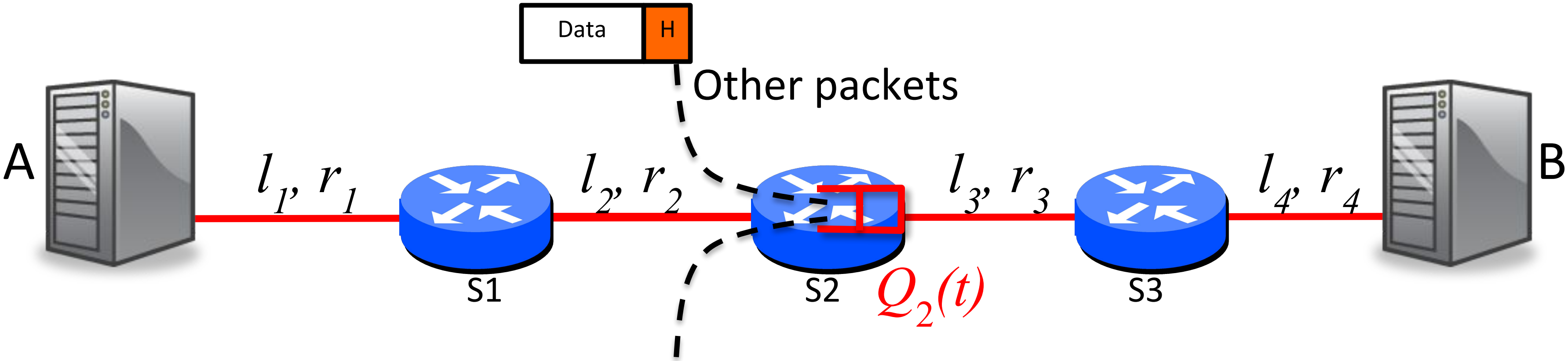
If the buffer is too small

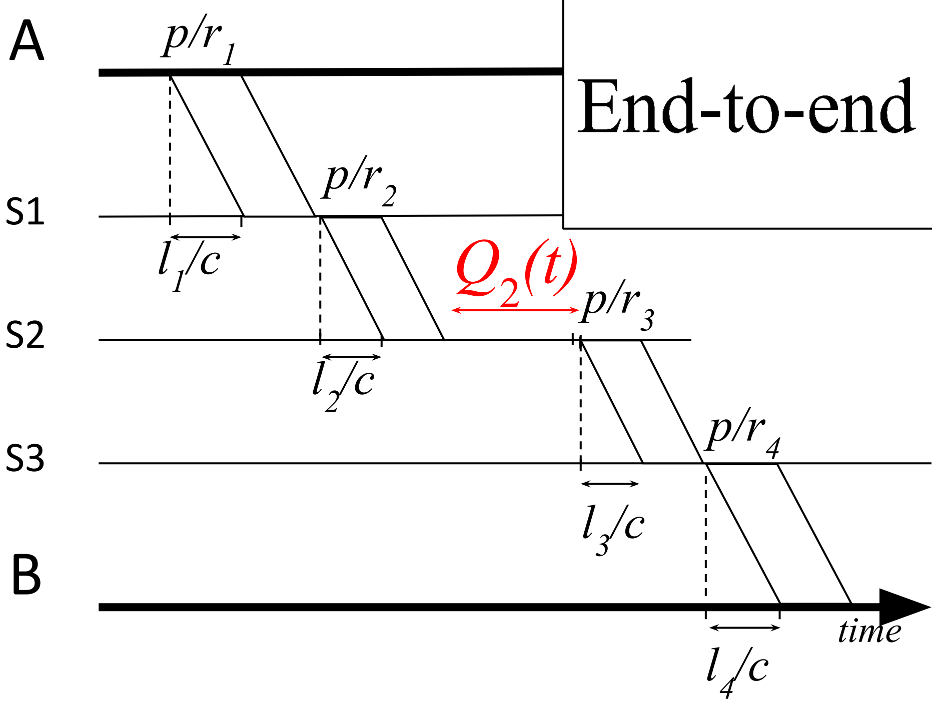


Playback buffer

- With packet switching, end-to-end delay is variable.
- We use a playback buffer to absorb the variation.

- We could just make the playback buffer very big, but then the video would be delayed at the start.
- Therefore, applications estimate the delay, set the playback buffer, and resize the buffer if the delay changes.





End-to-end delay, $t = \sum_i \left(\frac{p}{r_i} + \frac{l_i}{c} + Q_i(t) \right)$

Queueing adds variable and unpredictable delay

Summary

Real-time applications use playback buffers to absorb the variation in queueing delay.

<End>