EN.601.414/614 Computer Networks

Basic

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Spring 2019 (MW 3:00-4:15pm in Shaffer 301)

https://github.com/xinjin/course-net

Agenda

- **Overview of the basics**
  - How is the network shared?
  - How do we evaluate a network?
  - What is a network made of?

But wait…

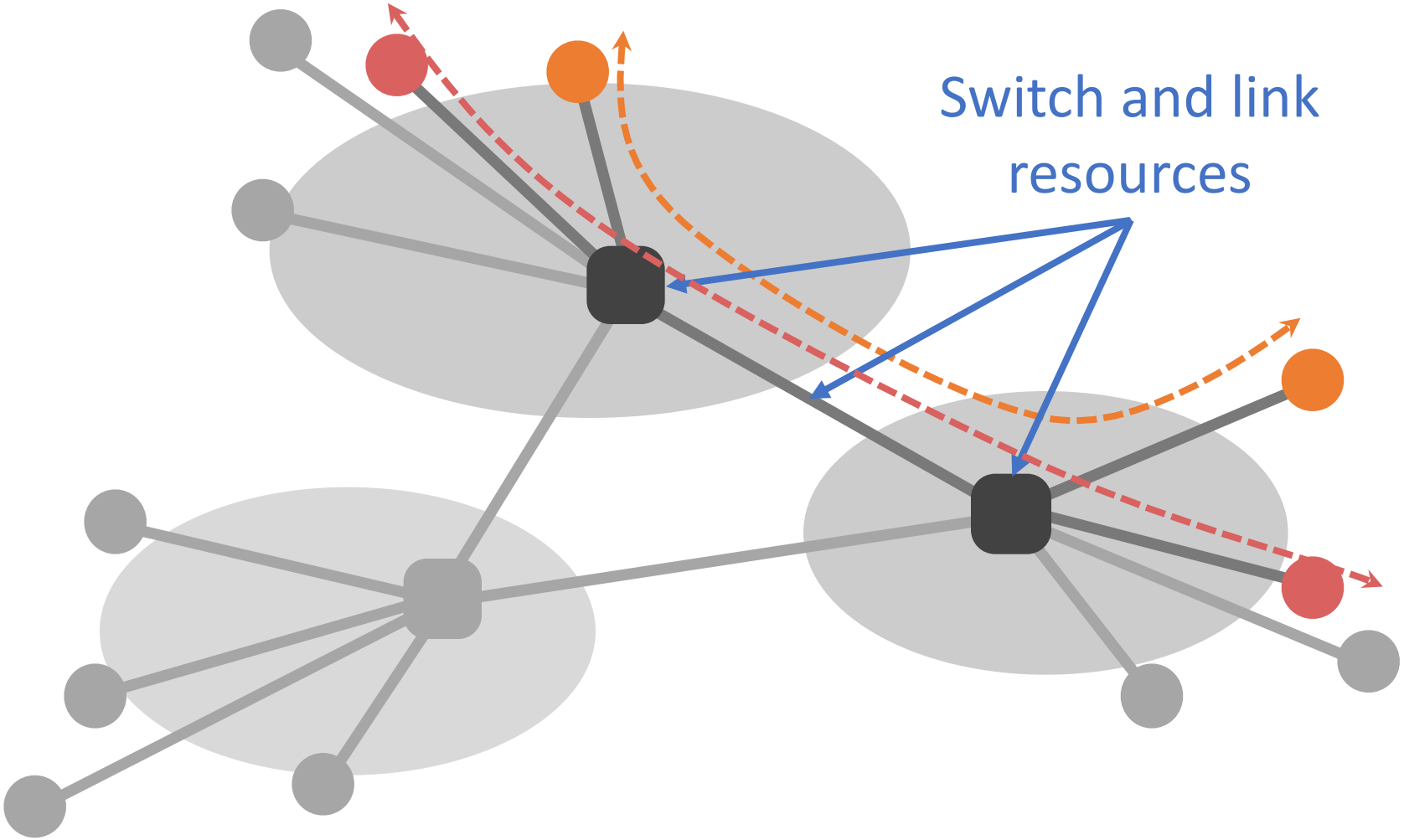
Why is the network shared?

Switched networks

- **End-systems and networks connected by switches instead of directly connecting them**

- **Why?**
  - Allows us to scale
  - For example, directly connecting N nodes to each other would require N^2 links!

When do we need to share the network?

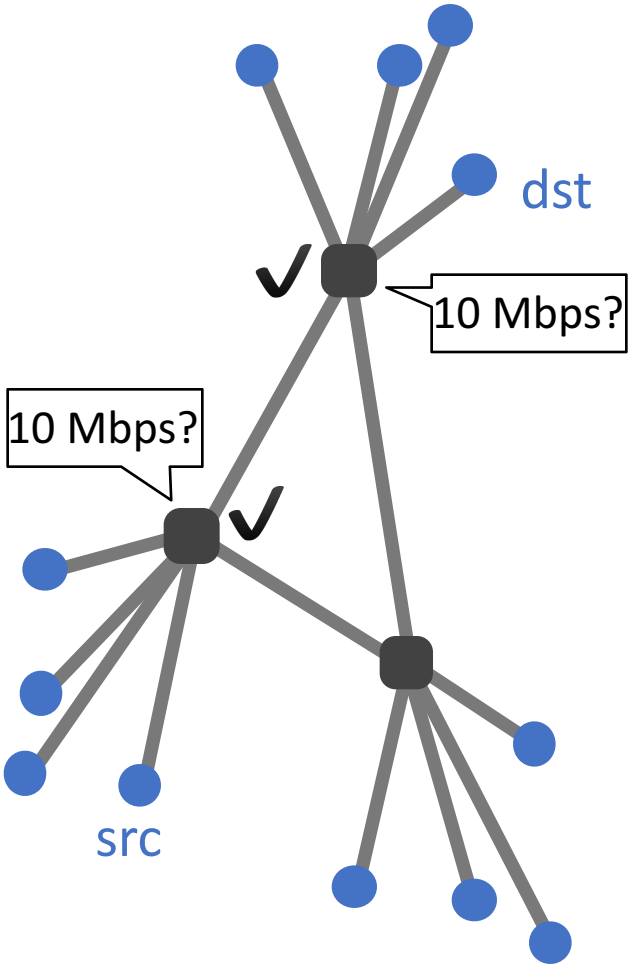


Two ways to share switched networks

- **Circuit switching**
  - Resource reserved per connection
  - Admission control: per connection
- **Packet switching via statistical multiplexing**
  - Packets treated independently, on-demand
  - Admission control: per packet
- **Hybrid: virtual circuits**
  - Emulating circuit switching with packets (see text)

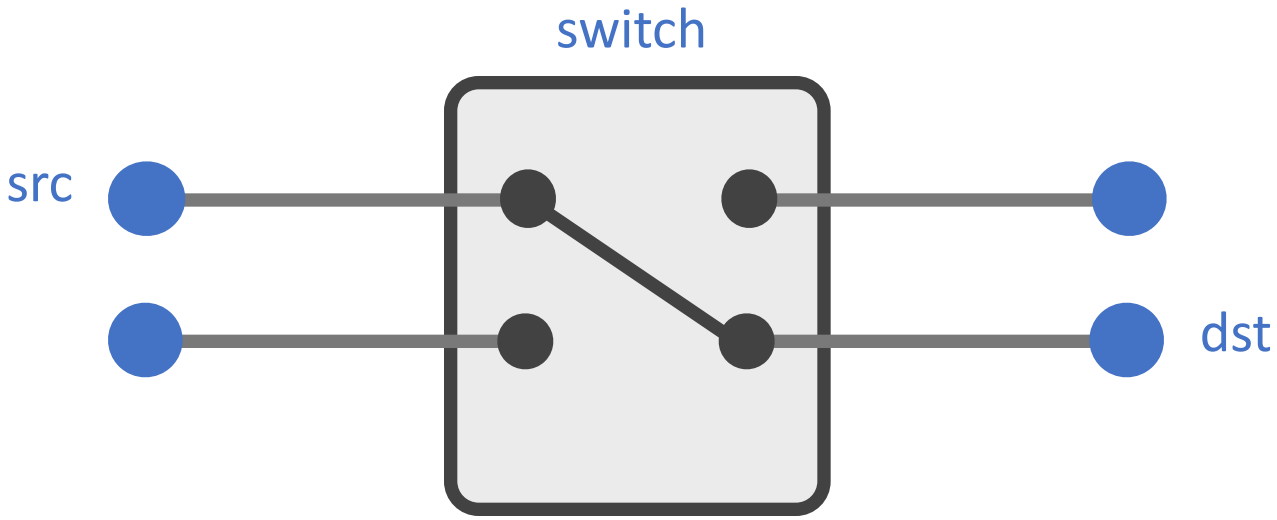
Circuit switching

1. src sends reservation request to dst
2. Switches create circuit *after* admission control
3. src sends data
4. src sends teardown request



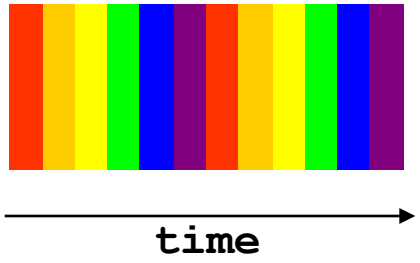
Circuit switching

- **Reservation establishes a “circuit” within a switch**

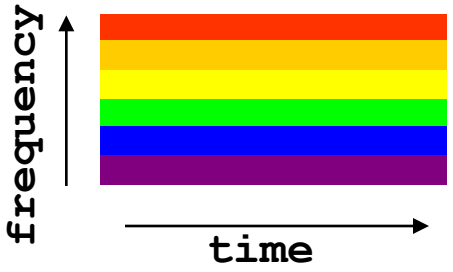


Many kinds of circuits

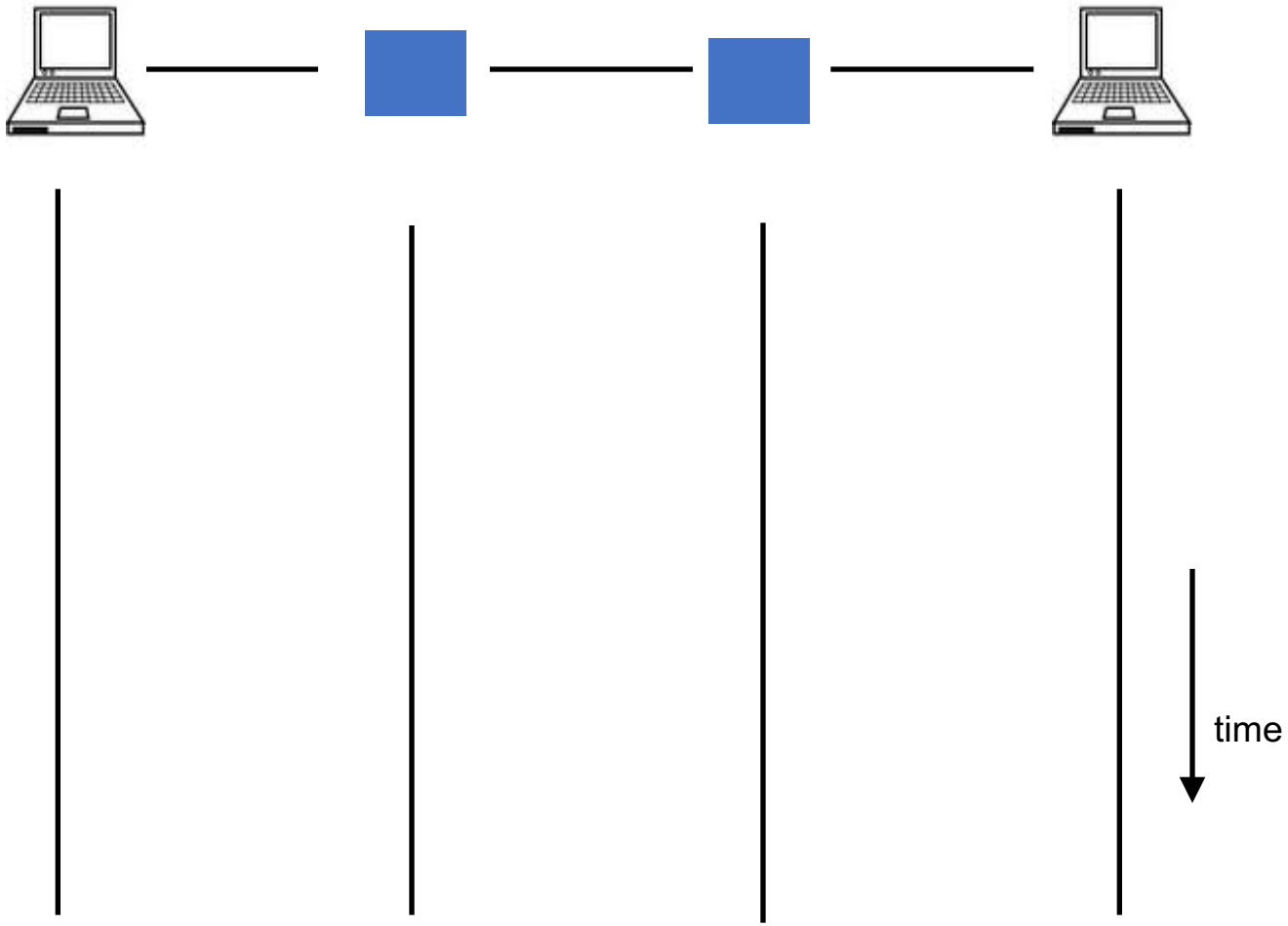
- **Time division multiplexing**
  - ➢ divide time in time slots
  - ➢ separate time slot per circuit



- **Frequency division multiplexing**
  - ➢ divide frequency spectrum in frequency bands
  - ➢ separate frequency band per circuit



Timing in circuit switching



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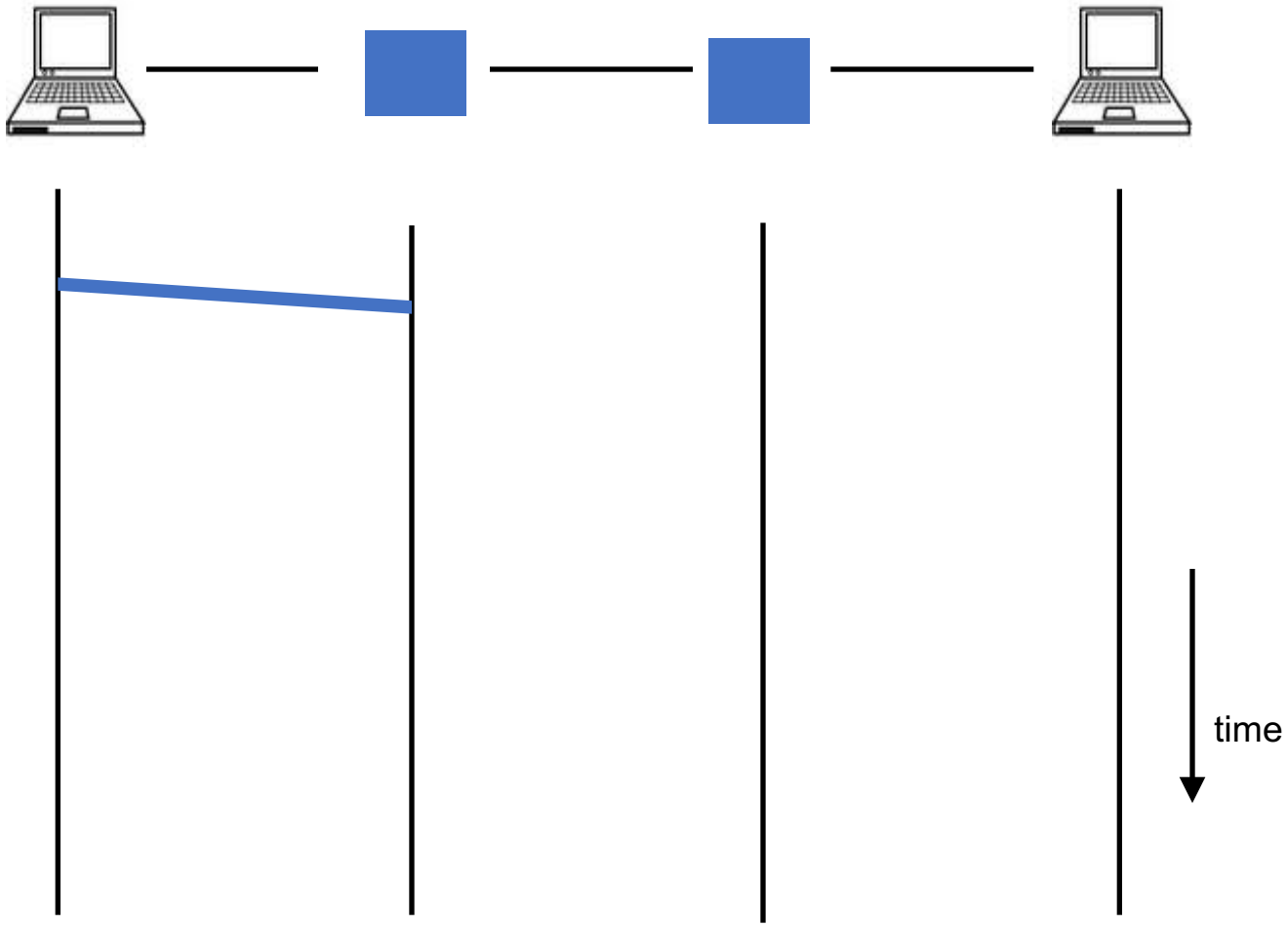

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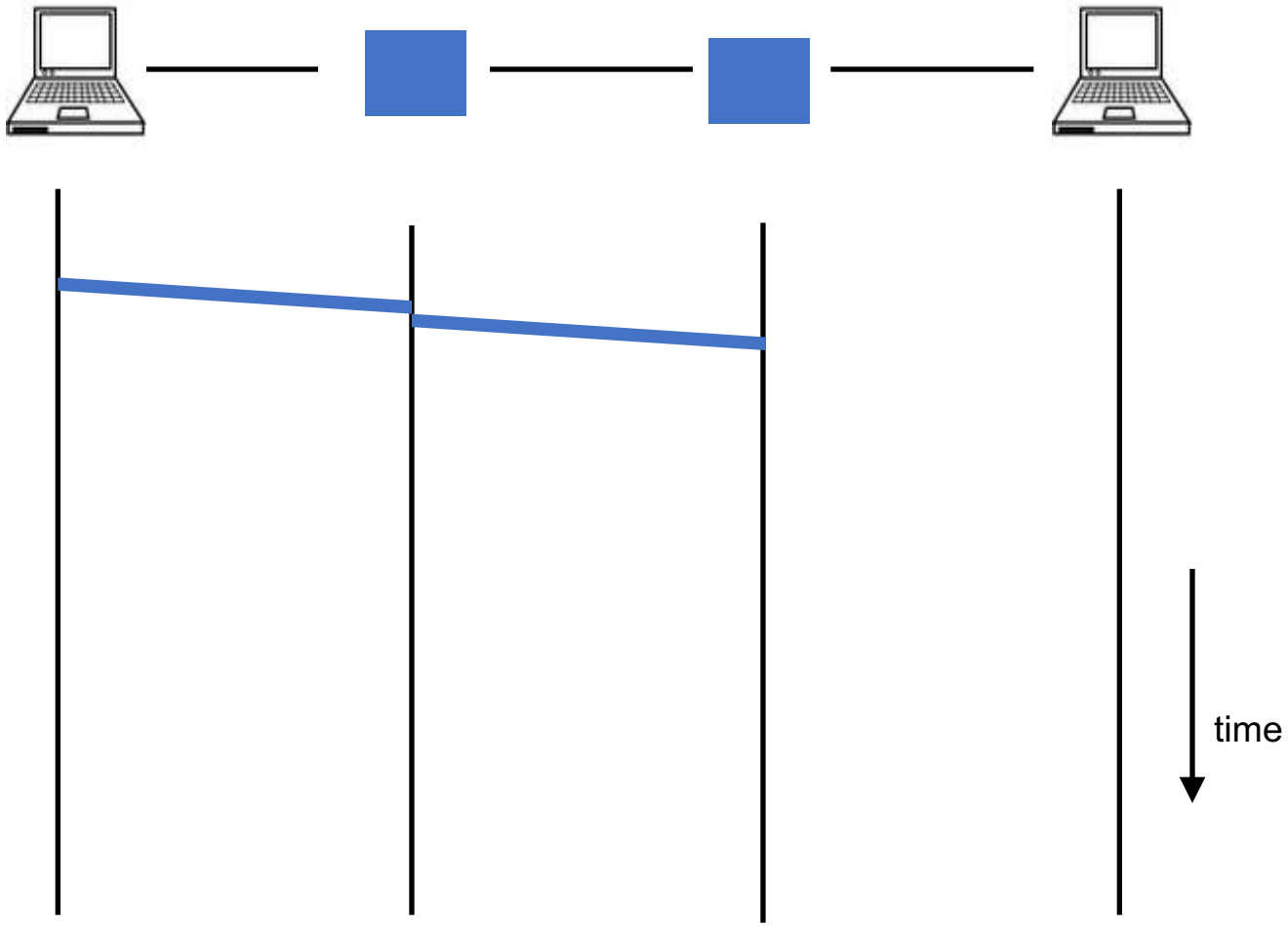
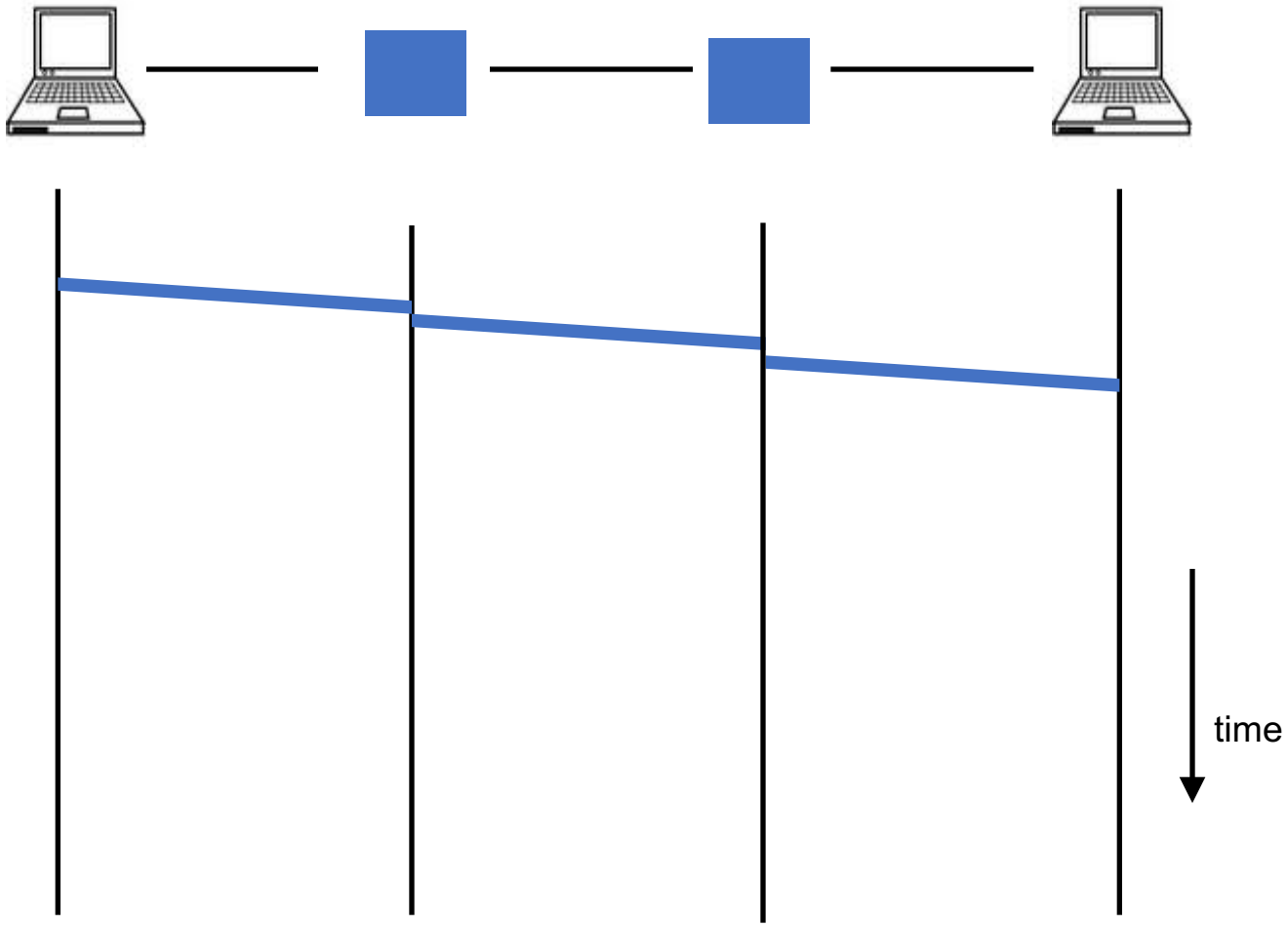
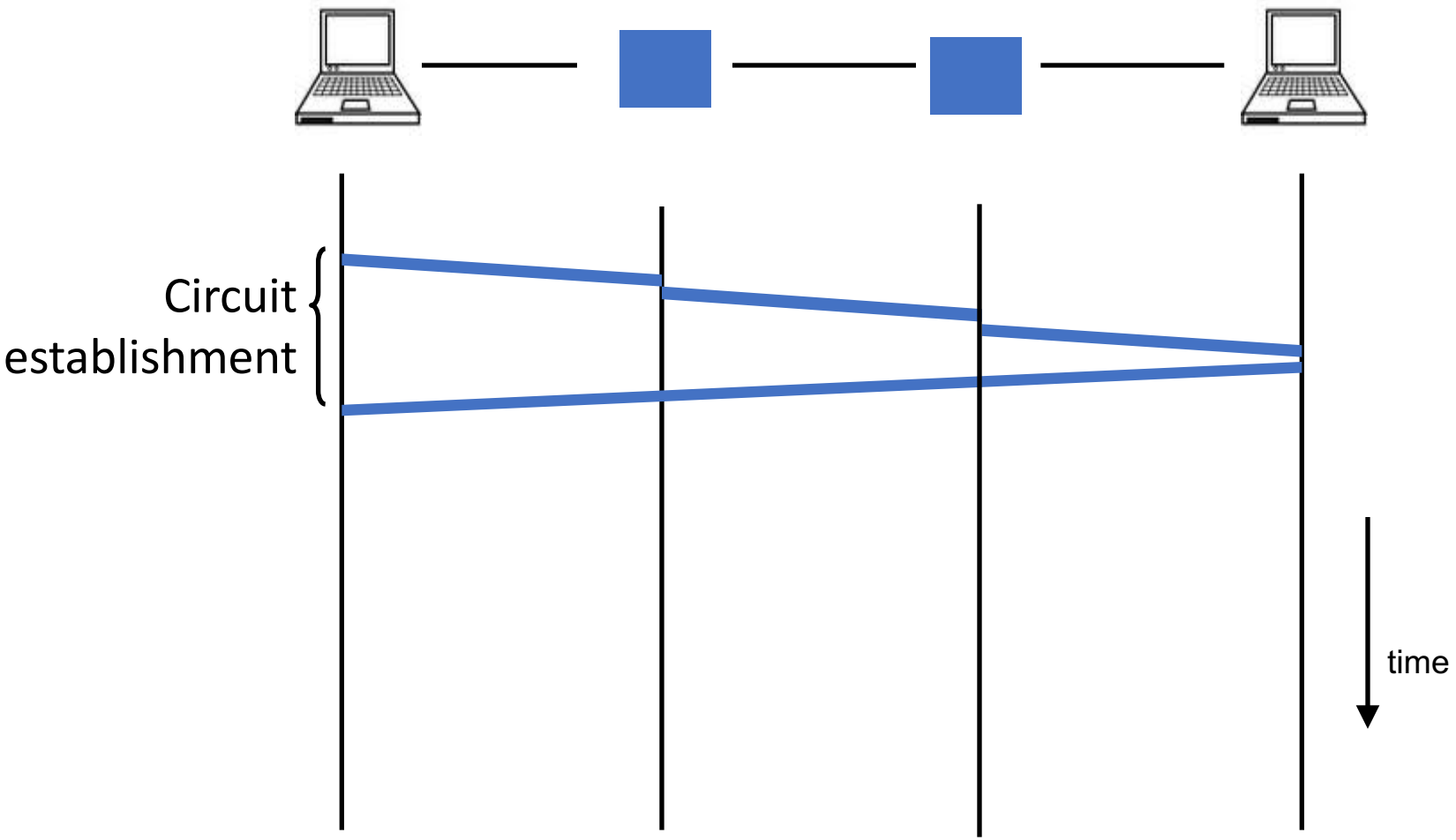


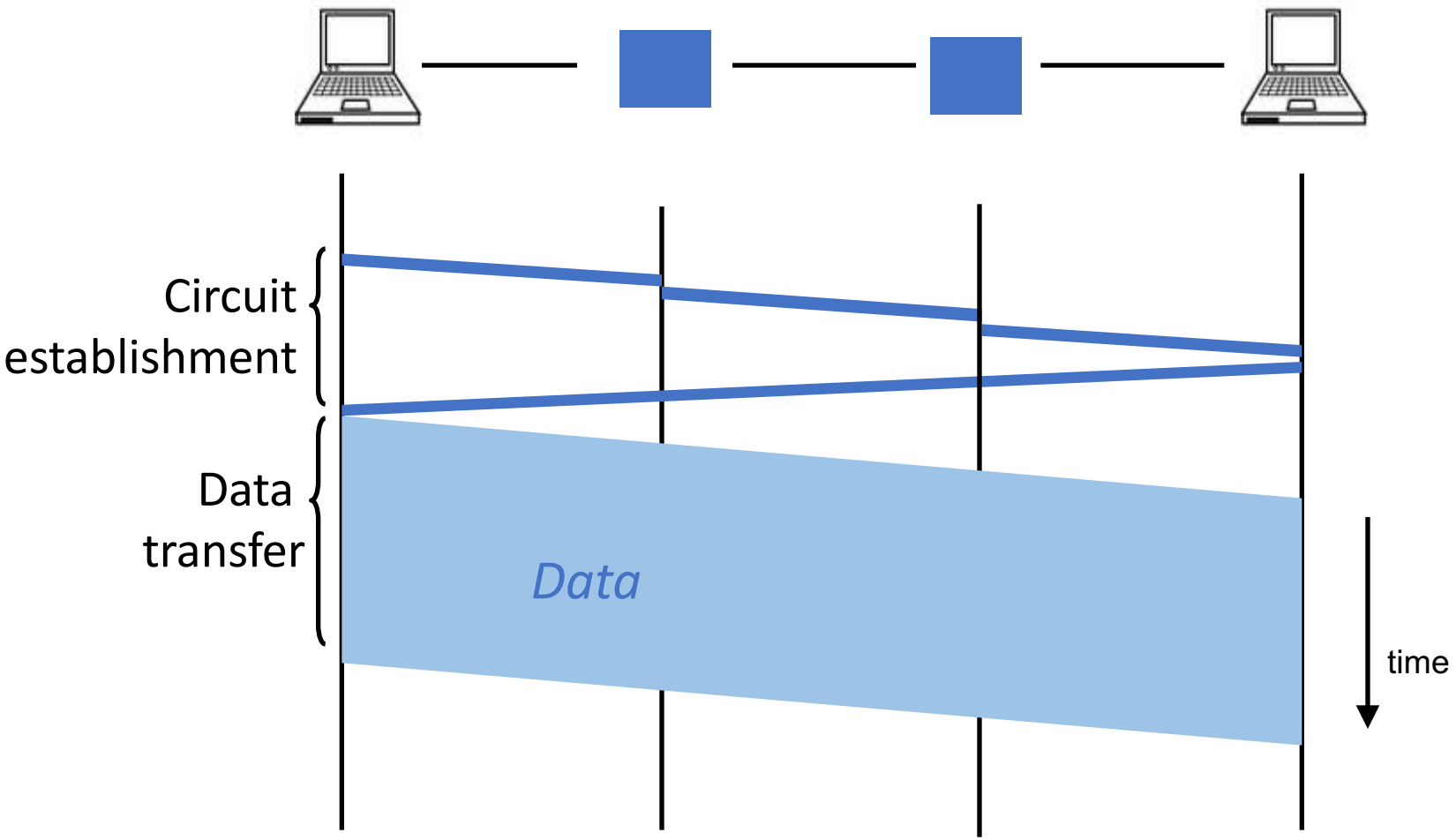
Timing in circuit switching



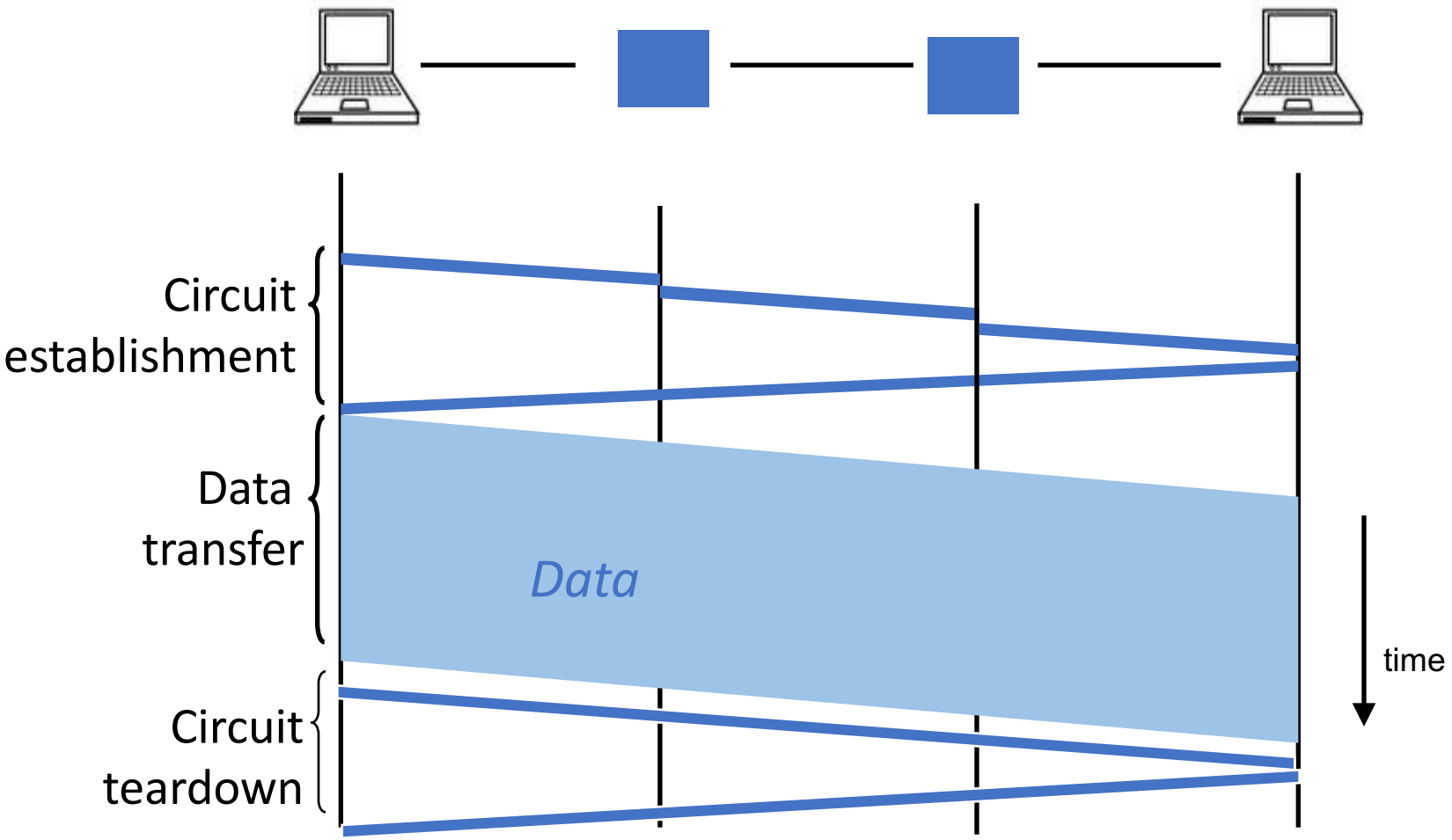
Timing in circuit switching



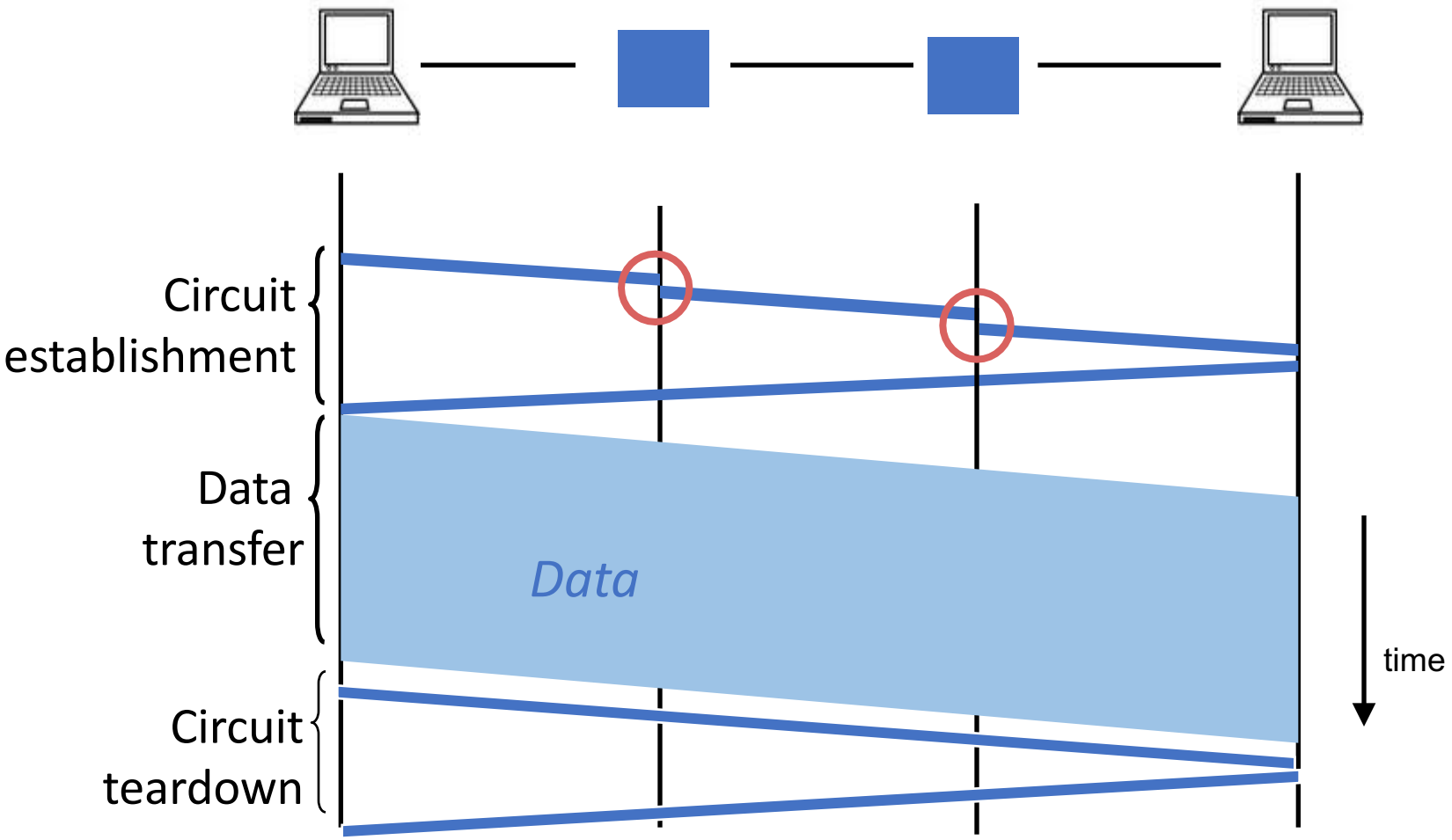
Timing in circuit switching



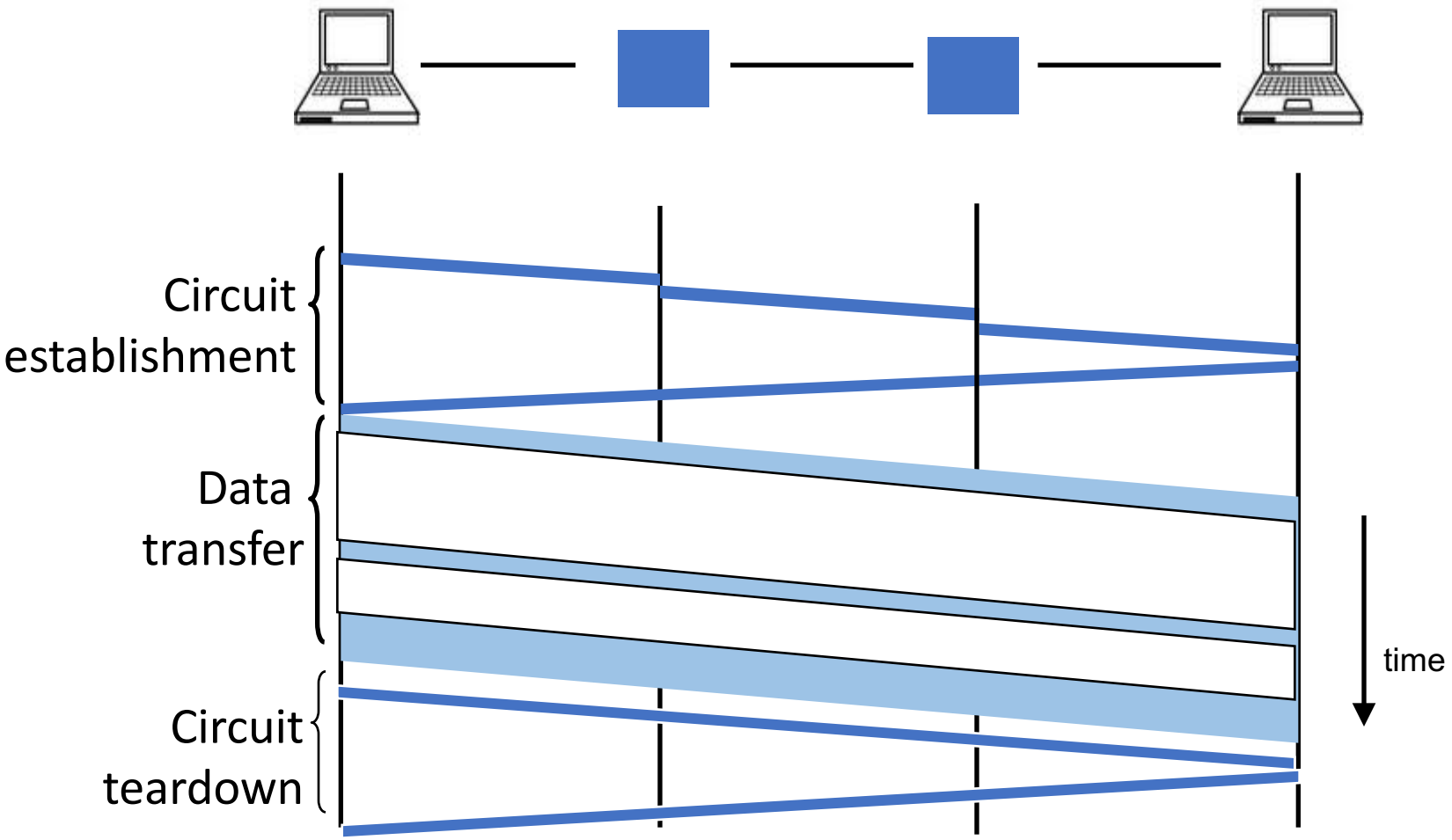
Timing in circuit switching



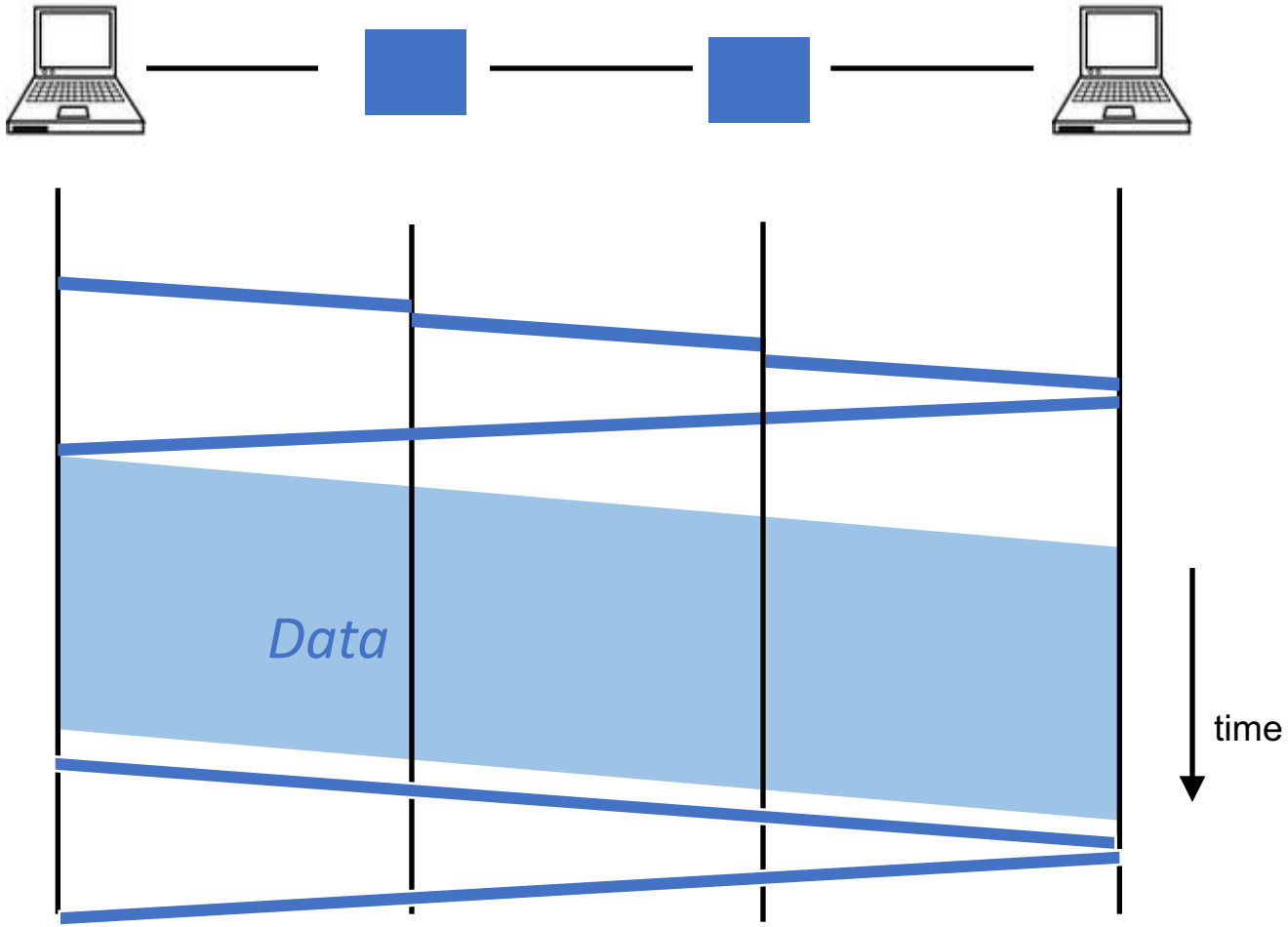
Why the delays?



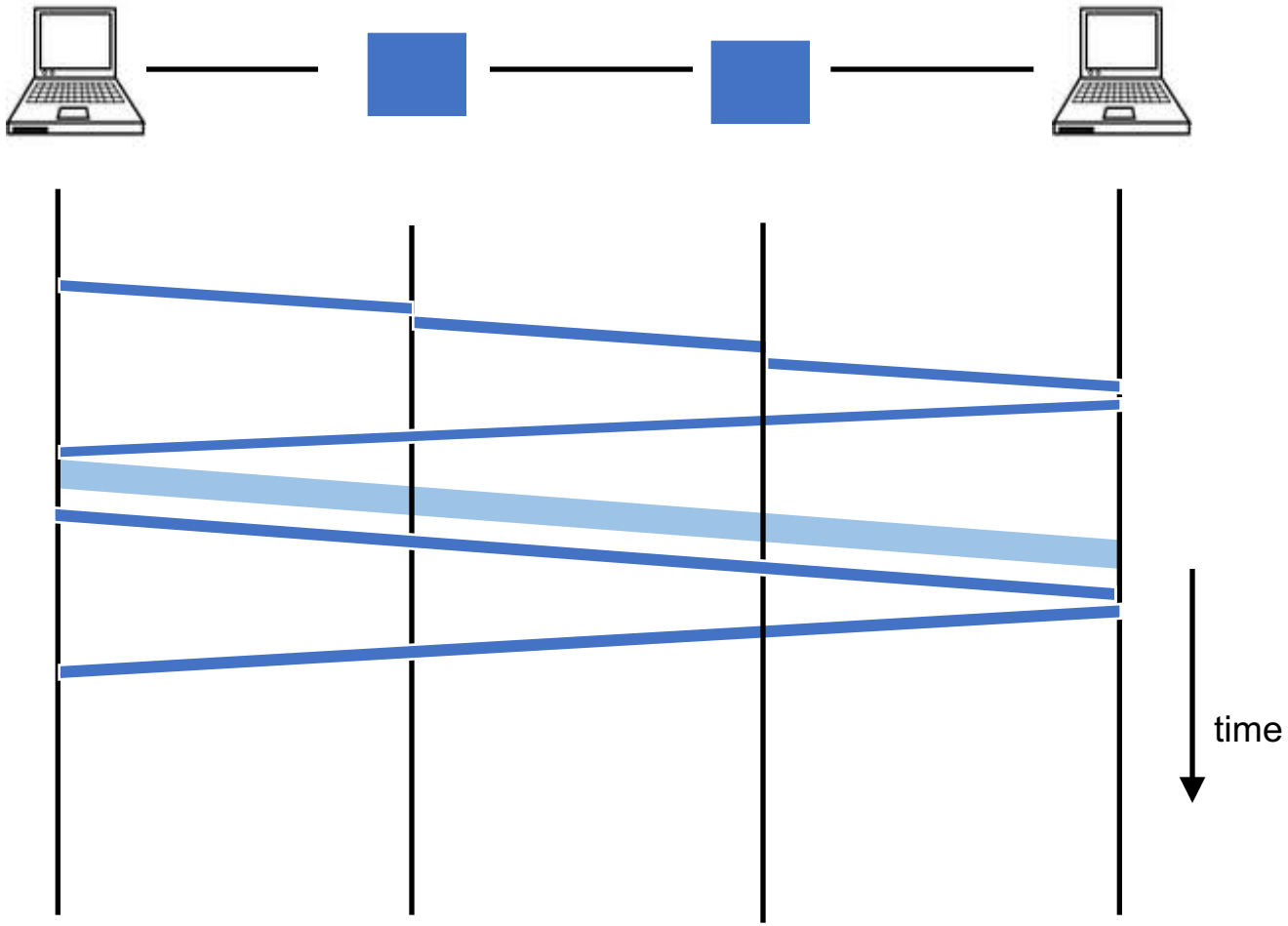
Timing in circuit switching



Timing in circuit switching



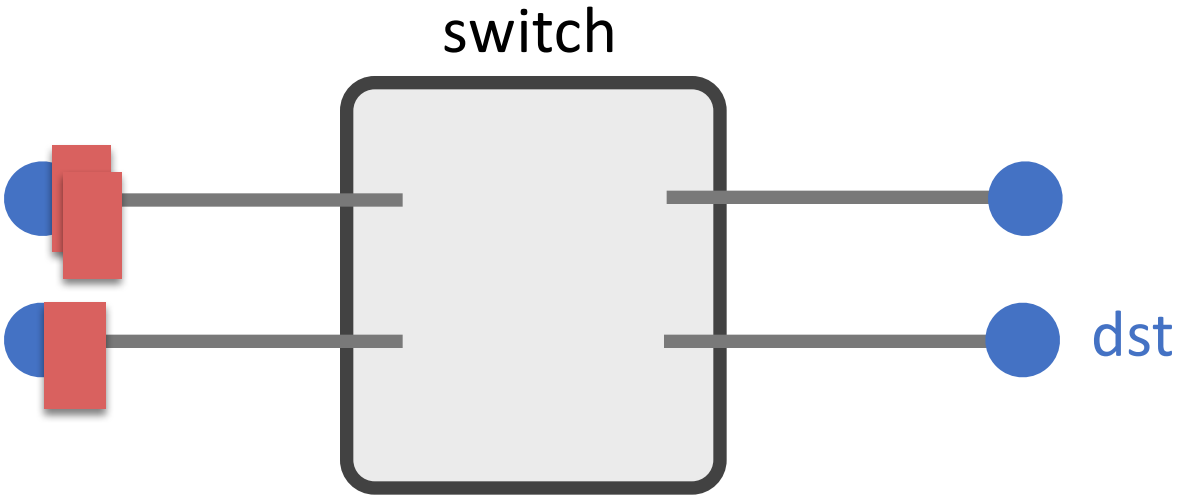
Timing in circuit switching



Circuit switching

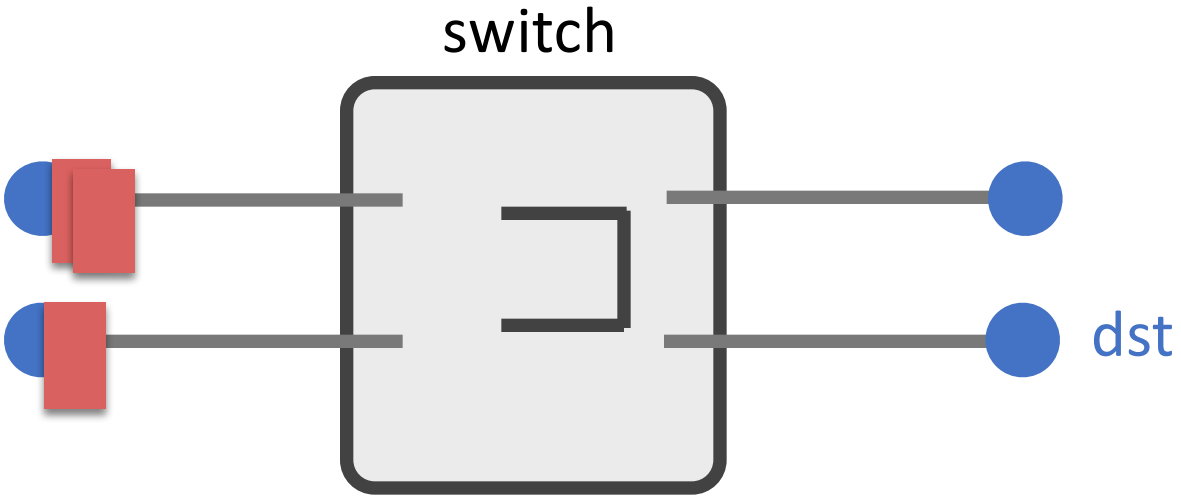
- **Pros**
  - Predictable performance
  - Simple/fast switching (once circuit established)
- **Cons**
  - Complexity of circuit setup/teardown
  - Inefficient when traffic is bursty
  - Circuit setup adds delay
  - Switch fails → its circuit(s) fails

Packet switching



- Each packet contains destination (dst)
- Each packet treated independently

Packet switching



- Each packet contains destination (dst)
- Each packet treated independently
- With buffers to absolve transient overloads

Packet switching

- **Pros**
  - Efficient use of network resources
  - Simpler to implement
  - Robust: can “route around trouble”
- **Cons**
  - Unpredictable performance
  - Requires buffer management and congestion control

Statistical multiplexing

- **Allowing more demands than the network can handle**
  - Hoping that not all demands are required at the same time
  - Results in unpredictability
  - Works well except for the extreme cases

How do we evaluate a network?

Performance metrics

- **Delay**
- **Loss**
- **Throughput**

Delay

- **How long does it take to send a packet from its source to destination?**

Delay

- **Consists of four components**
  - Transmission delay
  - Propagation delay

  } due to link properties

  - Queuing delay
  - Processing delay

  } due to traffic mix and switch internals

A network link

- **Link bandwidth**
  - Number of bits sent/received per unit time (bits/sec or bps)
- **Propagation delay**
  - Time for one bit to move through the link (seconds)
- **Bandwidth-Delay Product (BDP)**
  - Number of bits "in flight" at any time
- **BDP = bandwidth × propagation delay**

Examples

- **Same city over a slow link:**
  - Bandwidth: ~100Mbps
  - Propagation delay: ~0.1msec
  - BDP: 10,000bits (1.25KBytes)

- **Cross-country over fast link:**
  - Bandwidth: ~10Gbps
  - Propagation delay: ~10msec
  - BDP: 10^8bits (12.5MBytes)

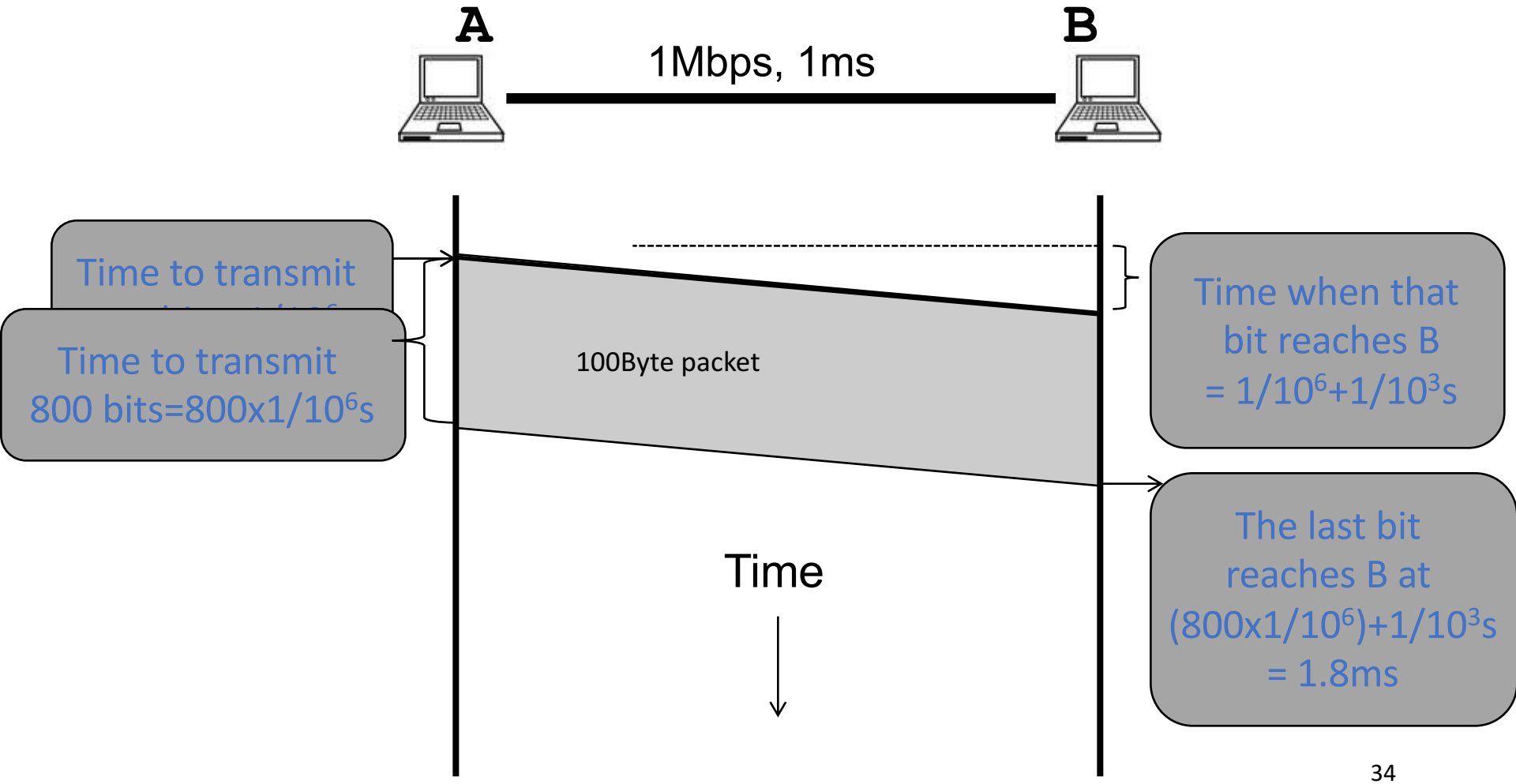
1. Transmission delay

- **How long does it take to push all the bits of a packet into a link?**
- **Packet size / Transmission rate of the link**
  - e.g., 1000 bits / 100 Mbits per sec = 10^{-5} sec

2. Propagation delay

- **How long does it take to move one bit from one end of a link to the other?**
- **Link length / Propagation speed of link**
  - E.g., 30 kilometers / $3*10^8$ meters per sec = 10^{-4} sec

Packet delay
Sending a 100-byte packet



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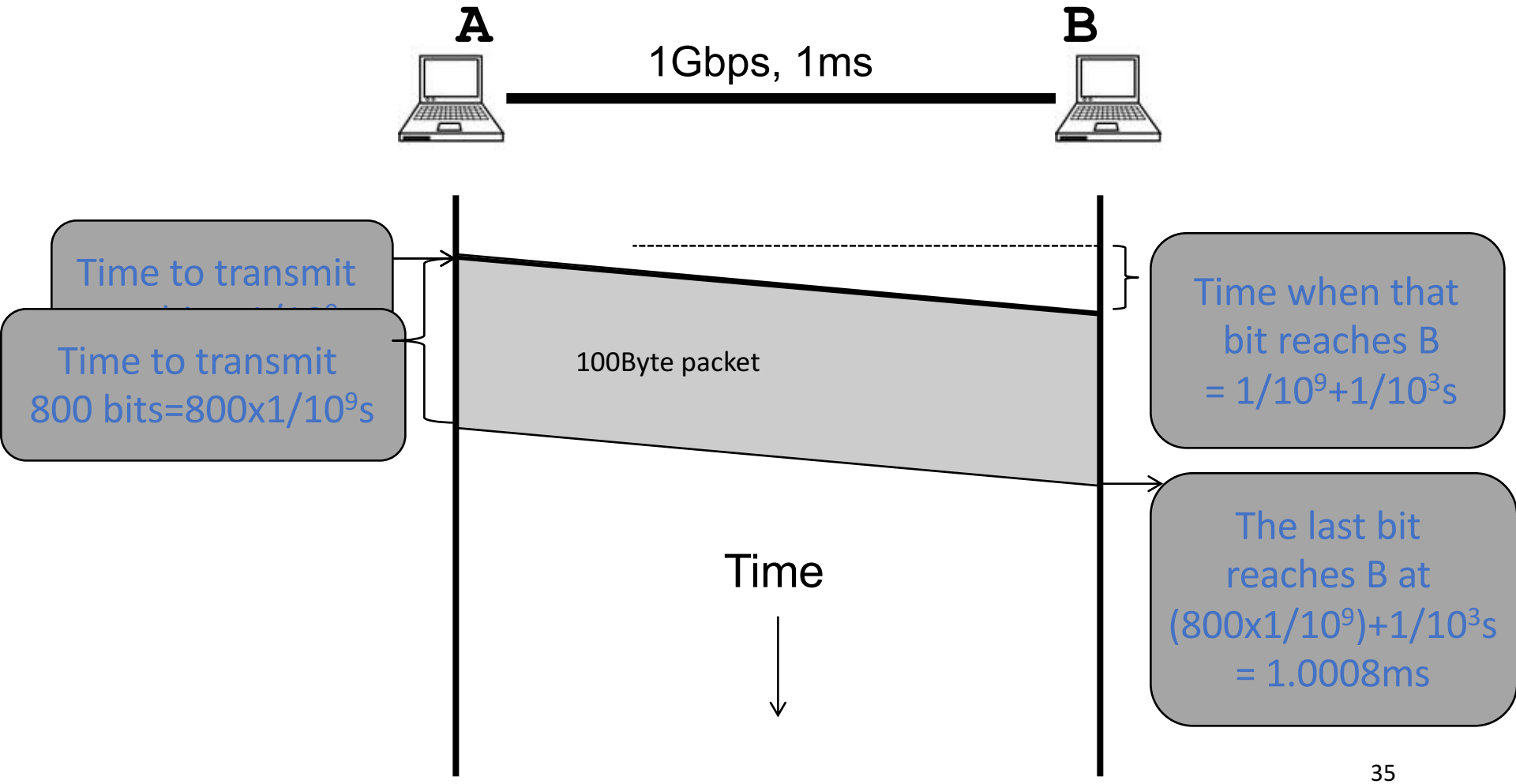
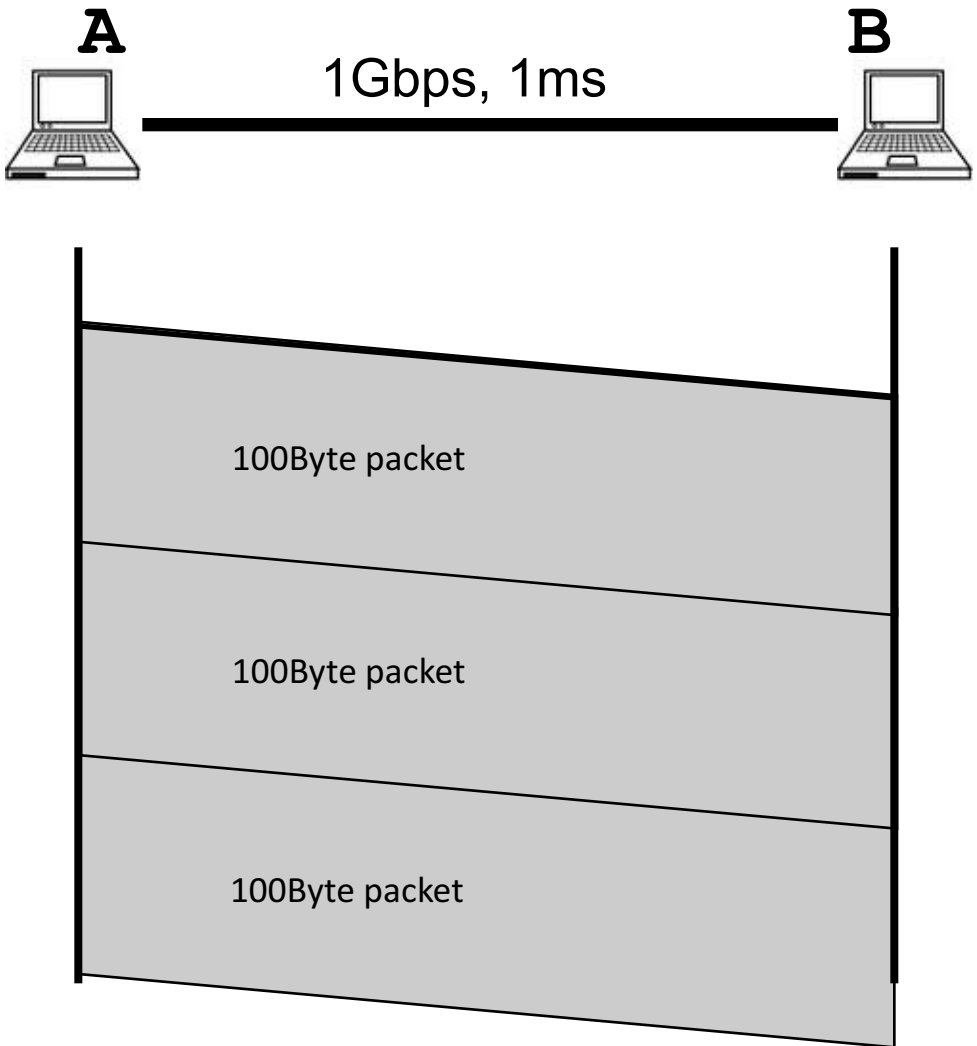
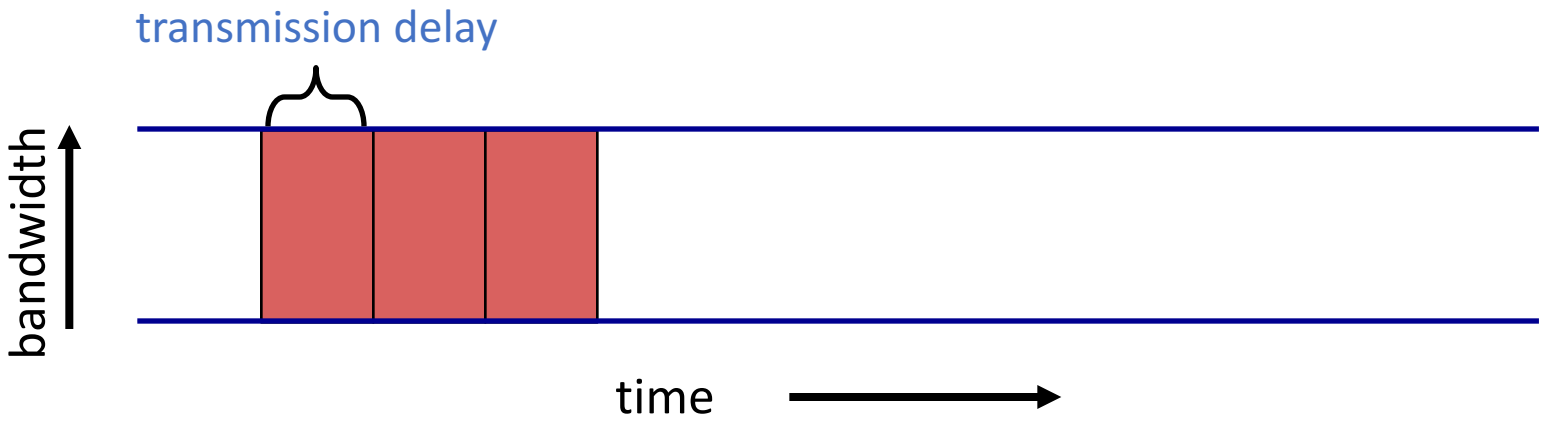


Sending a large file using 100-byte packets



Pipe view of a link

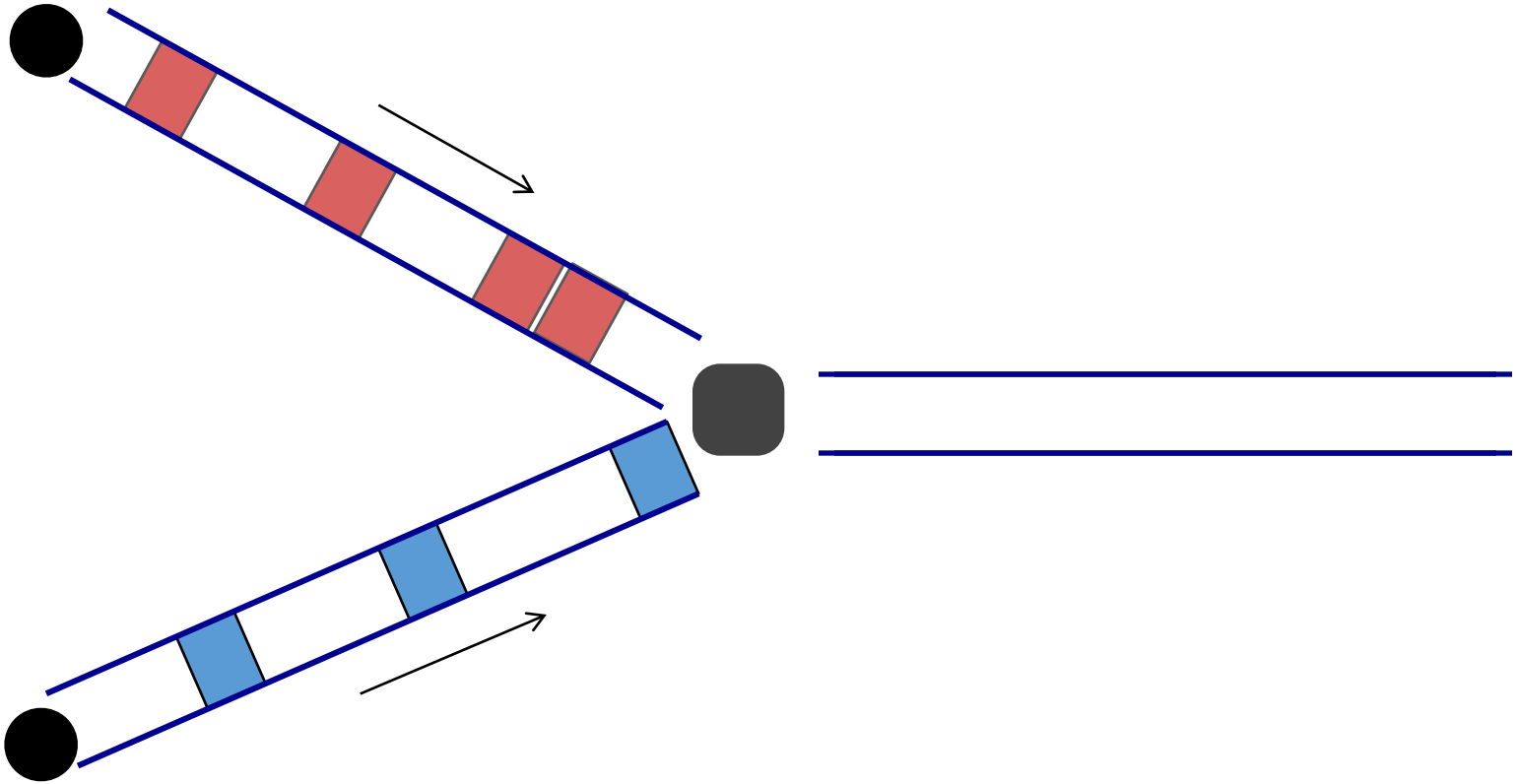


- **Transmission delay decreases as bandwidth increases**

3. Queuing delay

- **How long does a packet have to sit in a buffer before it is processed?**

Queueing delay: “pipe” view



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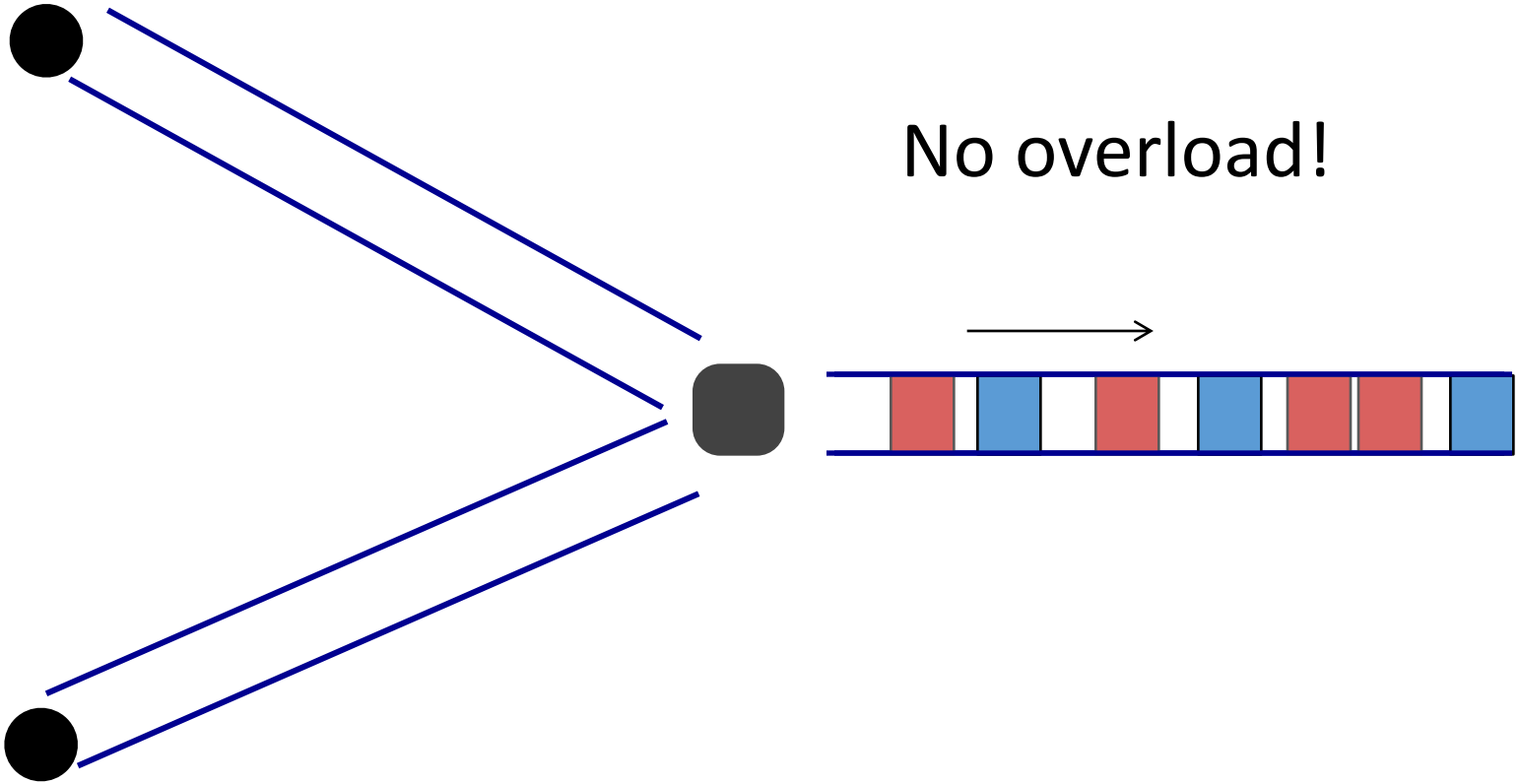
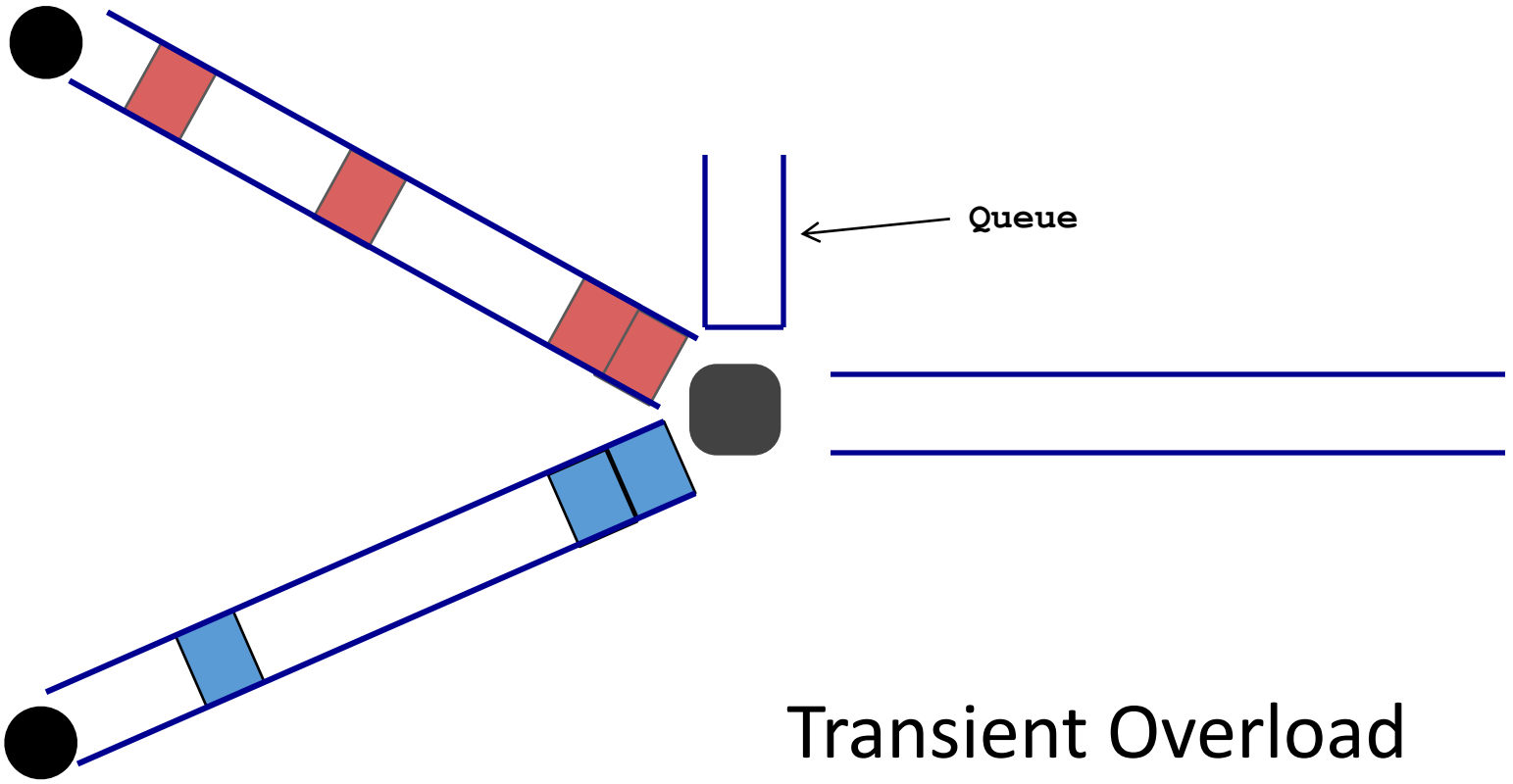


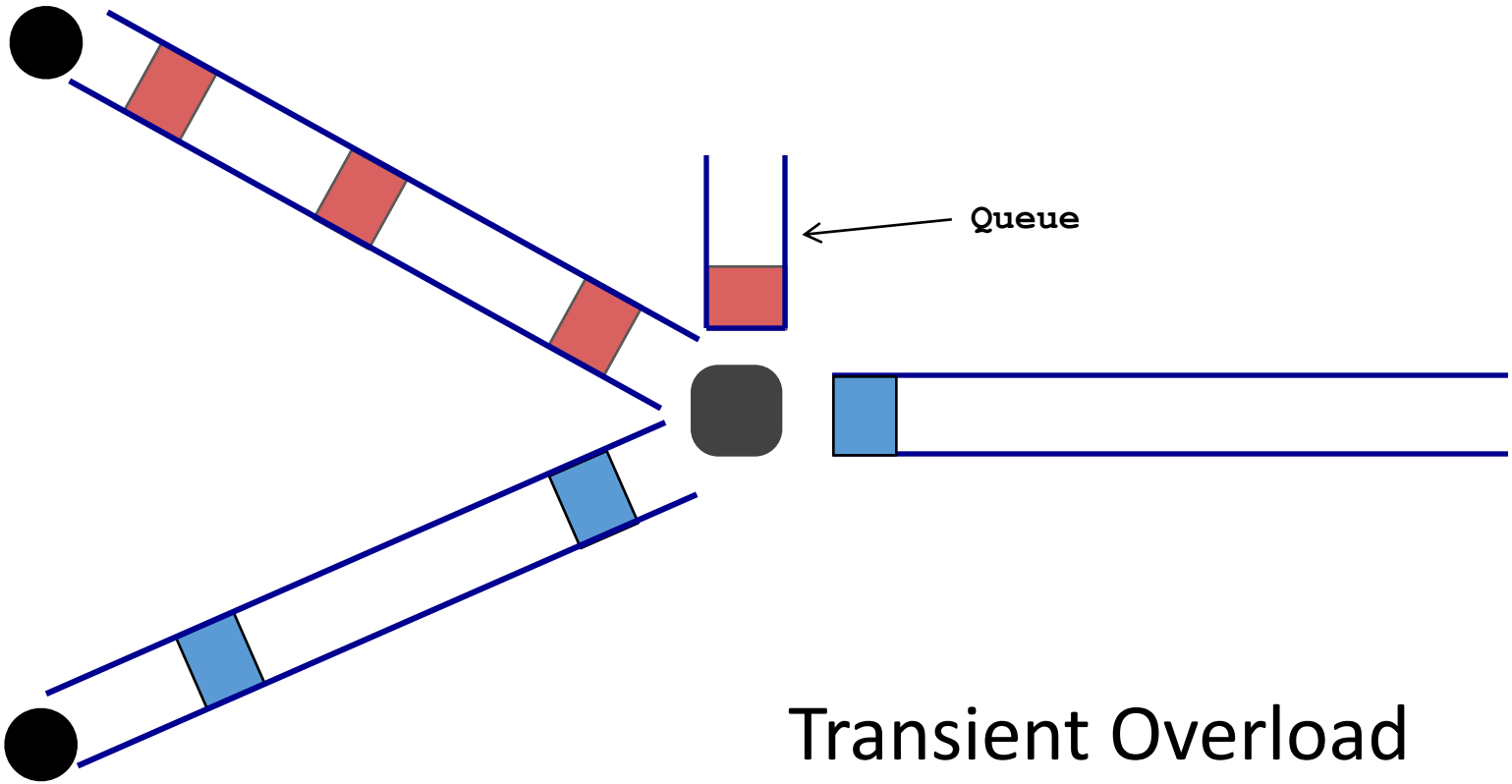
Queueing delay: “pipe” view



Transient Overload

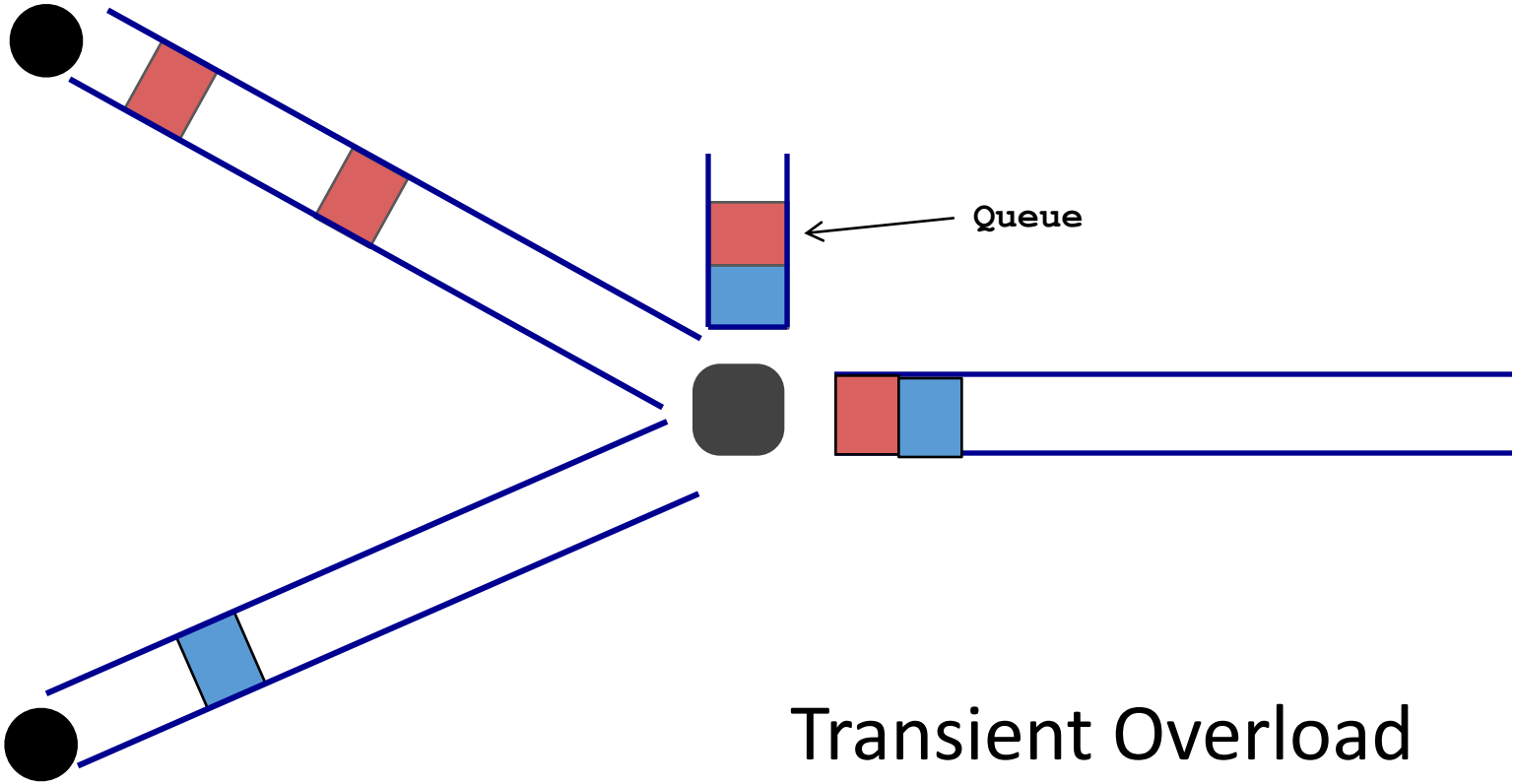
Not a rare event!

Queueing delay: “pipe” view



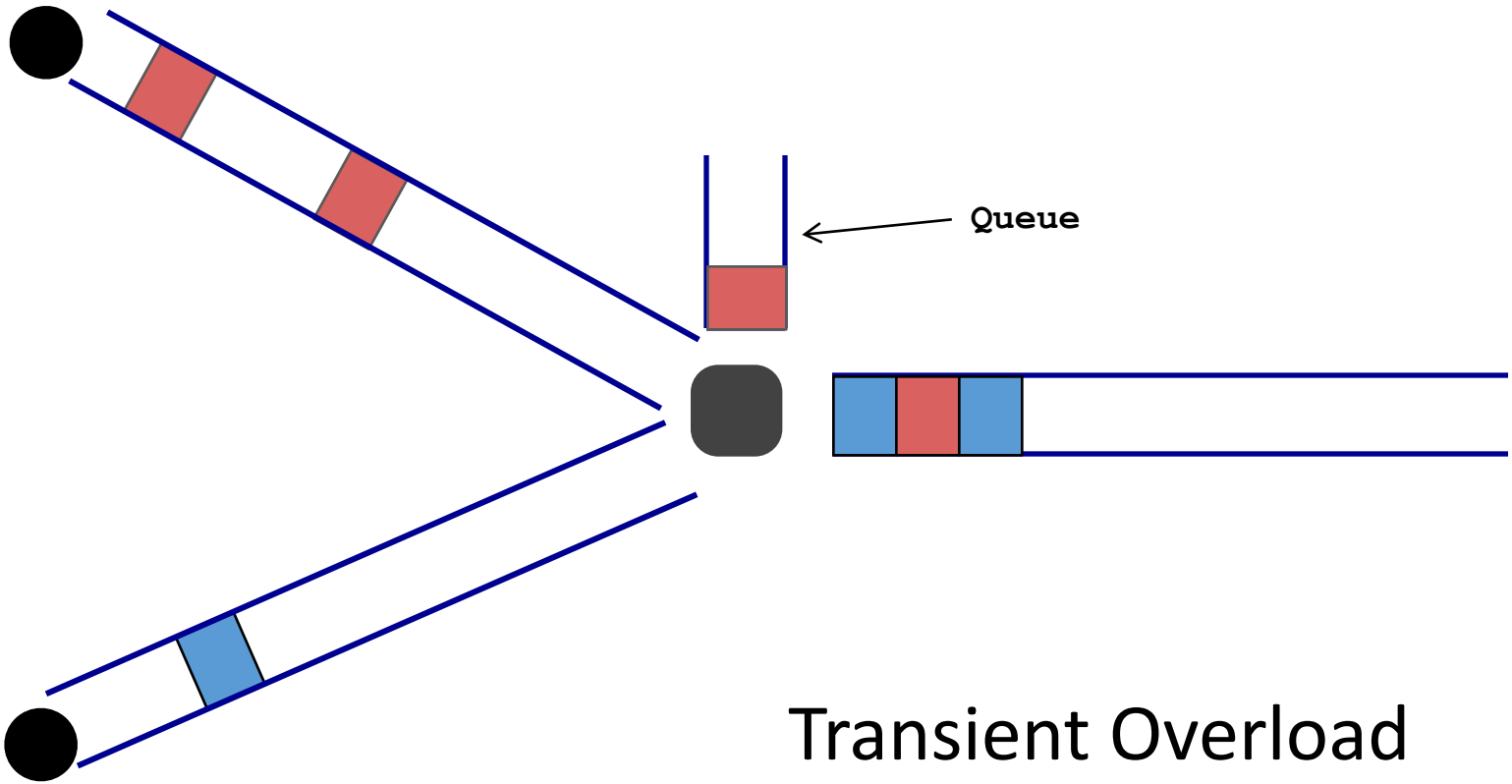
Transient Overload

Queueing delay: “pipe” view



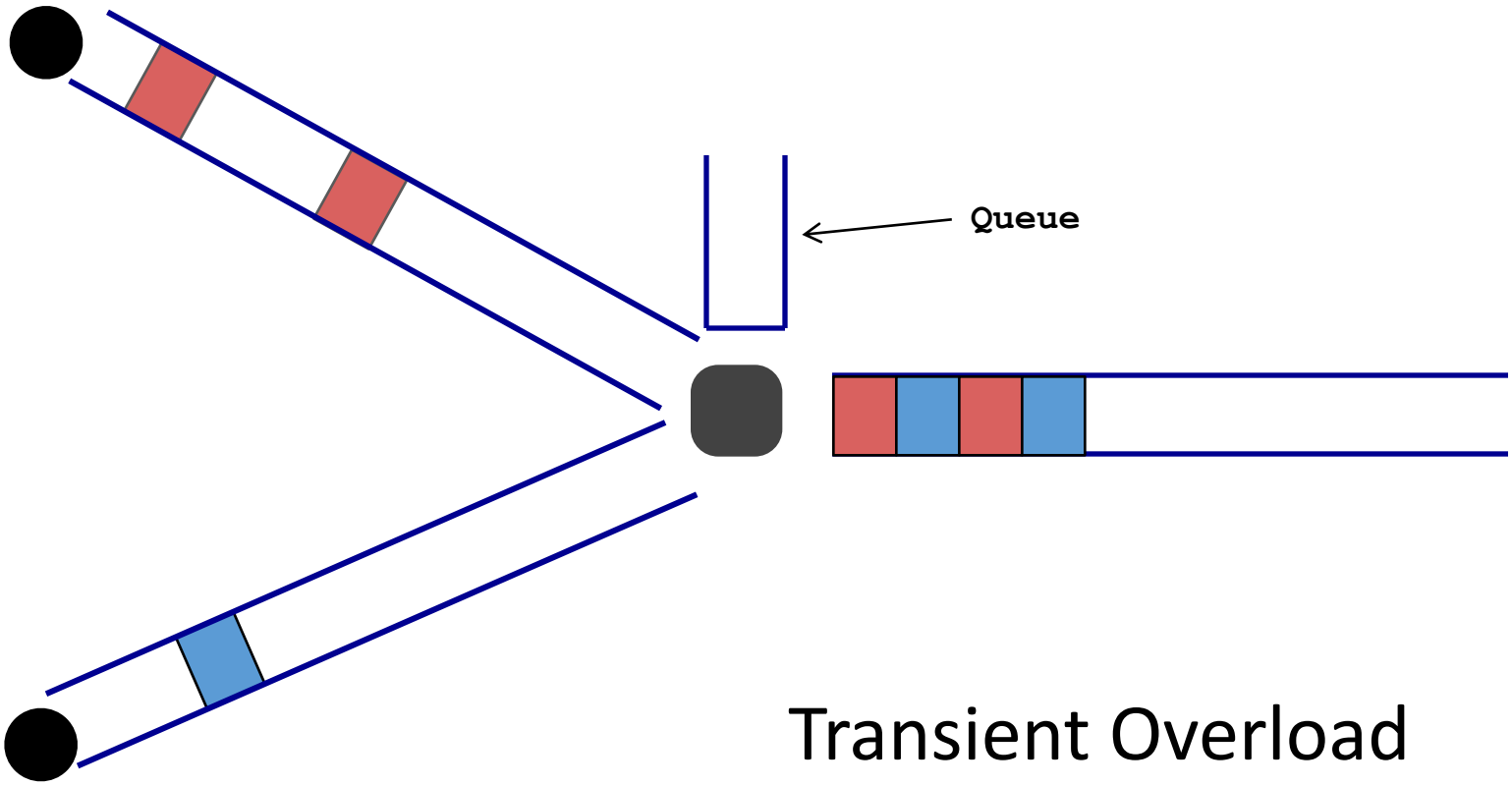
Transient Overload

Queueing delay: “pipe” view



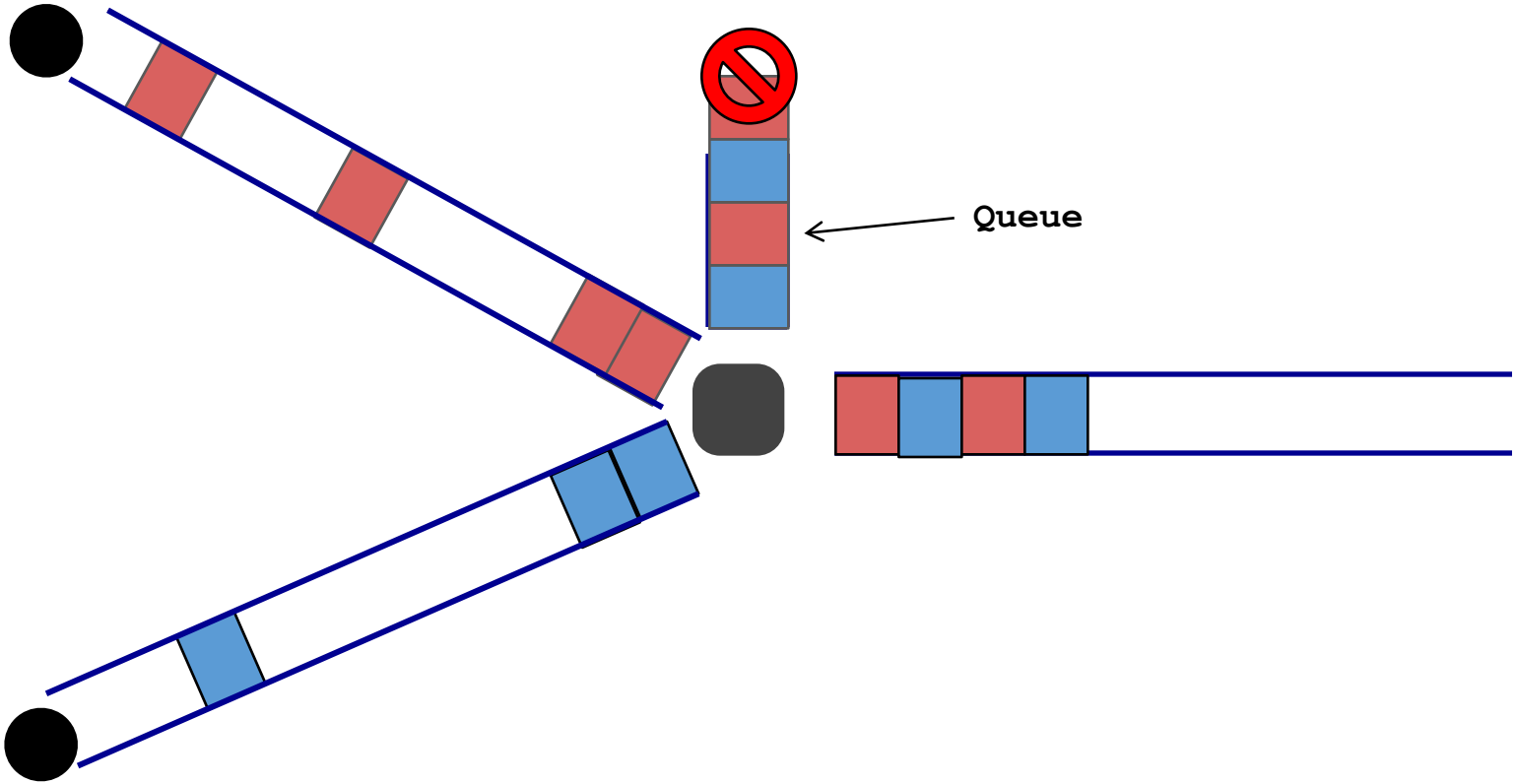
Transient Overload

Queueing delay: “pipe” view



Transient Overload

Persistent overload leads to packet loss



Queueing delay

- **How long does a packet have to sit in a buffer before it is processed?**

- **Depends on traffic pattern**
  - Arrival rate at the queue
  - Nature of arriving traffic (bursty or not?)
  - Transmission rate of outgoing link

Queueing delay

- **How long does a packet have to sit in a buffer before it is processed?**

- **Characterized with statistical measures**
  - Average queuing delay
  - Variance of queuing delay
  - Probability delay exceeds a threshold value

Queueing delay

- **The packet size is 1500 bytes. The link bandwidth is 10Gb/s. Assume the buffer size in the router is 10 packets. What is the maximum queueing delay?**
  - Transmission delay for one packet: $1500 \times 8 / (10 \times 10^9) = 1.2$ ms
  - Queueing delay: $9 \times 1.2 = 10.8$ ms

Basic queueing theory terminology

- **Arrival process: how packets arrive**
  - Average rate A
  - Peak rate P
- **W: average time packets wait in the queue**
  - W for “waiting time”
- **L: average number of packets waiting in the queue**
  - L for “length of queue”

Little's Law (1961)

- **L = A x W**

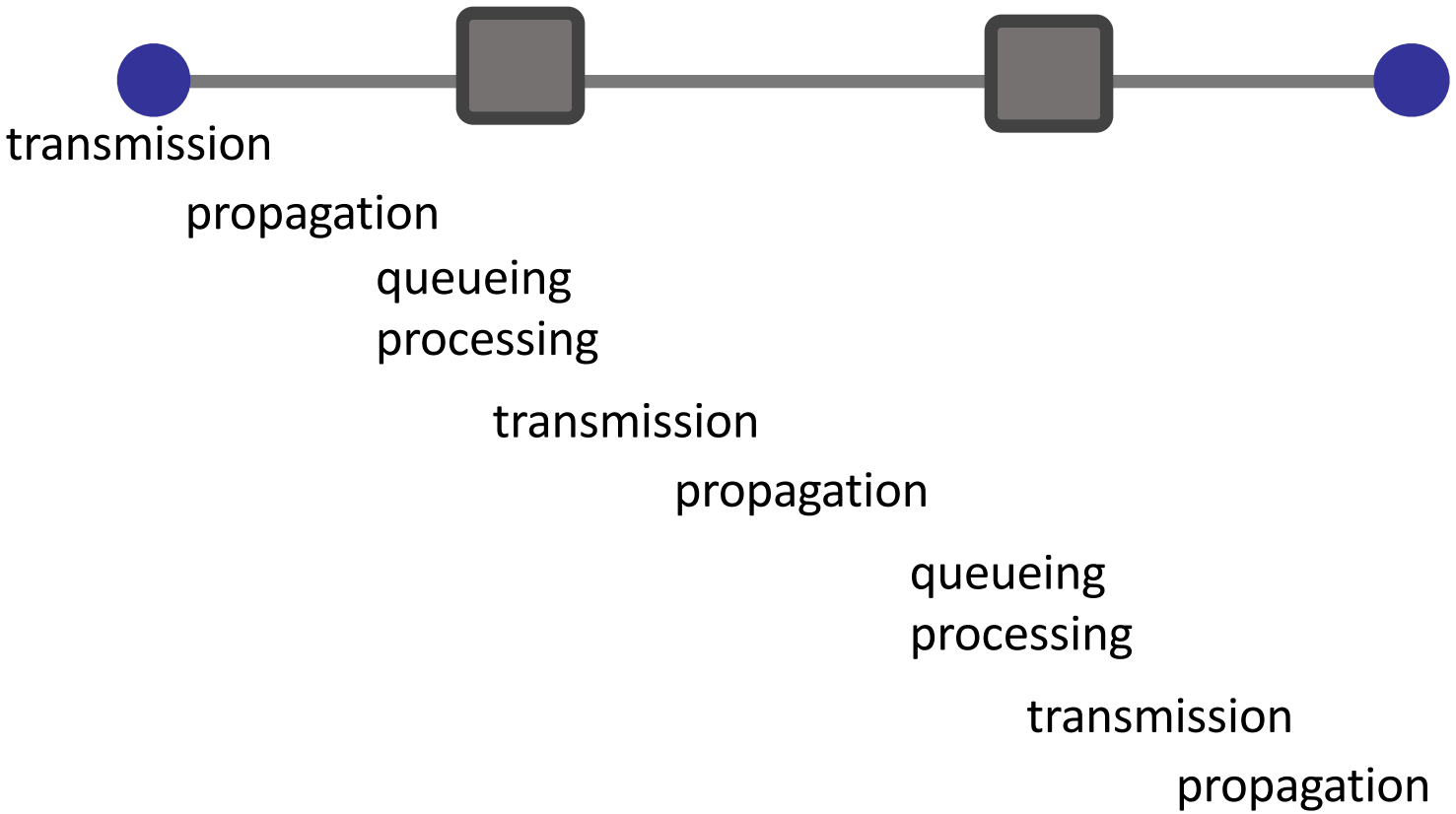
- **Compute L: count packets in queue every second**
  - How often does a single packet get counted? W times

- **Why do you care?**
  - Easy to compute L, harder to compute W

4. Processing Delay

- **How long does the switch take to process a packet?**
  - Negligible

End-to-end delay



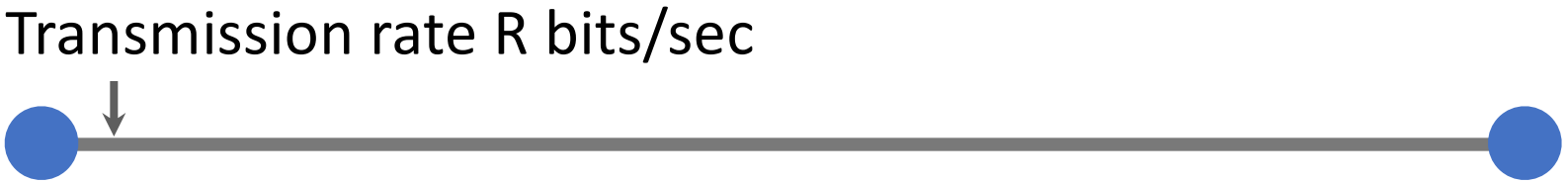
Loss

- **What fraction of the packets sent to a destination are dropped?**

Throughput

- **At what rate is the destination receiving data from the source**

Throughput



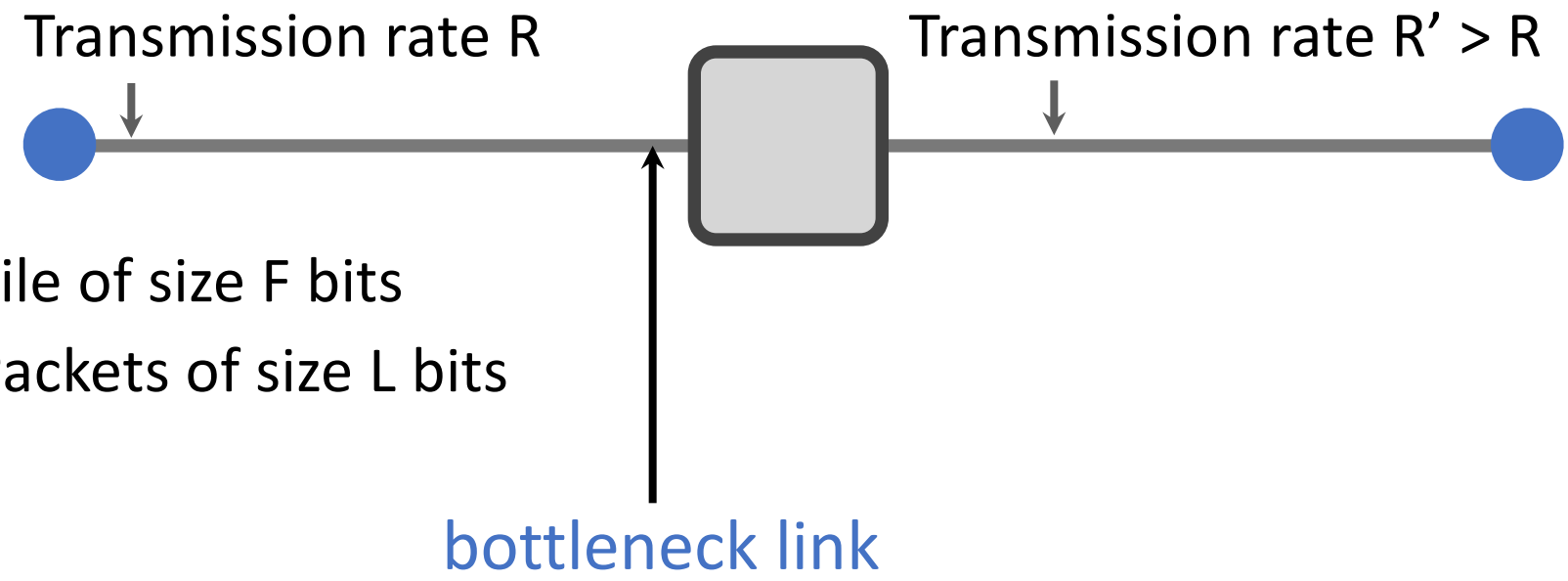
File of size F bits

Packets of size L bits

Transfer time (T) = F/R + propagation delay

Average throughput = F/T ≈ R

End-to-end throughput



Average throughput = **min{R, R'} = R**

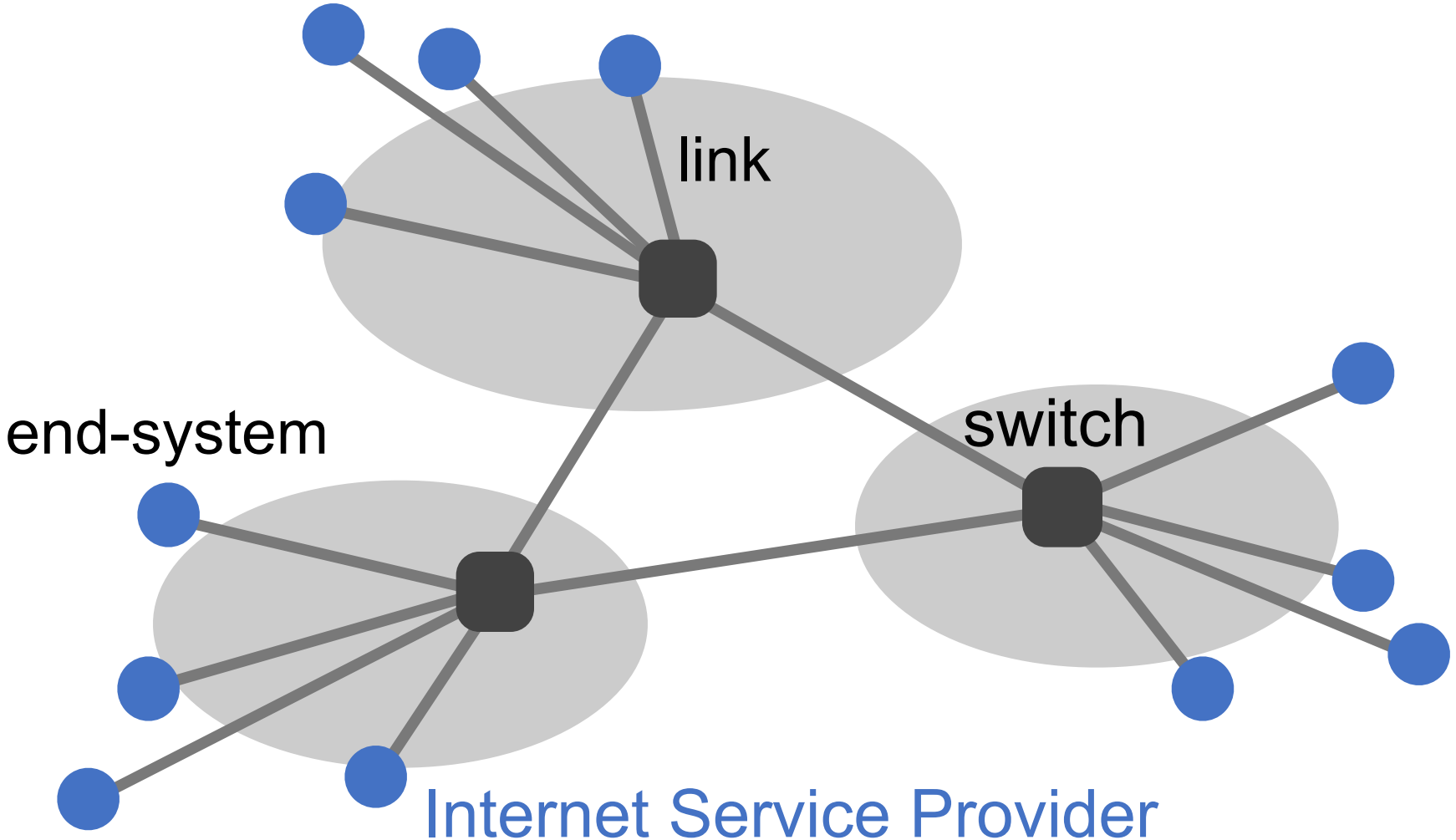
Summary

- **How is it shared?**
  - On-demand or via reservation
- **How do we evaluate a network?**
  - Bandwidth, delay, loss, BDP, …
- **What is a network made of?**
  - Whatever physical infrastructure exist
  - See backup slides

Thanks!
Q&A

What is the network made of?

What is a network made of?



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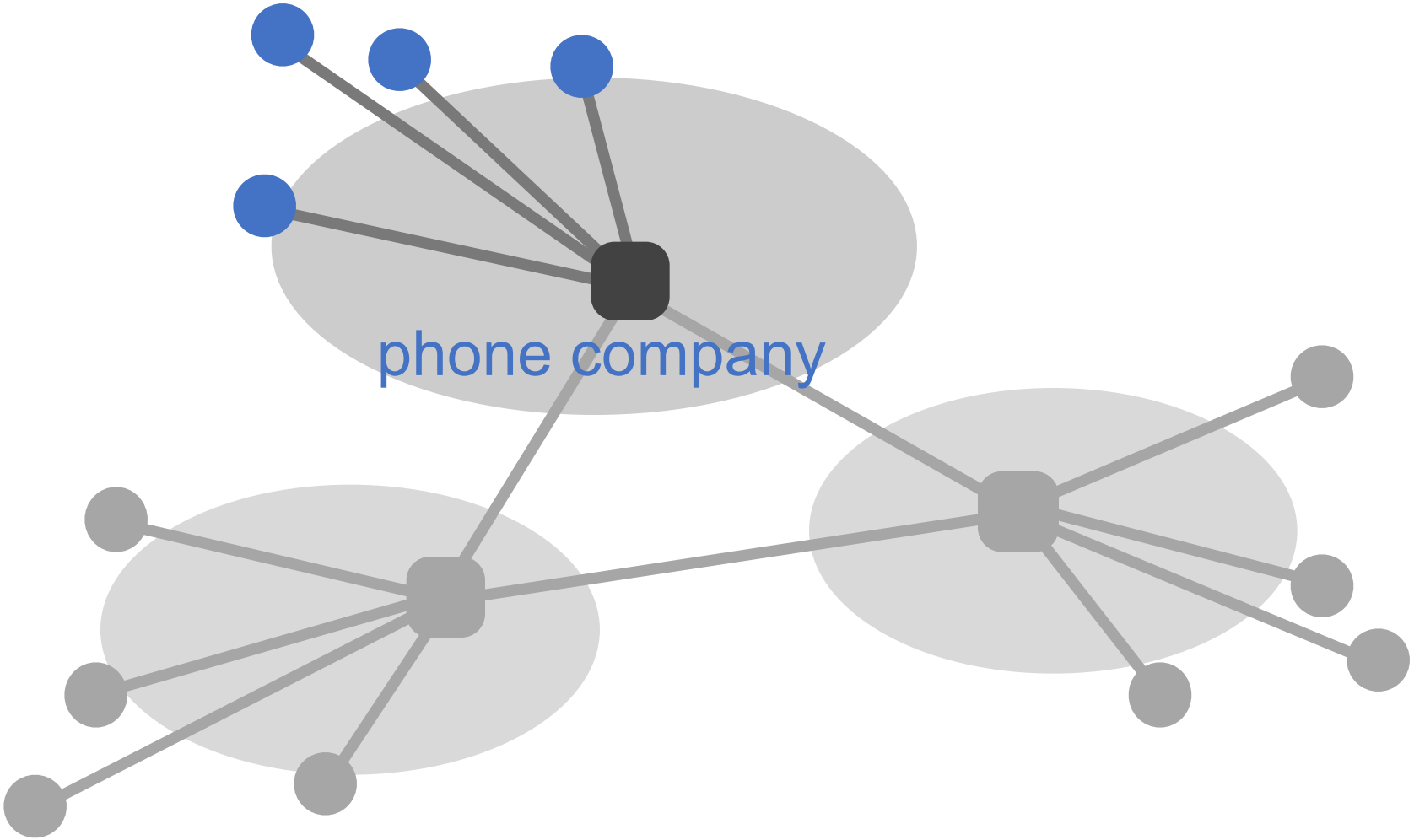

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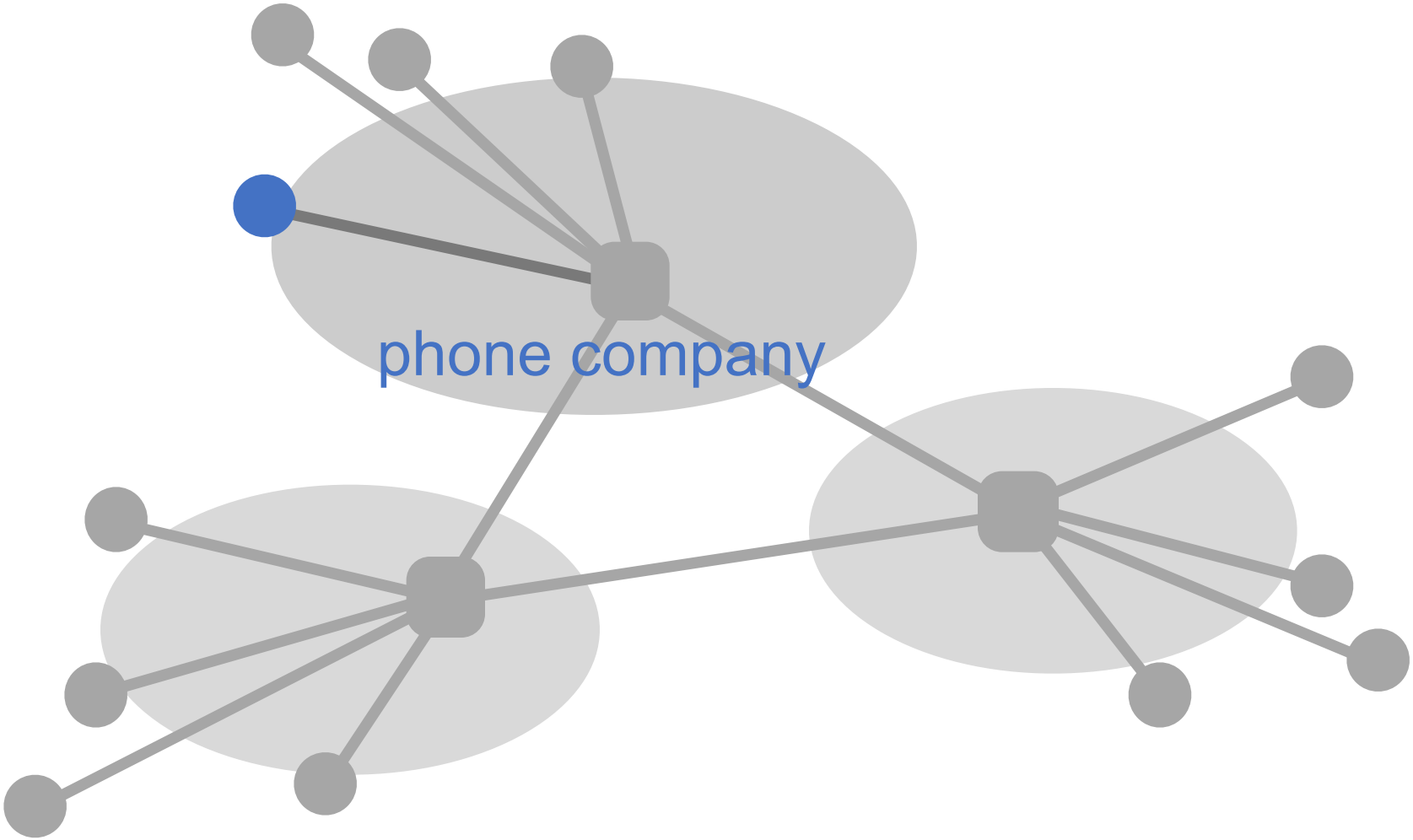
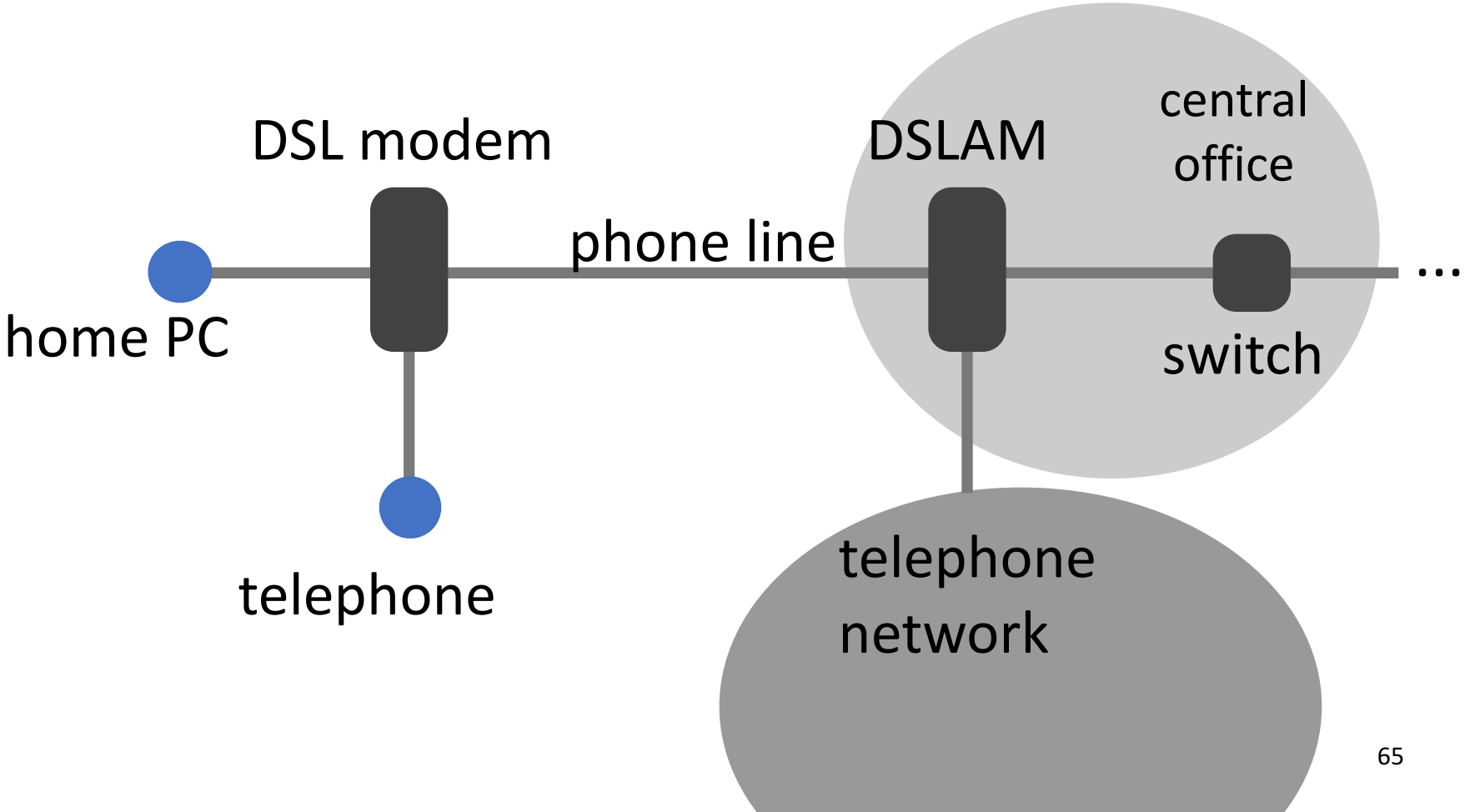


The last hop

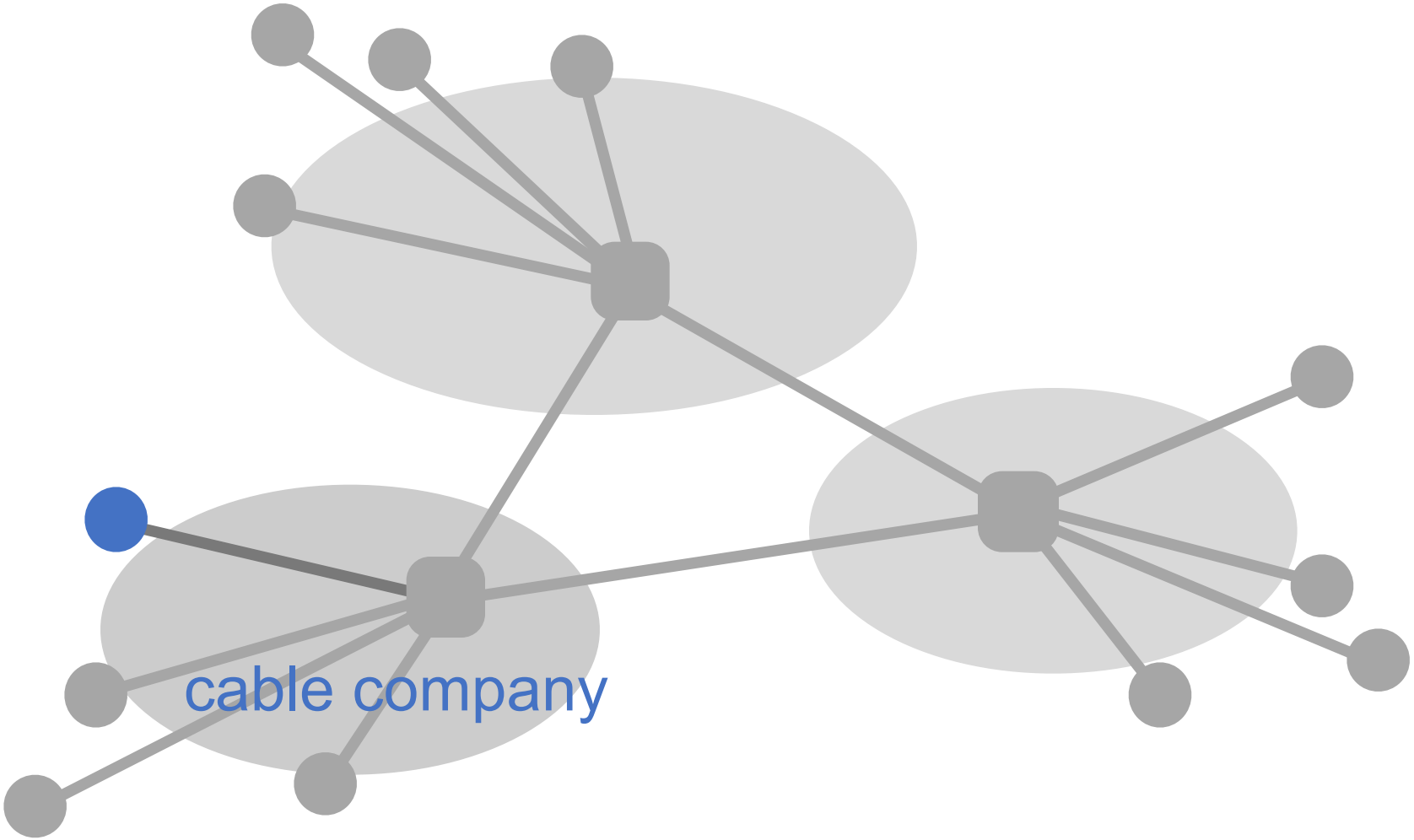
How do we connect?



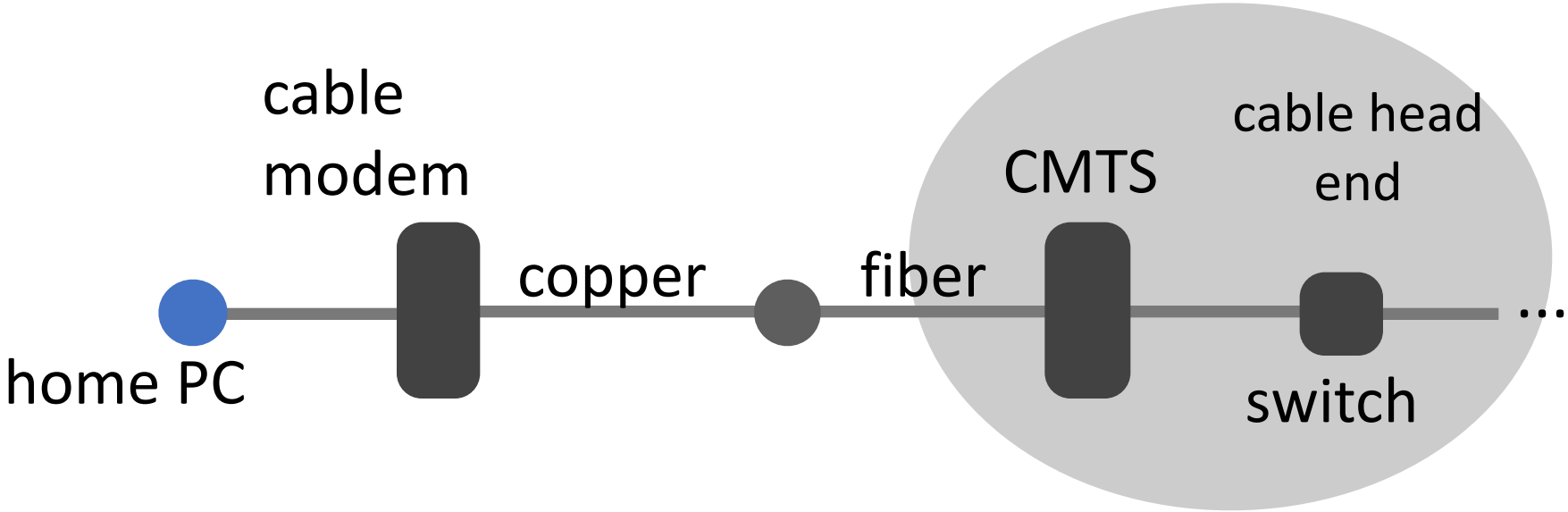
Digital Subscriber Line (DSL)

- **Twisted pair copper**
- **3 separate channels**
  - downstream data channel
  - upstream data channel
  - 2-way phone channel
- **up to 25 Mbps downstream**
- **up to 2.5 Mbps upstream**

How about an cable provider as an ISP?



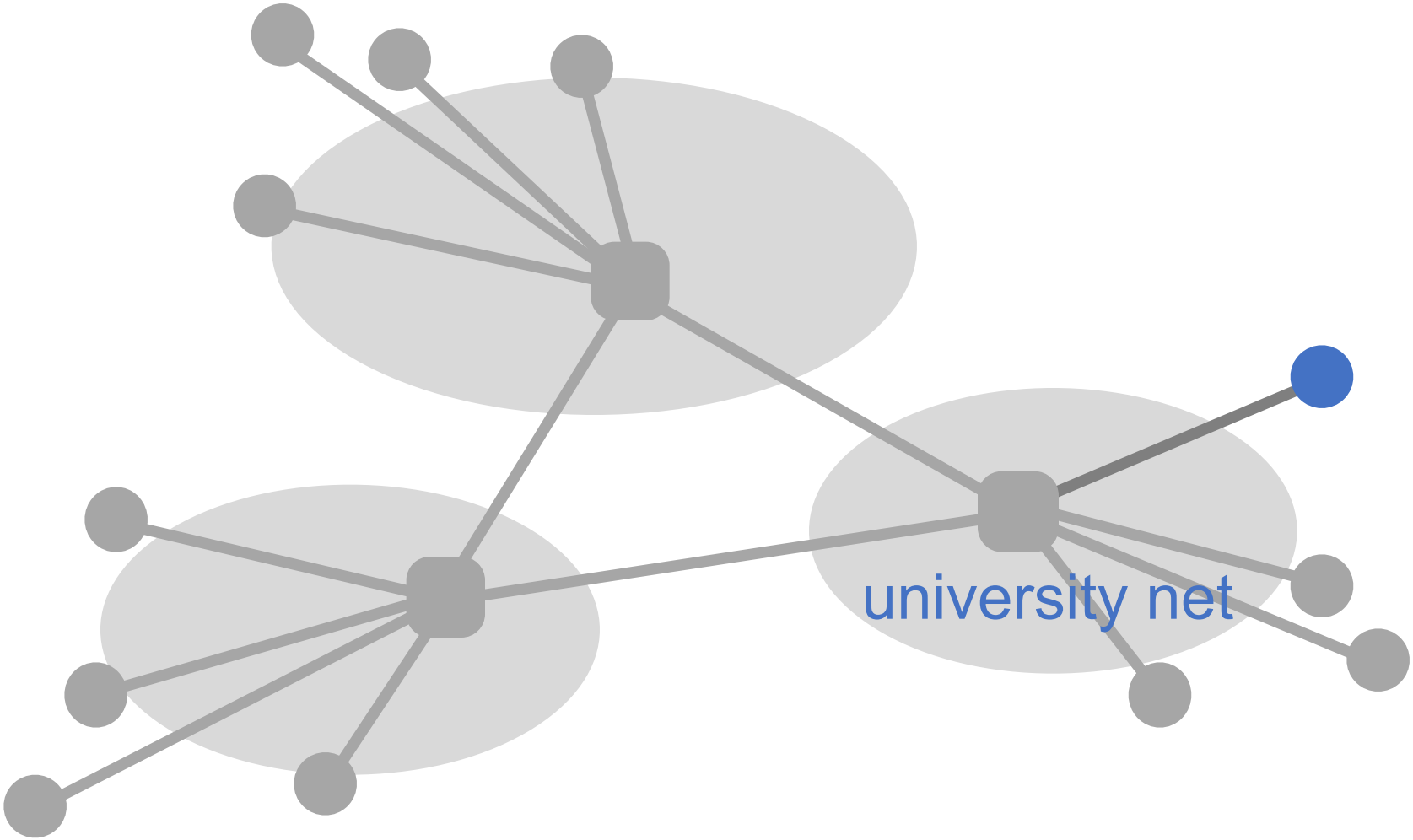
Connecting via cable



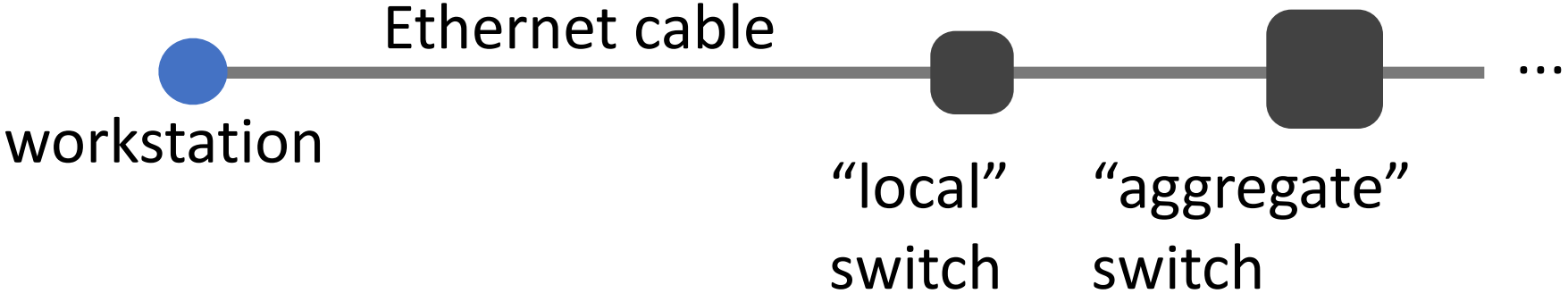
Cable

- **Coaxial copper & fiber**
- **Up to 42.8 Mbps downstream**
- **Up to 30.7 Mbps upstream**
- **Shared broadcast medium**

Any other means?



Ethernet


Ethernet cable
...
workstation
“local” switch
“aggregate” switch

Ethernet

- **Twisted pair copper**
- **100 Mbps, 1 Gbps, 10 Gbps (each direction)**

Many other ways

- **Cellular (smart phones)**
- **Satellite (remote areas)**
- **Fiber to the Home (home)**
- **Optical carrier (Internet backbone)**

Where is WiFi?