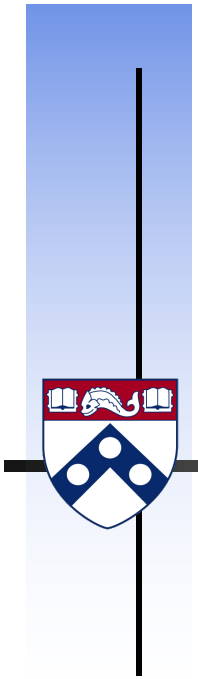


CIS 553: Networked Systems

Physical Layer

January 29, 2020

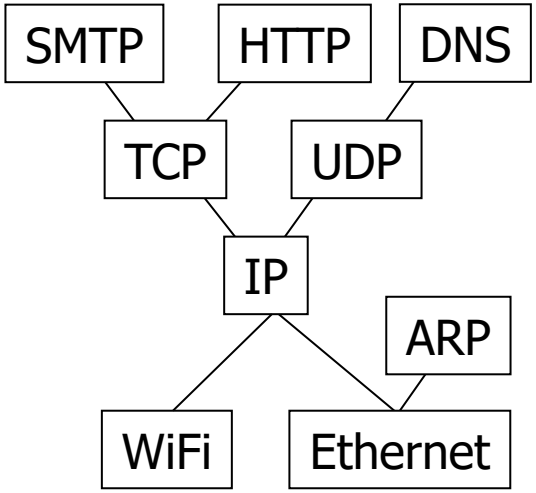
Agenda

- Design goals of the Internet 
  - Taxonomy of networks 
  - Design goals (Clark '88) 
  - Layering and the end-to-end principle 

- Physical Layer
  - Media types
  - Performance metrics

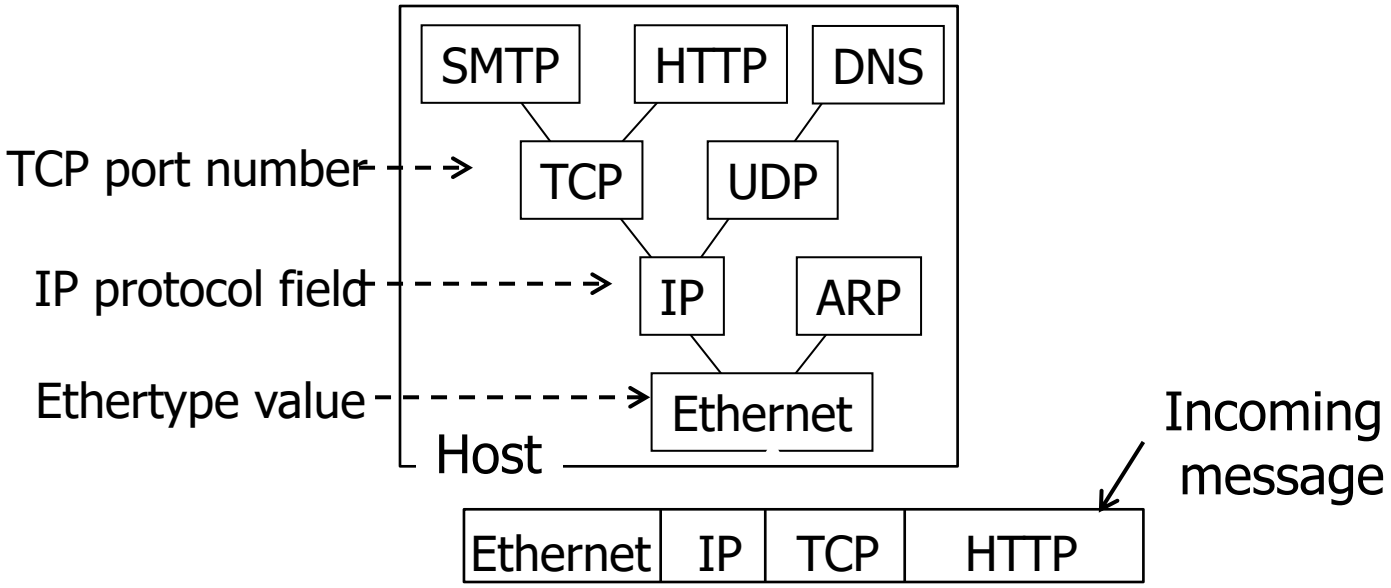
Multiplexing and Demultiplexing

- Outgoing message must be encapsulated with the correct header
- Incoming message must be passed to the protocols that it uses



Demultiplexing (Cont.)

- Done with demultiplexing keys in the headers



Which Layer is Right for Me?

http://web.mit.edu/Saltzer/www/publications/endtoend/endtoend.txt

- Consider file transfer from A's hard drive to B's hard drive over the network
- Transient failures at many levels
  - Disk errors
  - Incorrect software (FS, FTP, network, …)
  - Hardware errors (CPU, memory, network, disk, system crash, …)
- Implementing reliability at lower layers is insufficient!
  - Don't over-engineer if end-to-end checks are still required
  - Not everyone will need it anyway
- Many exceptions and gray areas
  - Performance, cost, engineering, …

E2E rule of thumb in network design

- If hosts can implement functionality correctly, implement it a lower layer only as a performance enhancement
- But do so only if it does not impose burden on applications that do not require that functionality
- Other examples in the paper include encryption, duplicate suppression, etc.

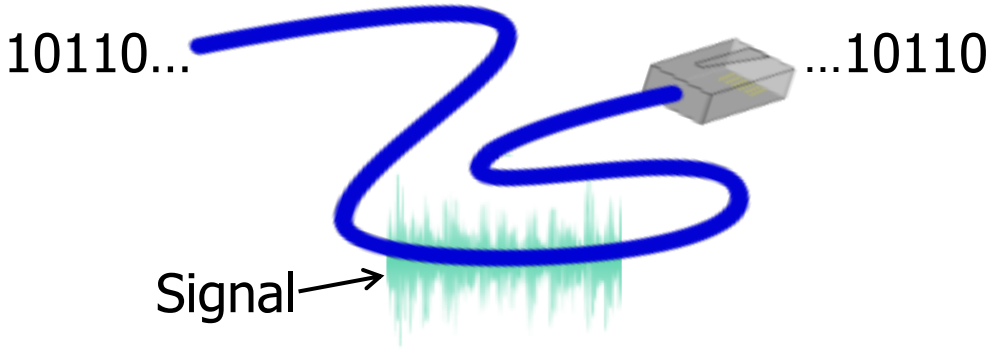
Agenda

- Design goals of the Internet 
  - Layering and the end-to-end principle 
- Physical Layer 

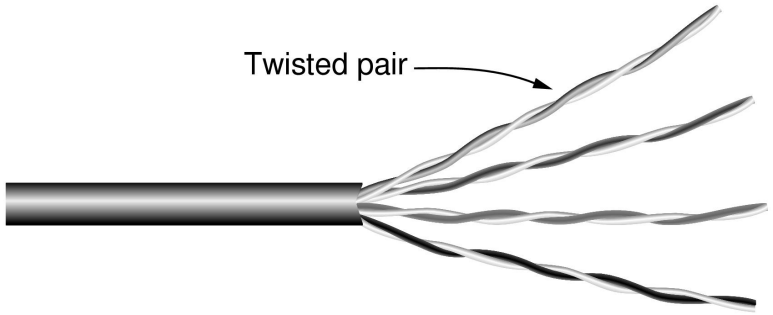
  - Media types
  - Performance Metrics

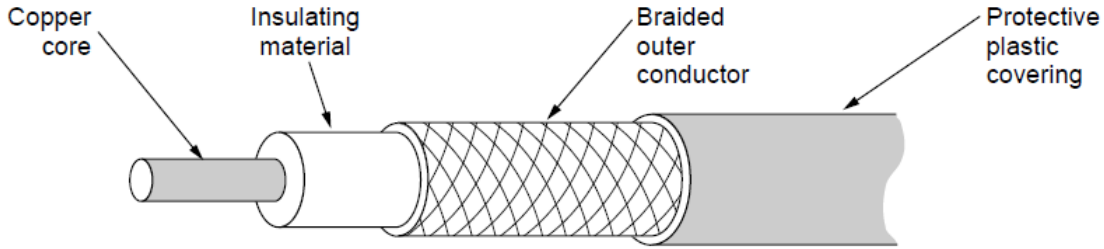
Scope of the Physical Layer

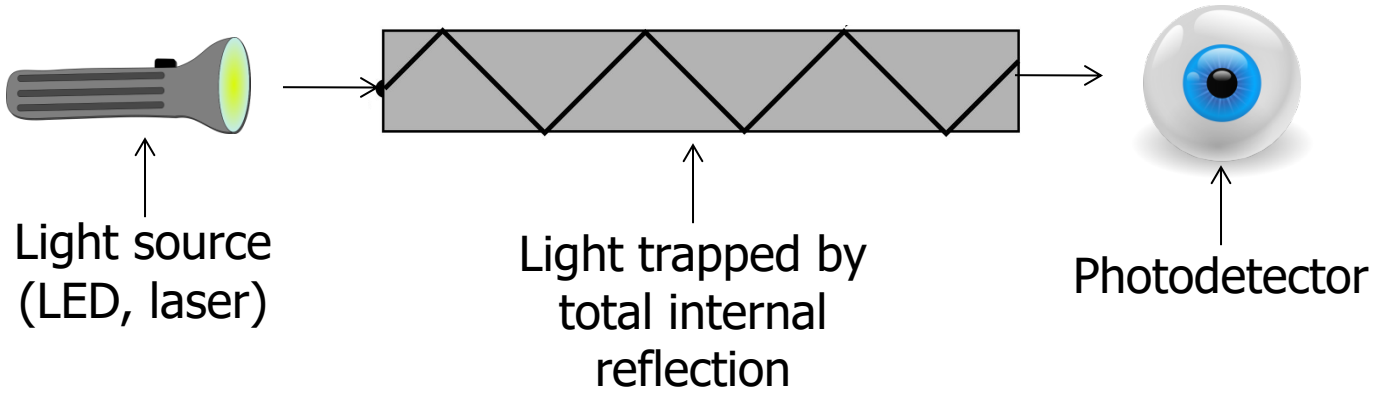
- Concerns how signals are used to transfer message bits over a link
  - Wires etc. carry analog signals
  - We want to send digital bits



Wires

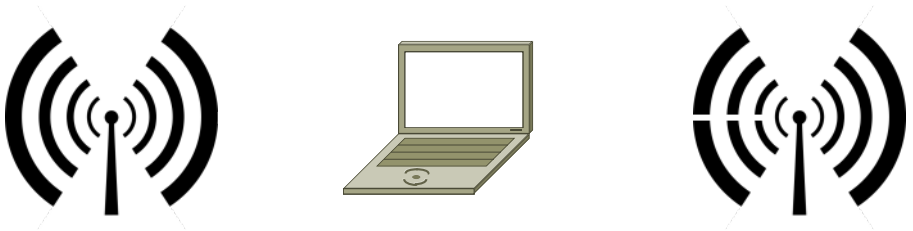

Twisted pair


Copper core
Insulating material
Braided outer conductor
Protective plastic covering


Light source (LED, laser)
Light trapped by total internal reflection
Photodetector

Wireless

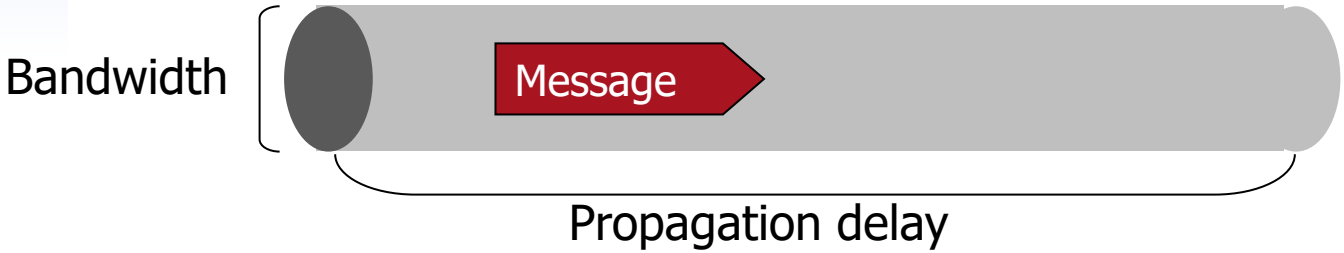
- Sender radiates signal over a region
  - In many directions, unlike a wire, to potentially many receivers
  - Nearby signals (same freq.) interfere at a receiver; need to coordinate use



Agenda

- Design goals of the Internet ✓
  - Layering and the end-to-end principle ✓
- Physical Layer ✓
  - Media types ✓
  - Performance Metrics NEXT

A Simple Model of a Link



Performance metrics:

- Delay (latency)
- Bandwidth (throughput, capacity, speed, etc.)
- Loss rate

- Also:
  - Broadcast vs Not
  - Full Duplex vs Half Duplex vs Simplex
  - SNR
  - etc.

Performance Metric: Latency

- Consists of four components
  - Transmission delay
  - Propagation delay
  - Queuing delay
  - Processing delay

due to link properties

due to traffic mix and switch internals

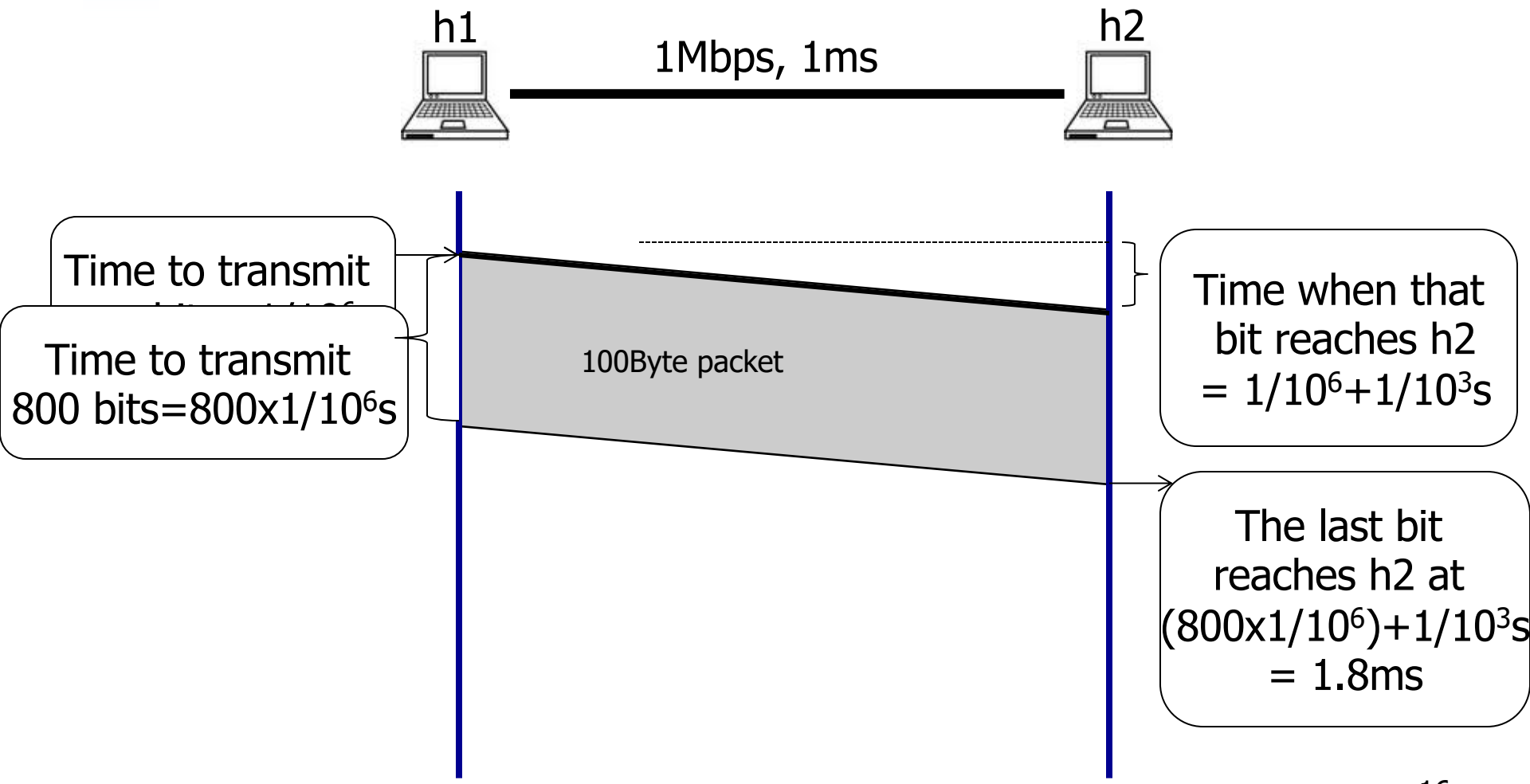
1. Transmission delay

- How long does it take to push all the bits of a message into a link?
- Message size / bandwidth of the link
  - e.g., 1000 bits / 100 Mbits per sec = 10 us

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 = 100 us

Packet delay
Sending a 100-byte packet



Packet delay
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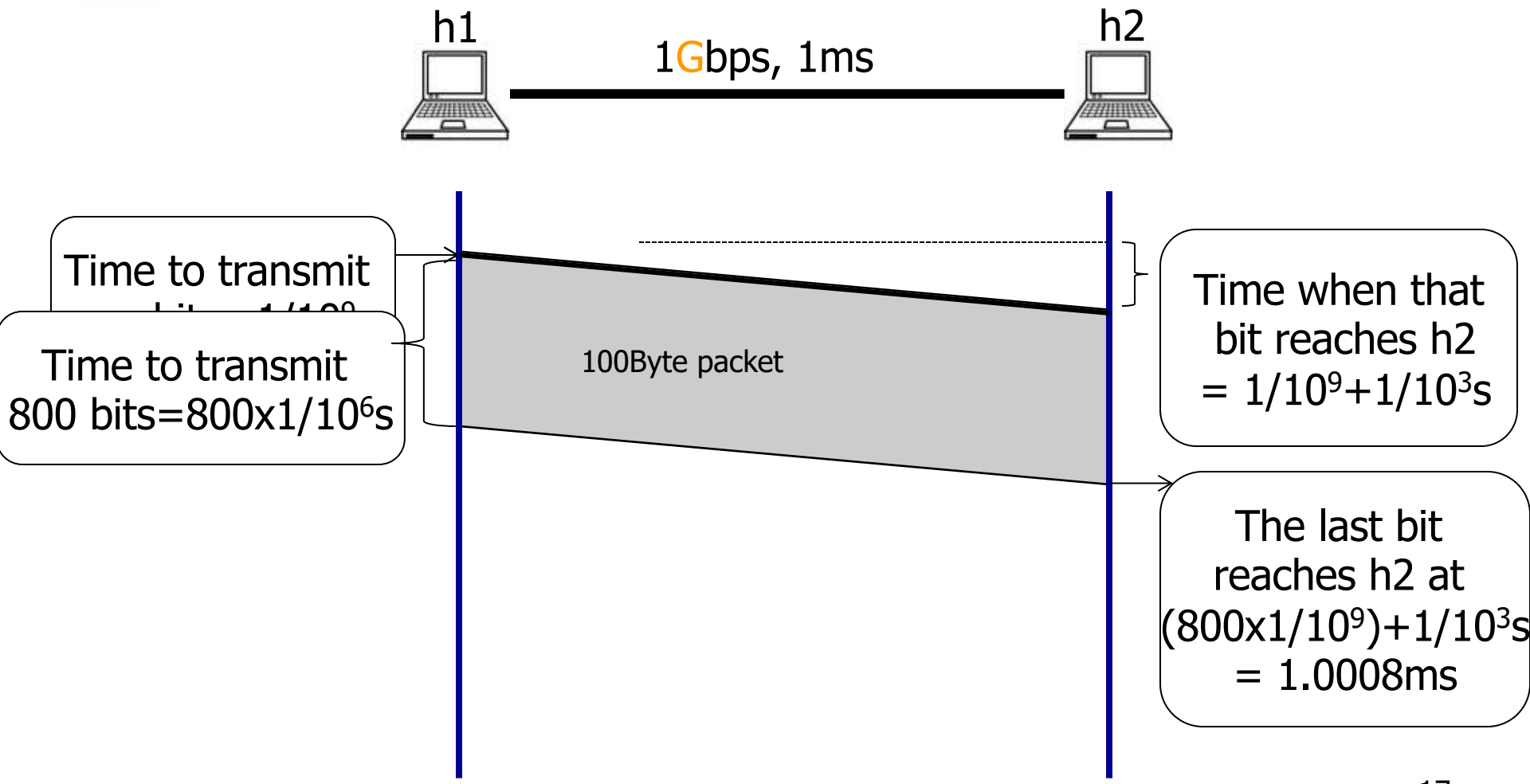
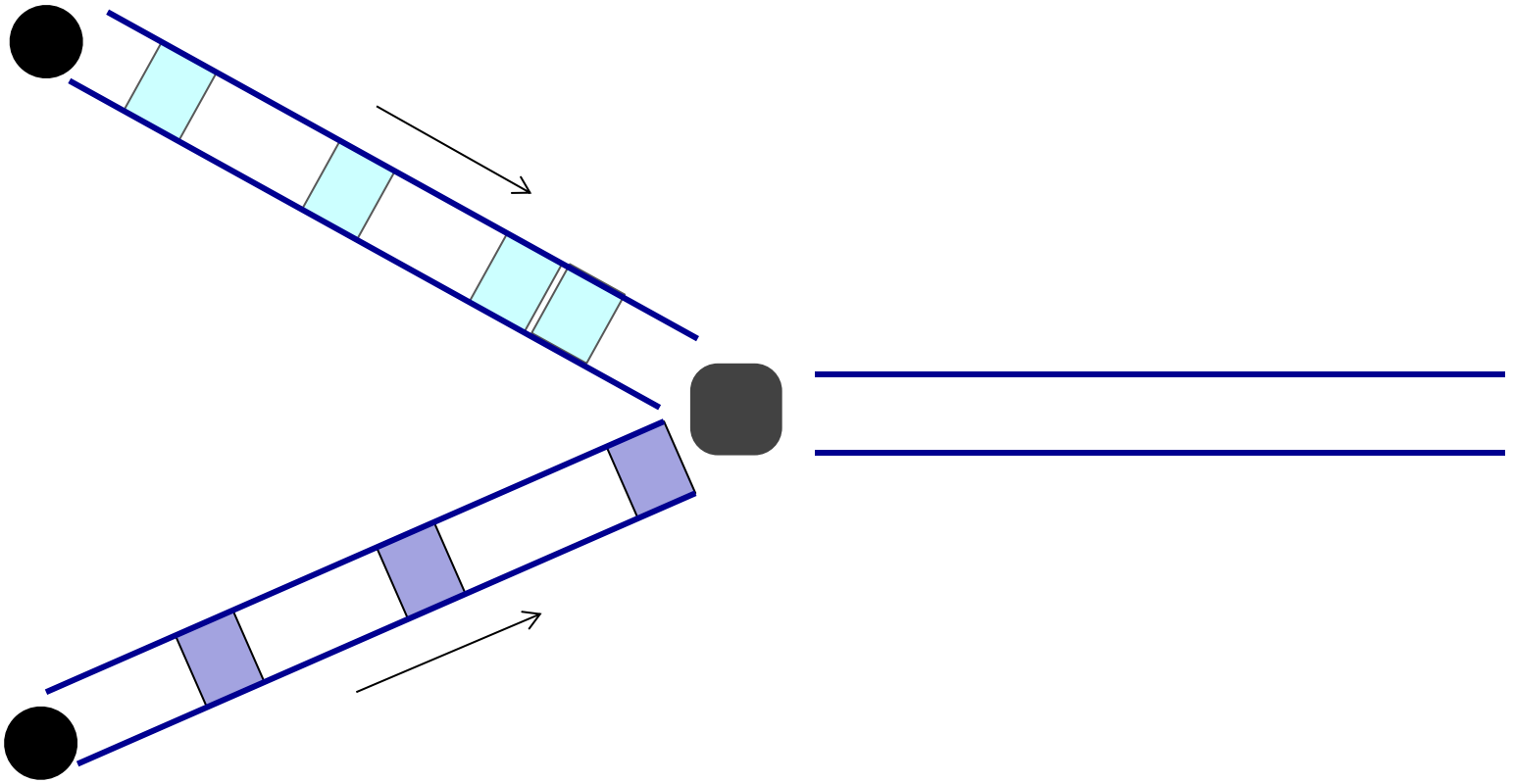


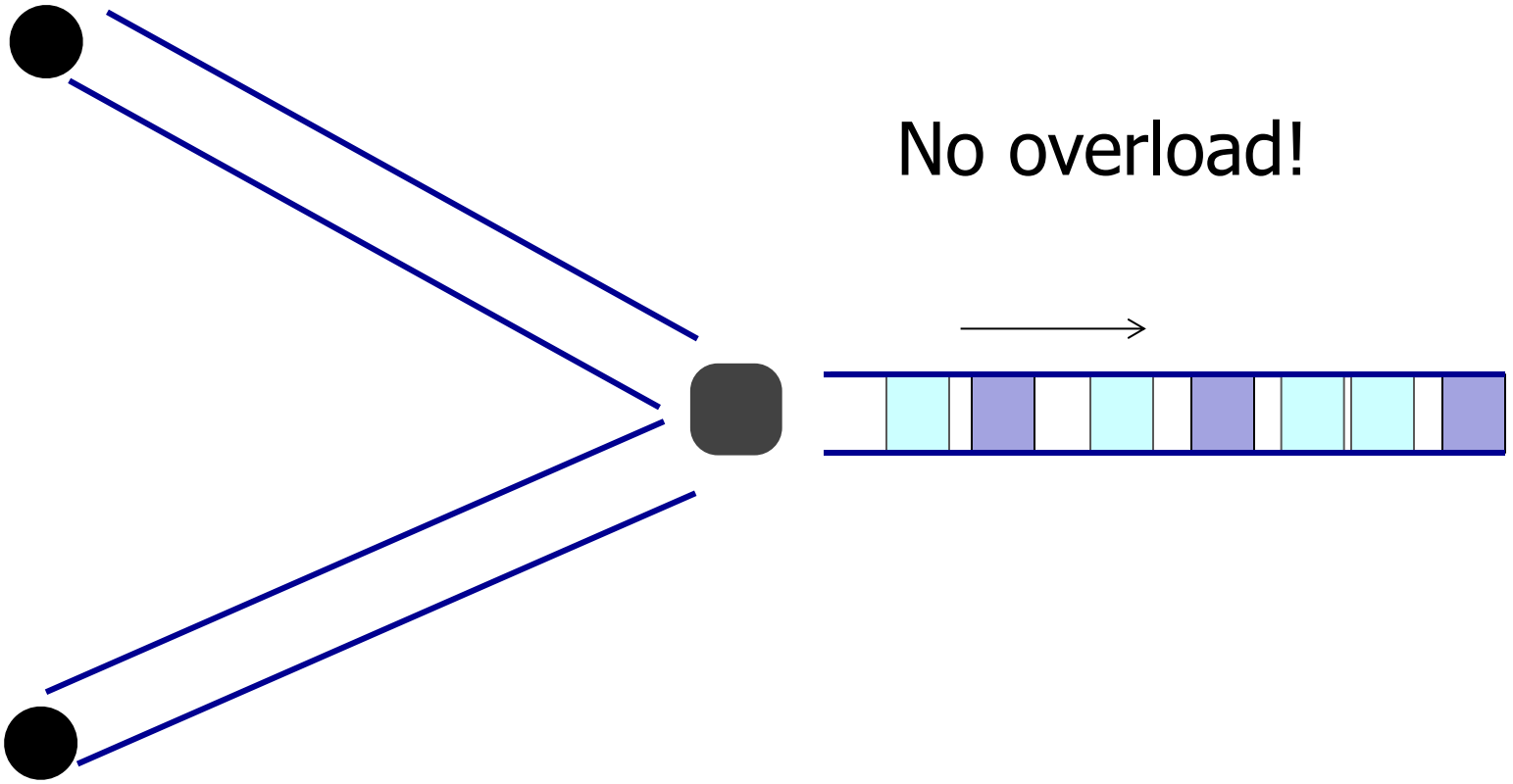
3. Queuing delay

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

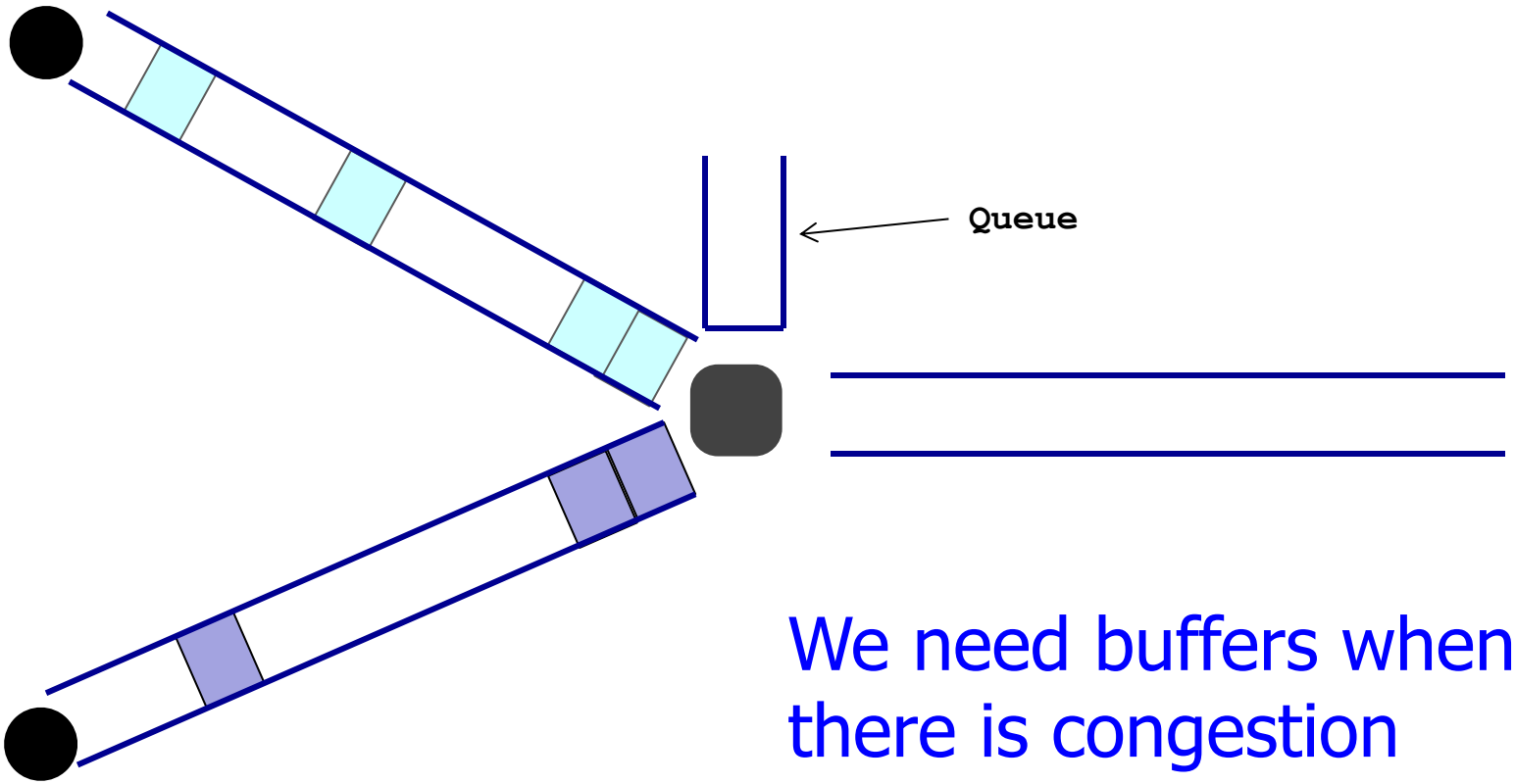
Why Do We Need Buffers?



Why Do We Need Buffers?

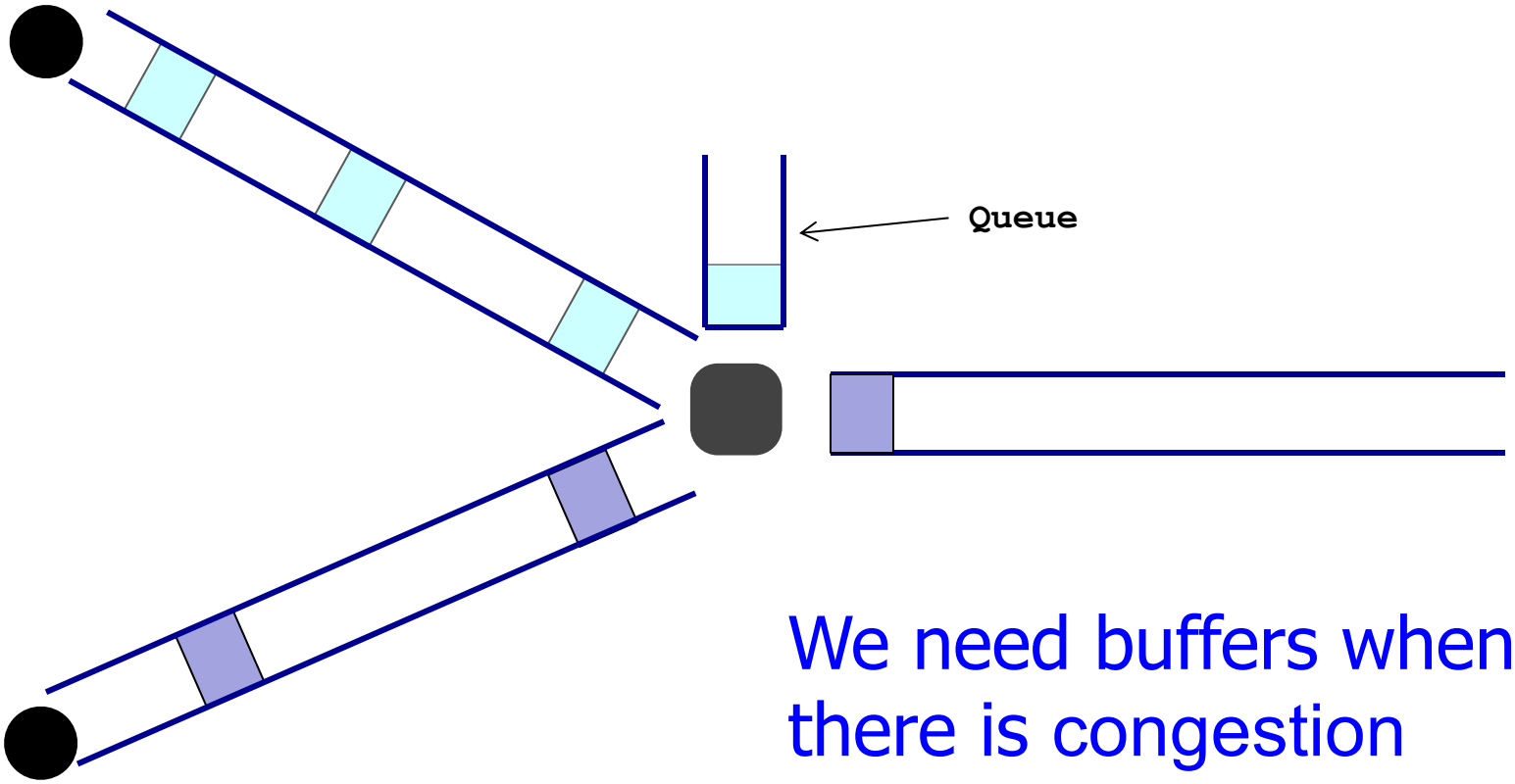


Why Do We Need Buffers?



We need buffers when there is congestion

Why Do We Need Buffers?



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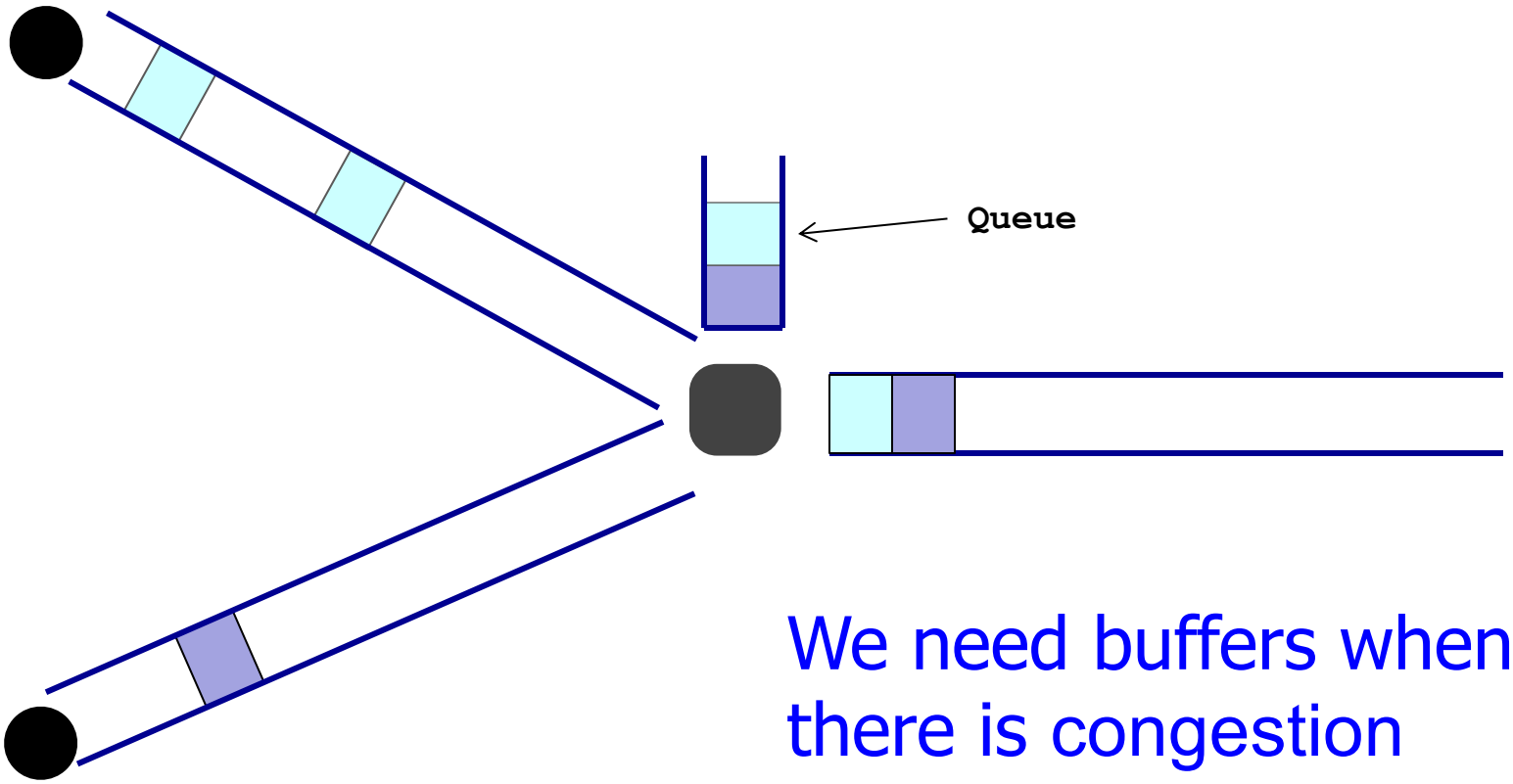

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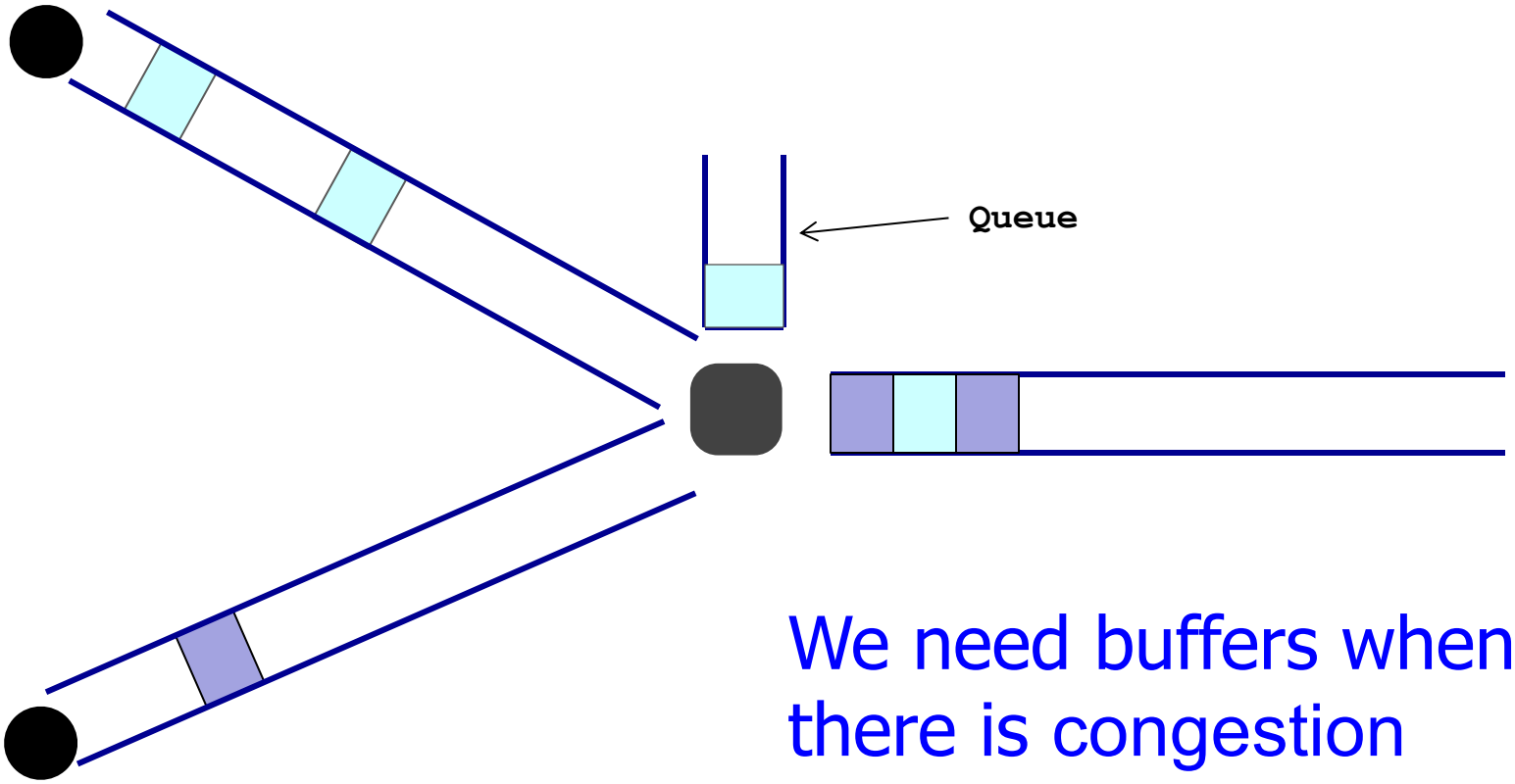

We need buffers when there is congestion

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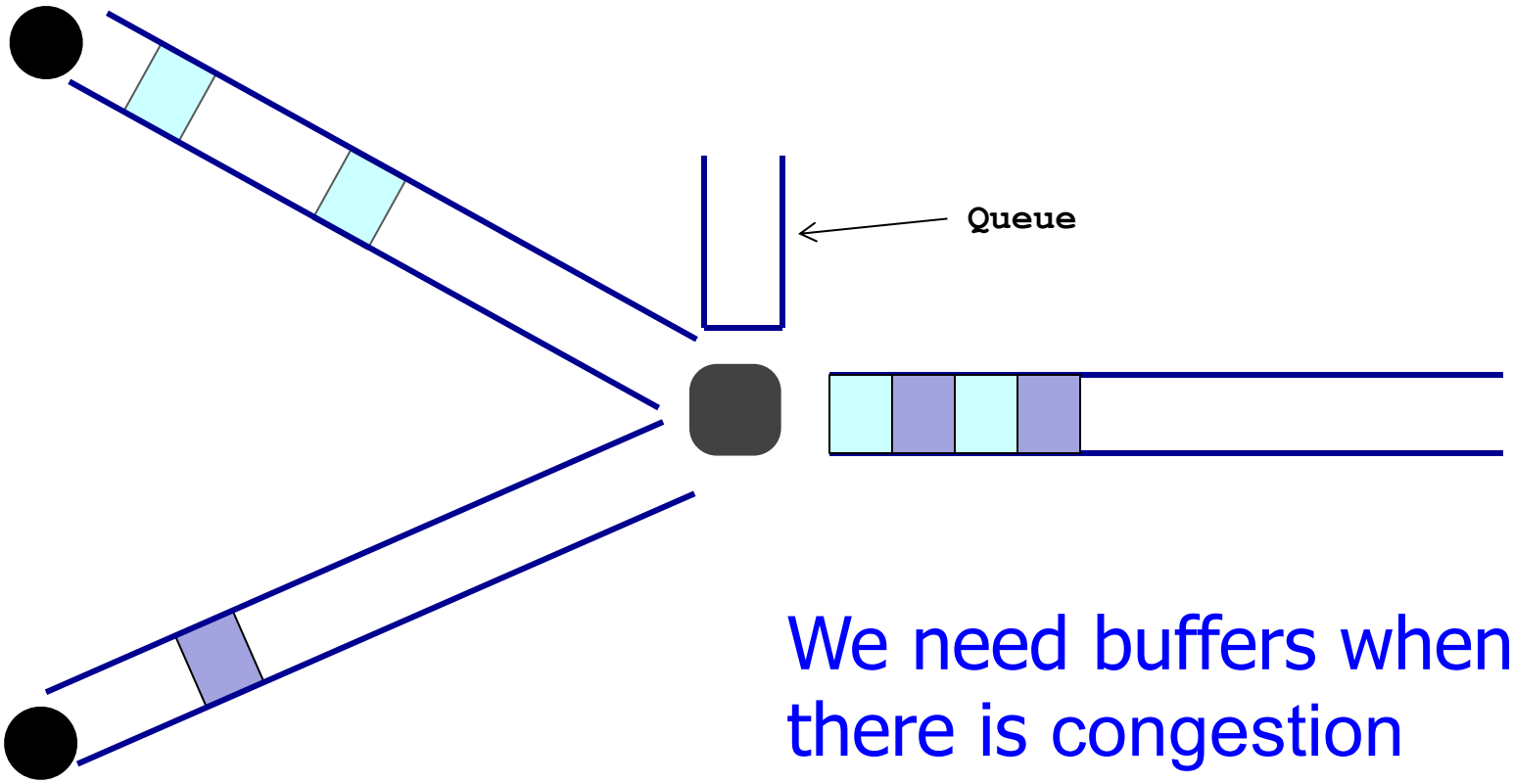
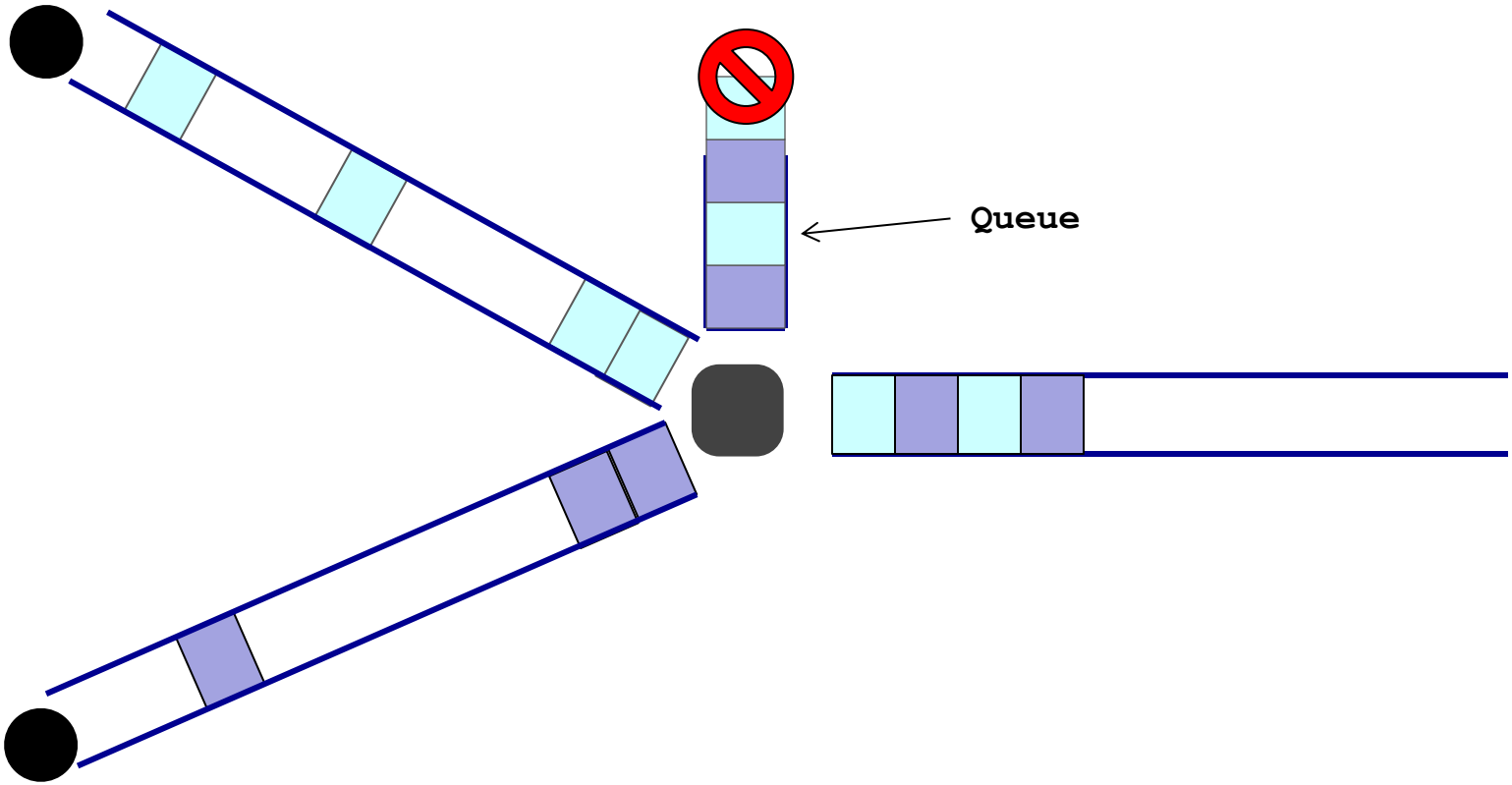


We need buffers when there is congestion

Not a rare event!

Persistent congestion => 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?)
  - Bandwidth of outgoing link

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)

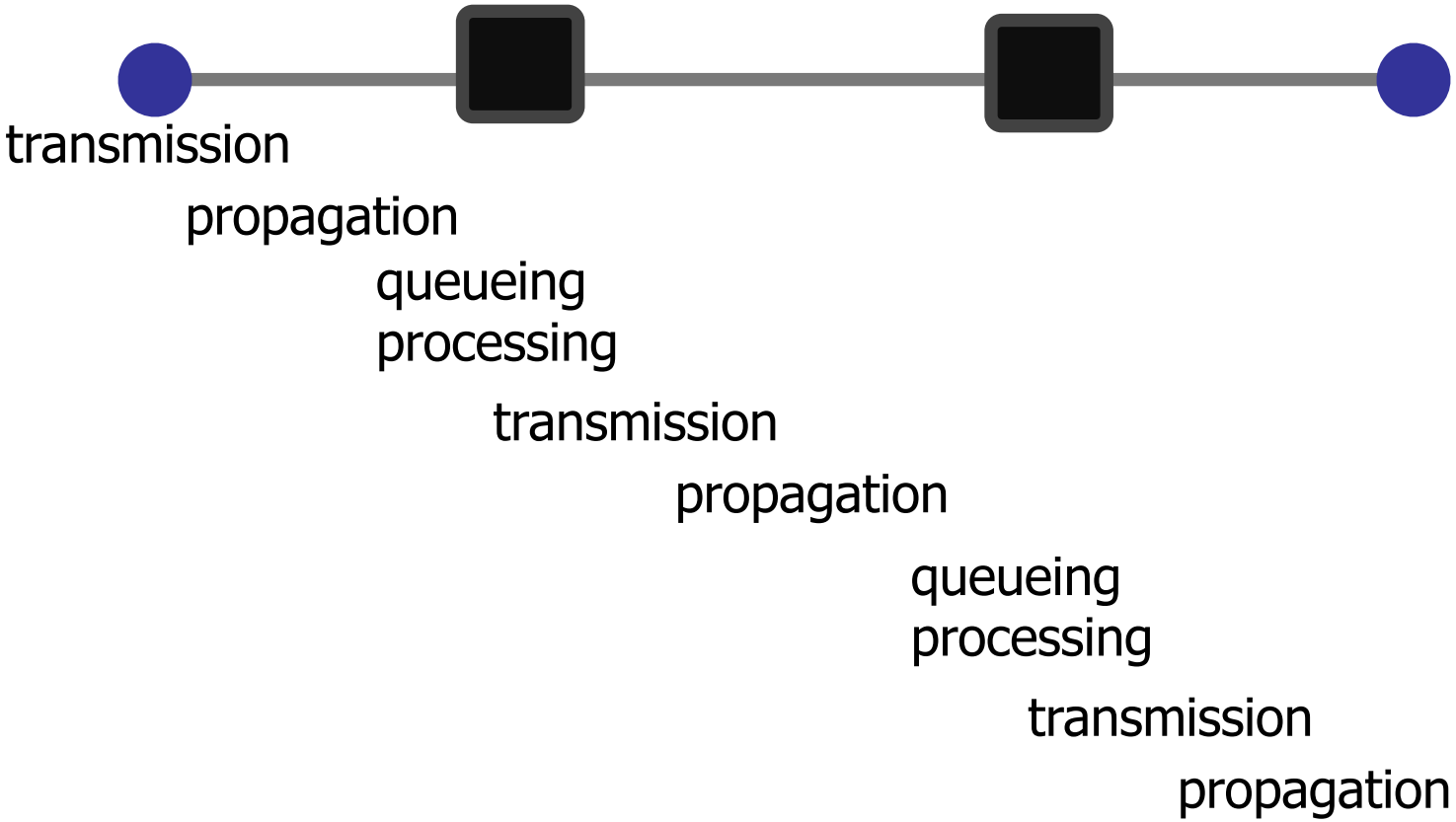
- L = A x W

- Can compute any variable given the other two
  - How big does my buffer need to be?
  - How fast do I need to handle packets to not overwhelm the buffer?

4. Processing Delay

- How long does the switch take to process a packet?
  - Negligible (100s of nanoseconds)

End-to-end delay



Performance Metric: Throughput

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

Throughput

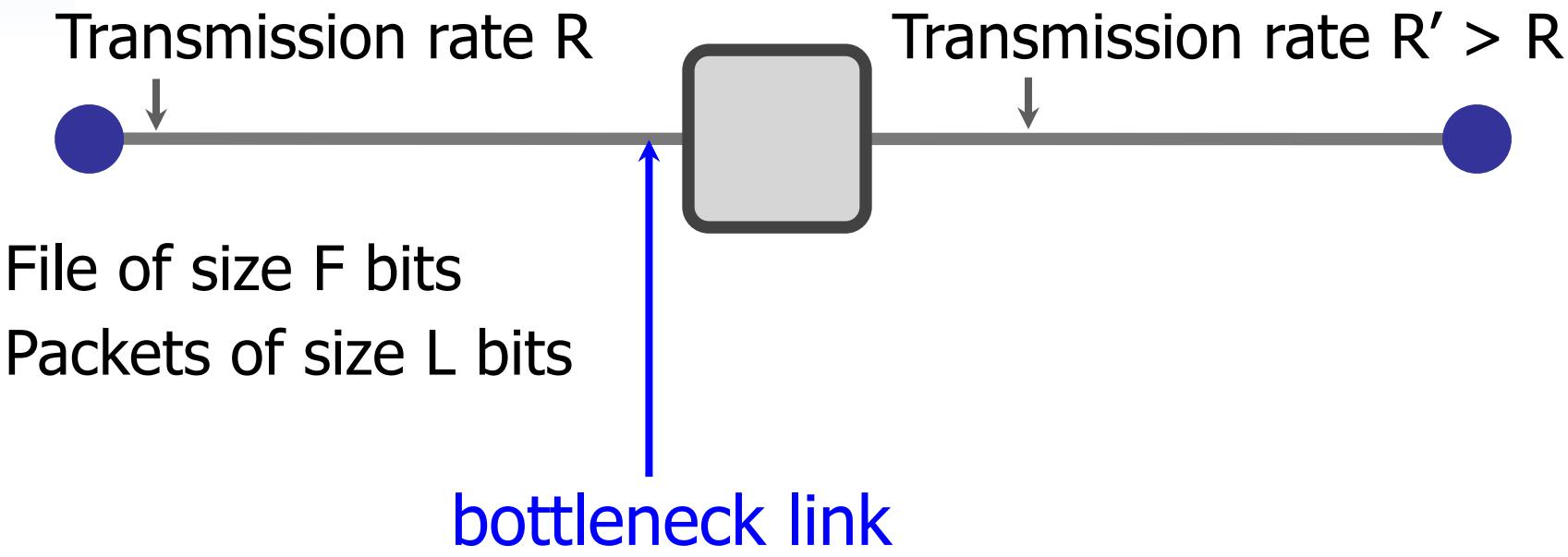
File of size F bits

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

Bandwidth-Delay Product

- Messages take space on the wire!

- The amount of data in flight is:
  - bandwidth-delay product (BDP)

    BDP = R x D
  - Measure in bits, or in messages
  - Small for LANs, big for "long fat" pipes

BDP 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)

Performance Metric: Loss

- What fraction of the packets are dropped?
- Bits are corrupted for a variety of reasons
  - Wired: Engineer link for the worst case
  - Wireless: Can't design for worst case, need to adapt data rate