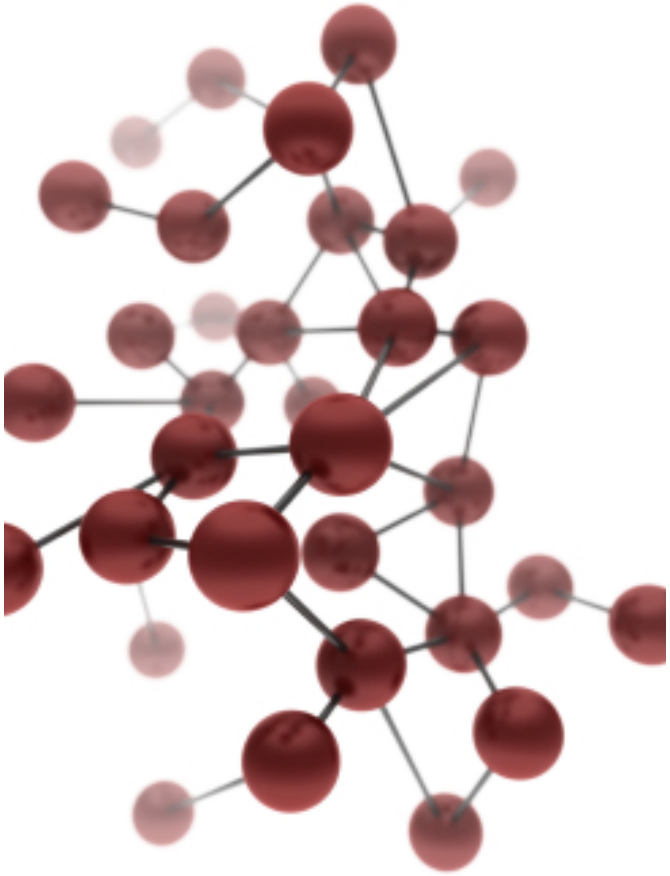


Lecture 3: Networking Concepts

Oct 8

Administrivia

- Monday: Guest lecture (ME!)

- Wednesday: No lecture, MORE time for project 1

Recap: The Internet is...

- A federated system
- Of enormous scale
- Dynamic range
- Diversity
- Constantly evolving
- Asynchronous in operation
- Failure prone
- Constrained by what's practical to engineer
- Too complex for theoretical models
- "Working code" needn't mean much
- Performance benchmarks are too narrow

Today

- What is a network made of?
- How is it shared?
- How do we evaluate a network?
- How is communication organized?

Performance Metrics

- Delay
- Loss
- Throughput

Delay

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

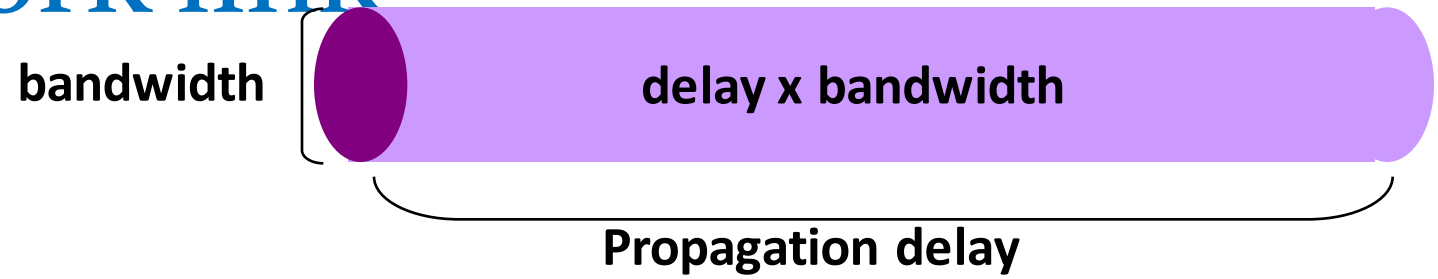
Delay

- Consists of four components
  - *transmission delay*
  - *propagation delay*
  - *queuing delay*
  - *processing delay*

due to link properties

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*

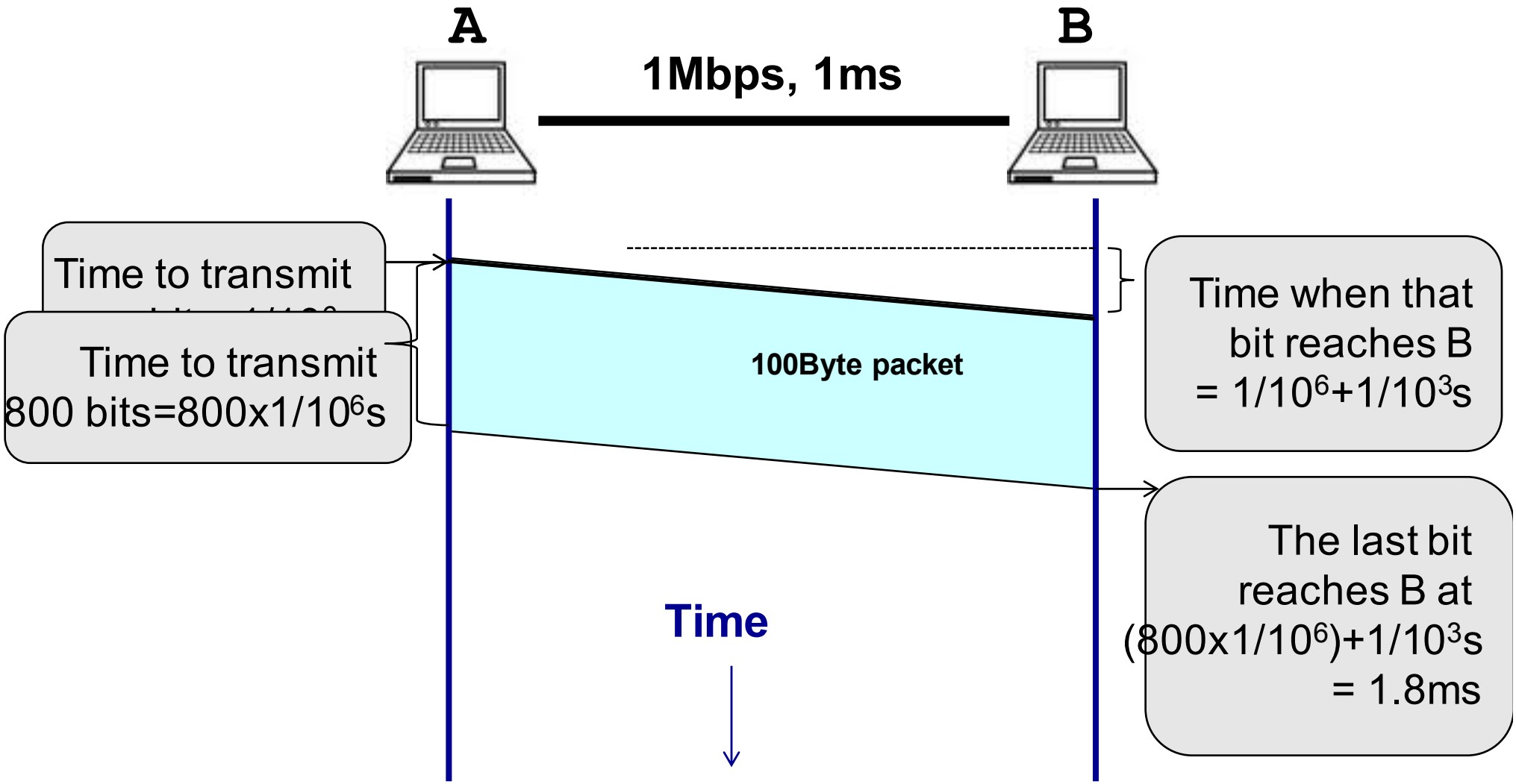
Examples

- 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)*

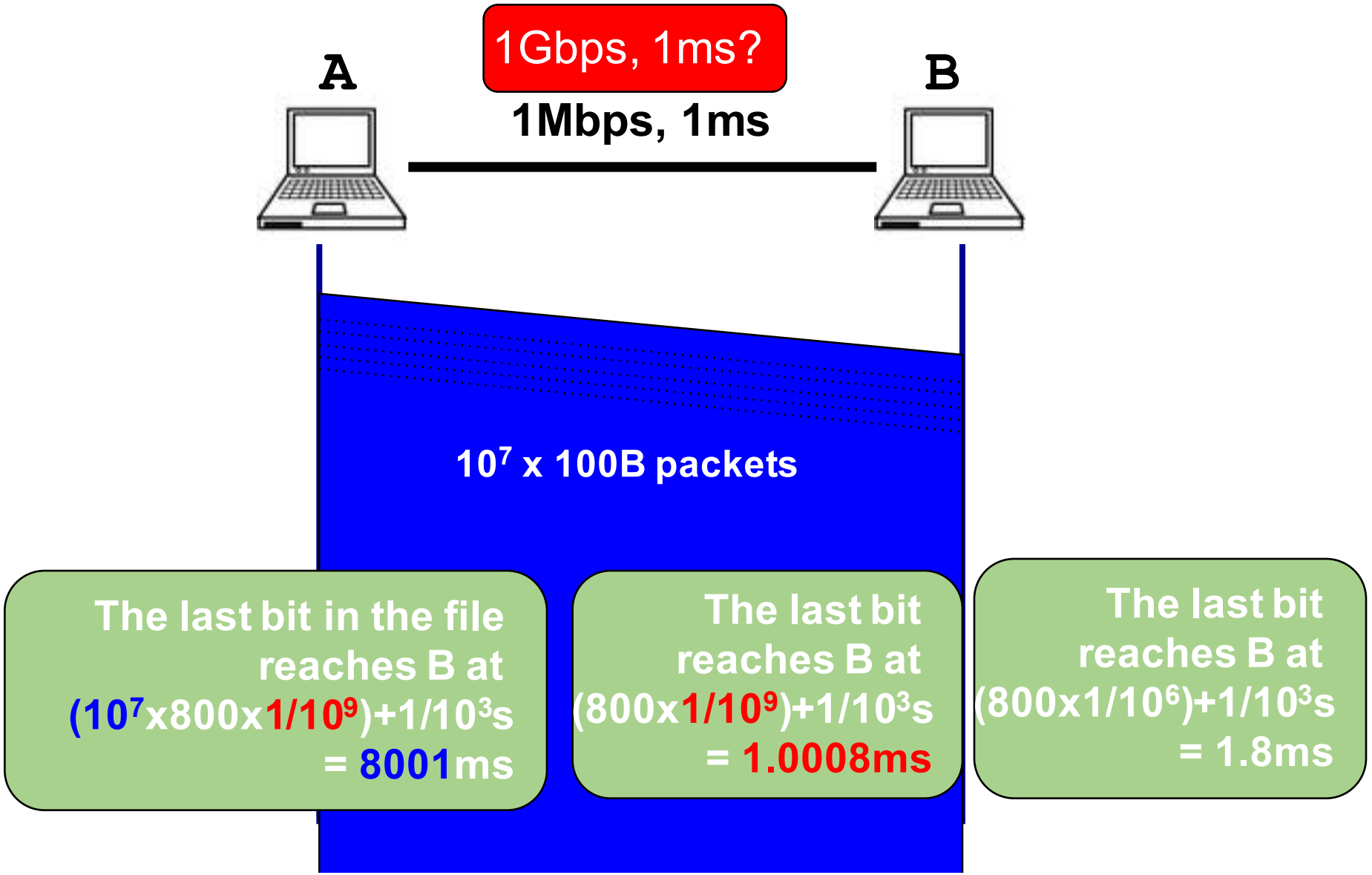
Packet Delay

Sending 100B packets from A to B?



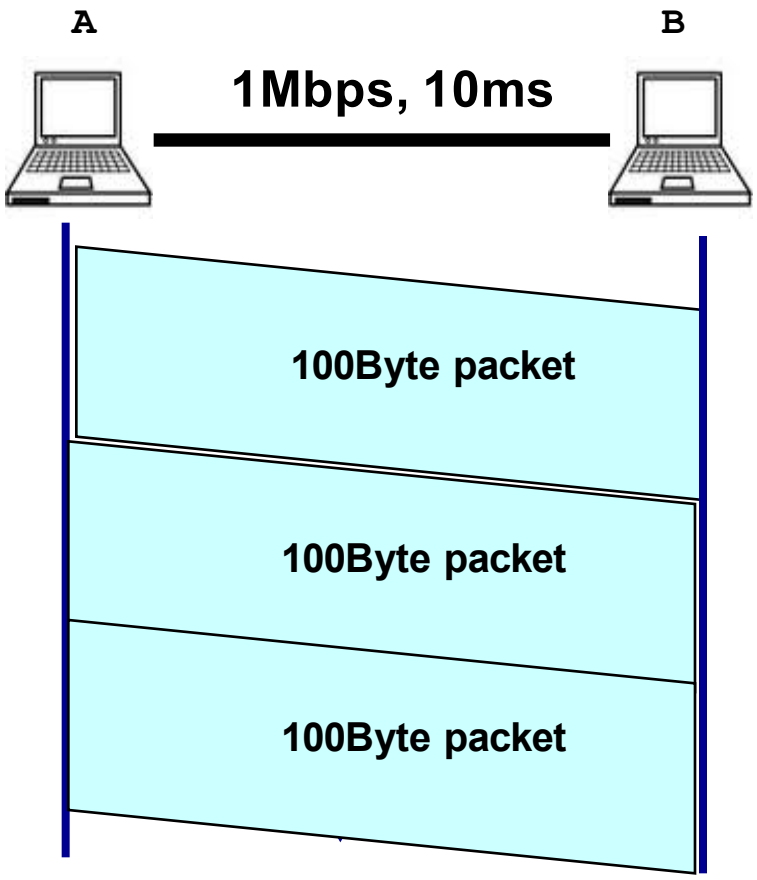
1GB file in 100B packets

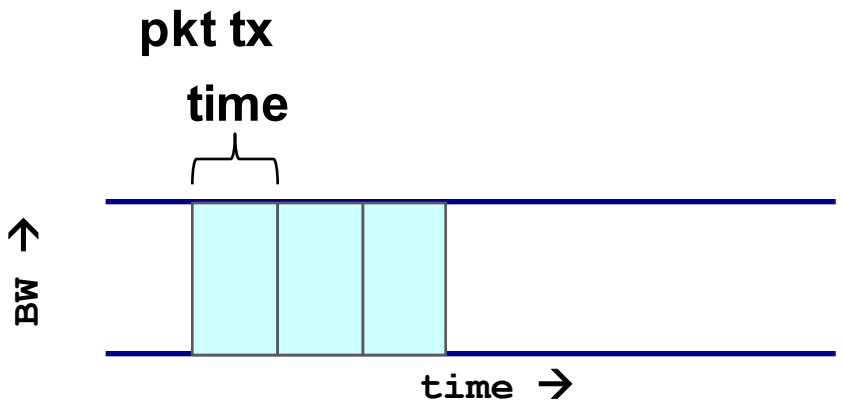
Sending 100B packets from A to B?



Packet Delay: The “pipe” view

Sending 100B packets from A to B?

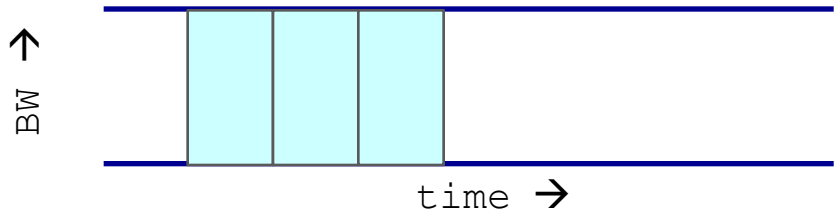




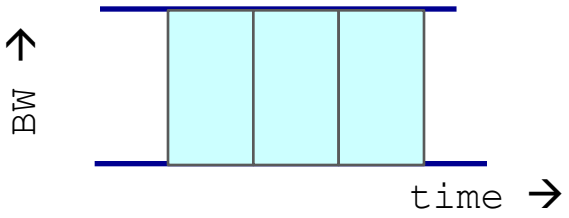
Packet Delay: The "pipe" view

Sending 100B packets from A to B?

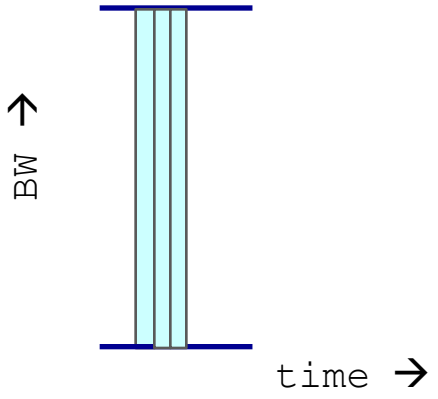
1Mbps, 10ms (BDP=10,000)



1Mbps, 5ms (BDP=5,000)

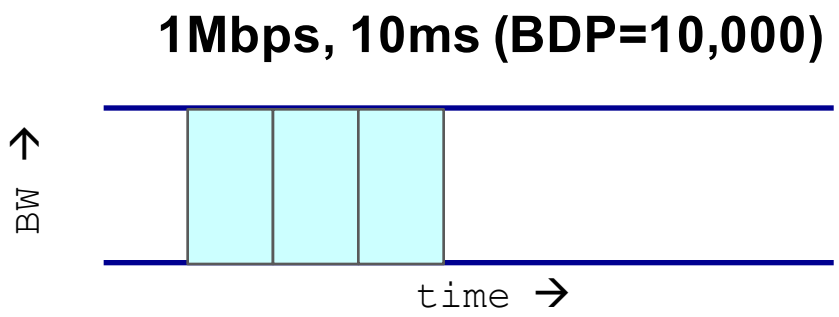


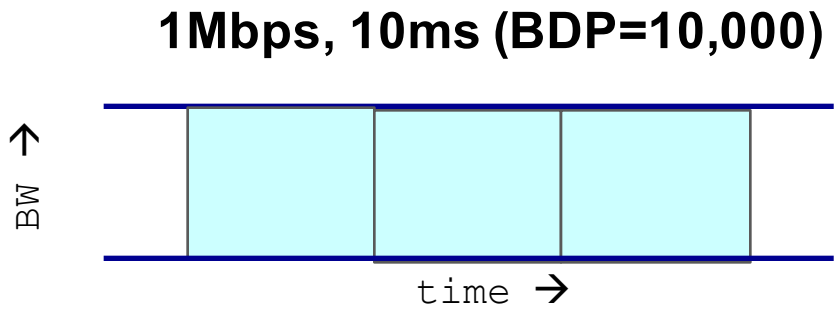
10Mbps, 1ms (BDP=10,000)



Pack 200B?: The “pipe” view

Sending 100B packets from A to B?





1. Transmission delay

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

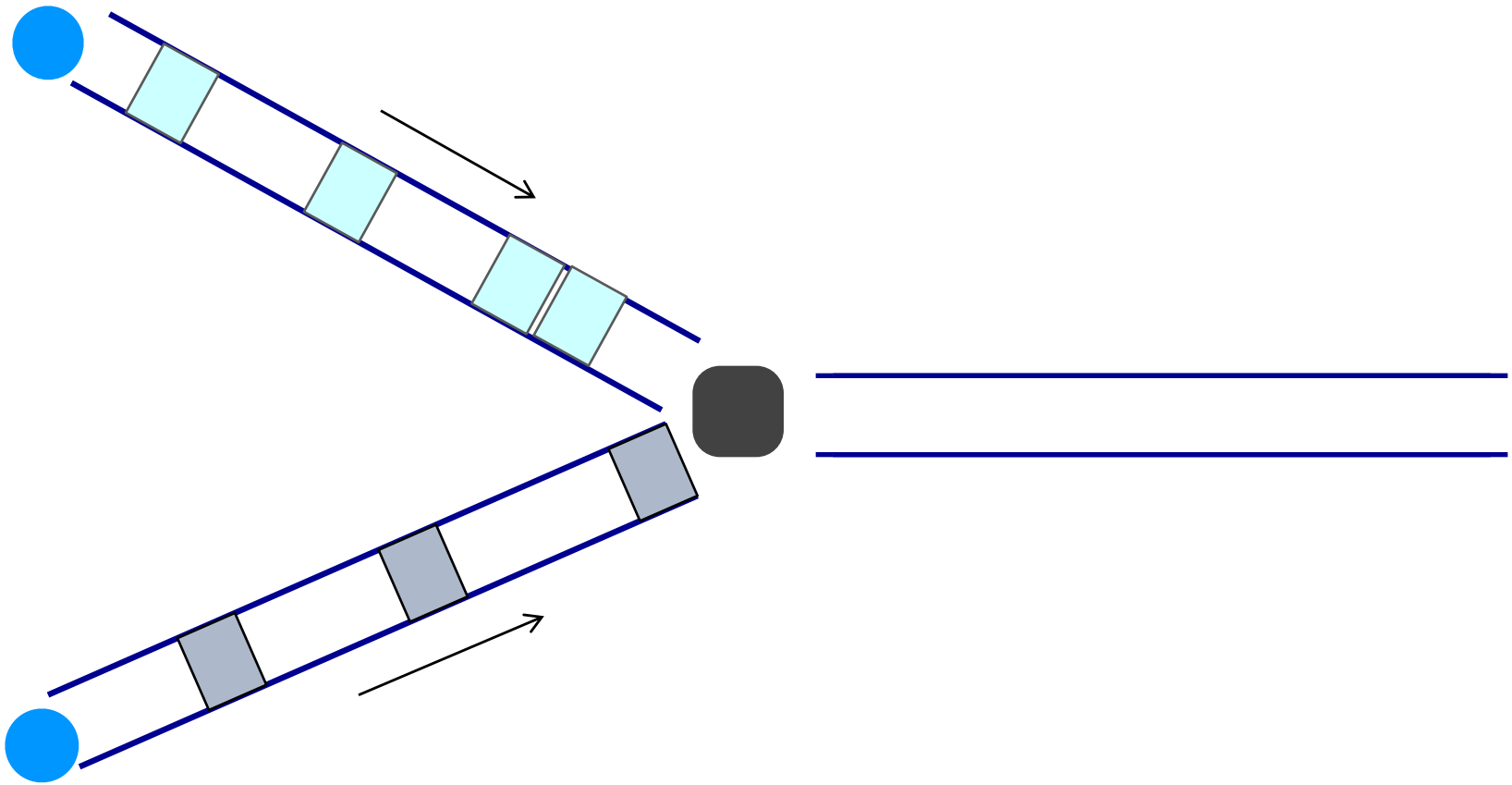
2. Propagation delay

- How long does it take to move one bit from one end of a link to the other?
- Link length / Link propagation delay
  - *E.g. 30 kilometers / 3 108 meters per sec = 10-4 sec*

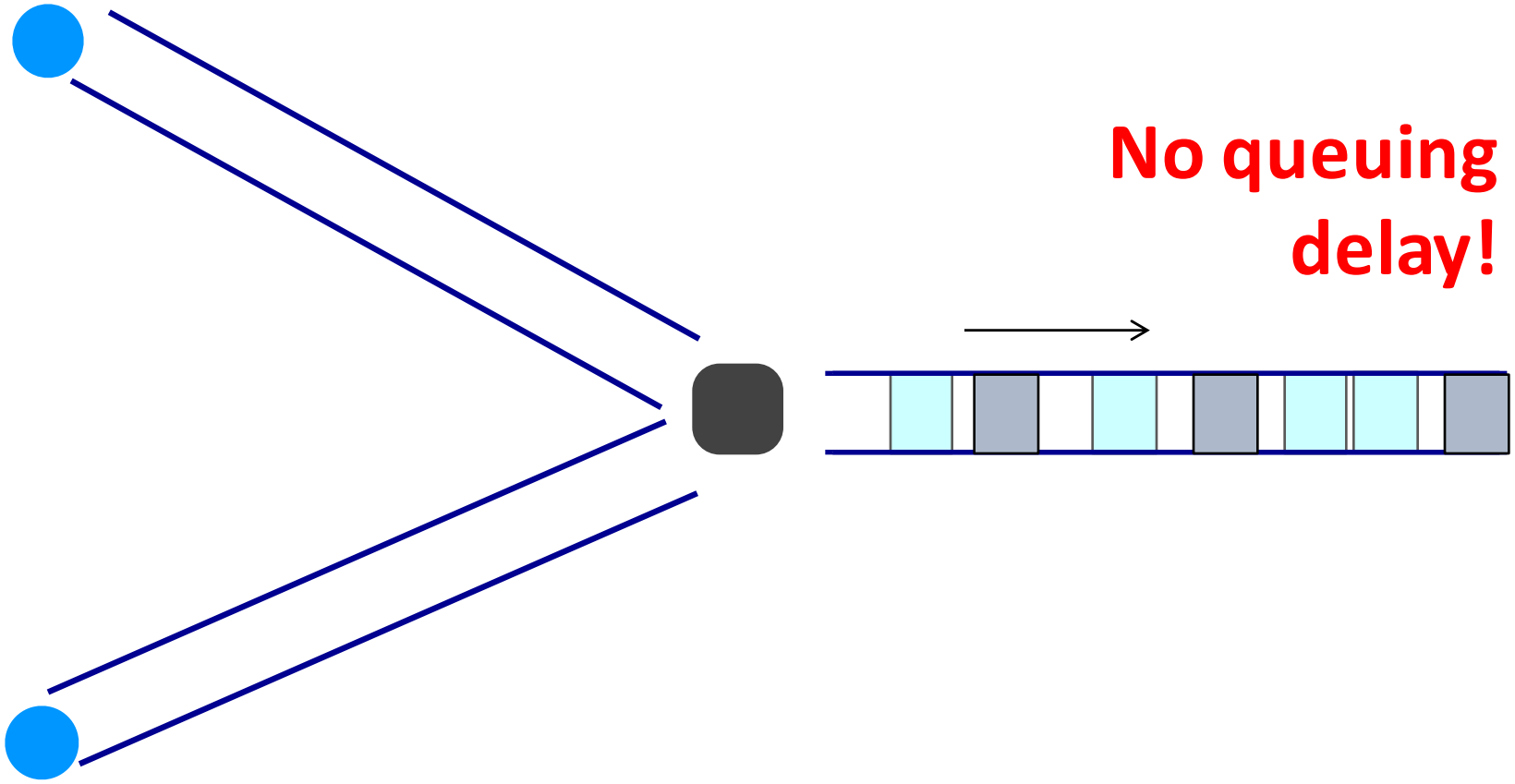
3. Queuing delay

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

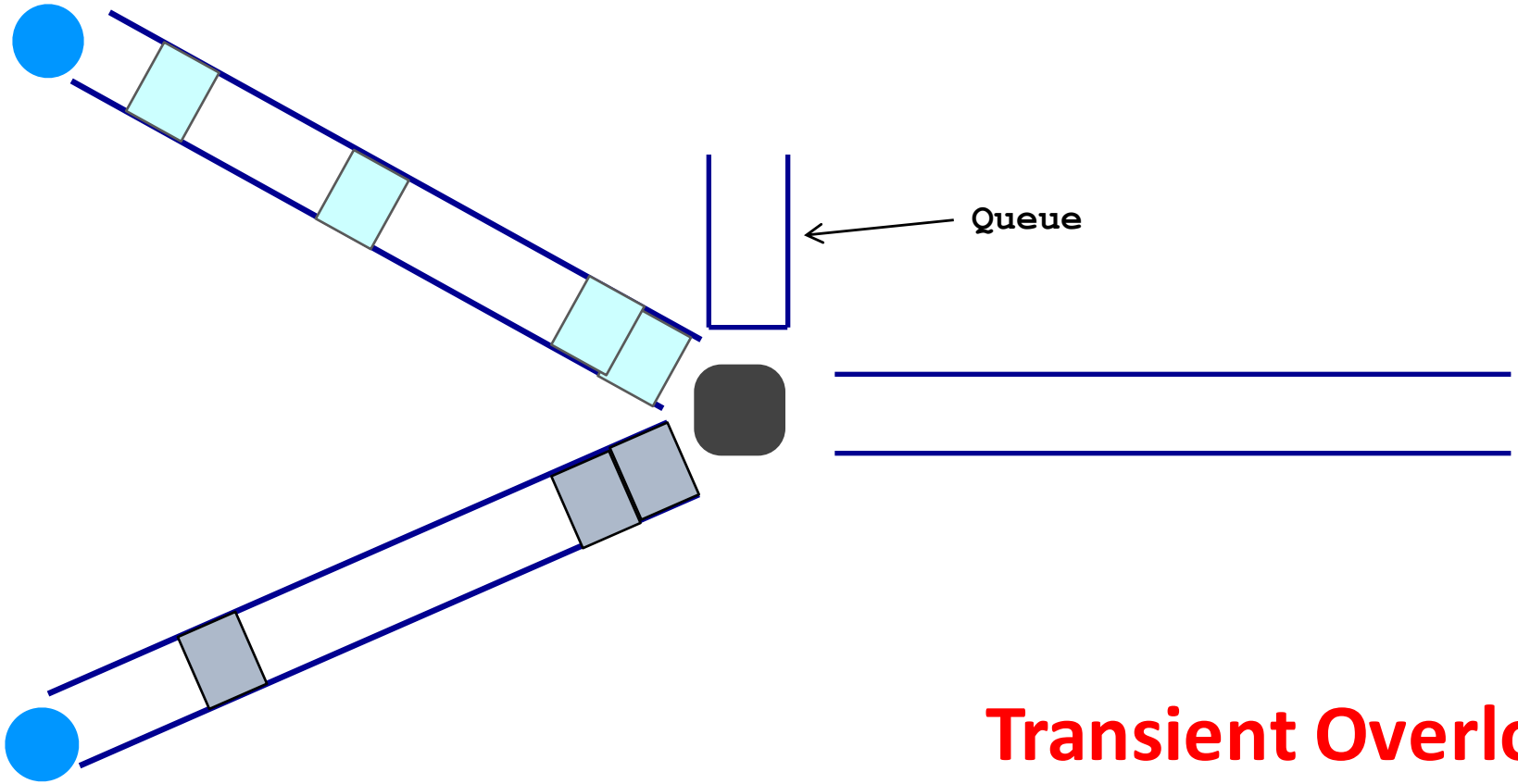
Queuing delay: “pipe” view



Queuing delay: “pipe” view



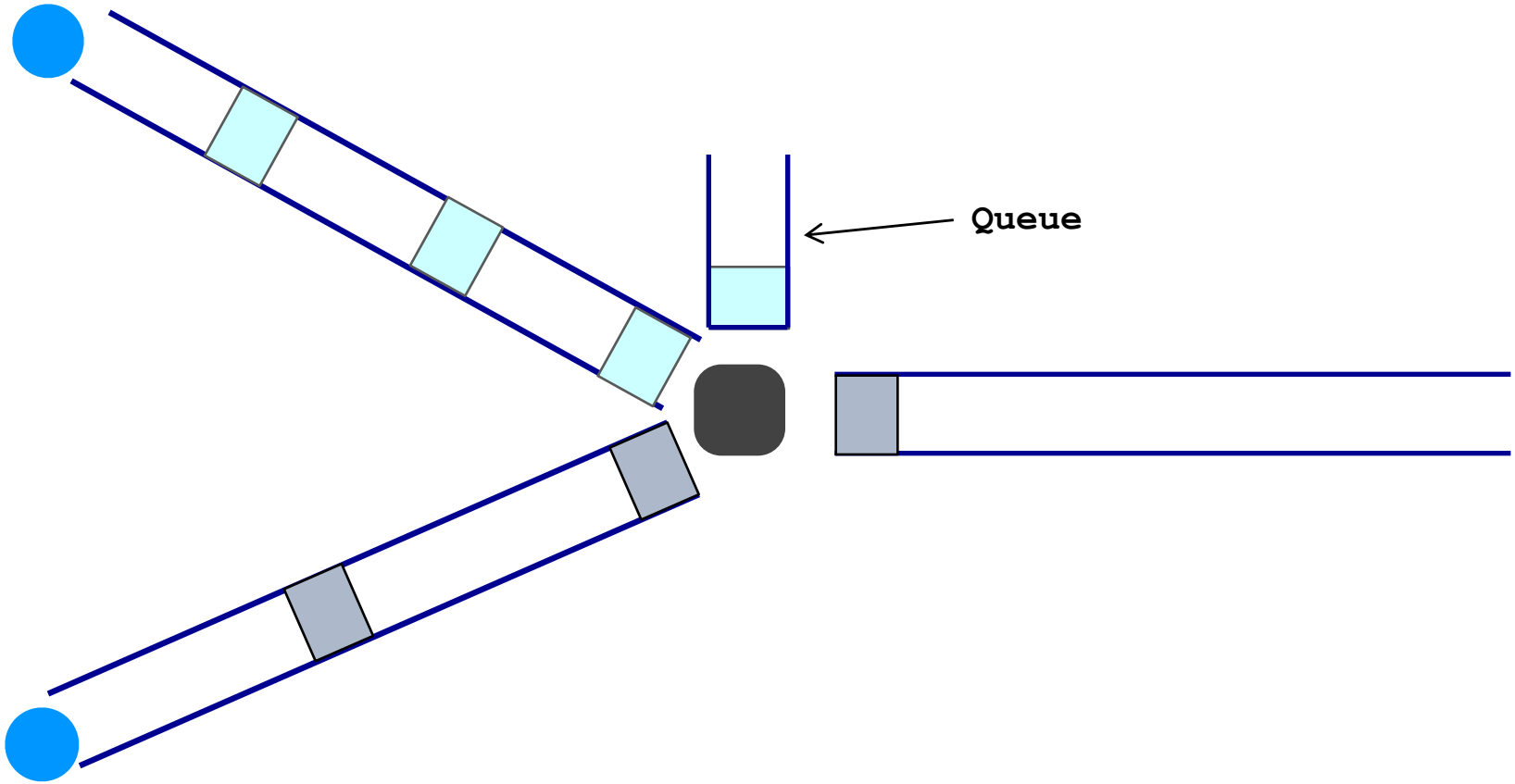
Queuing delay: “pipe” view



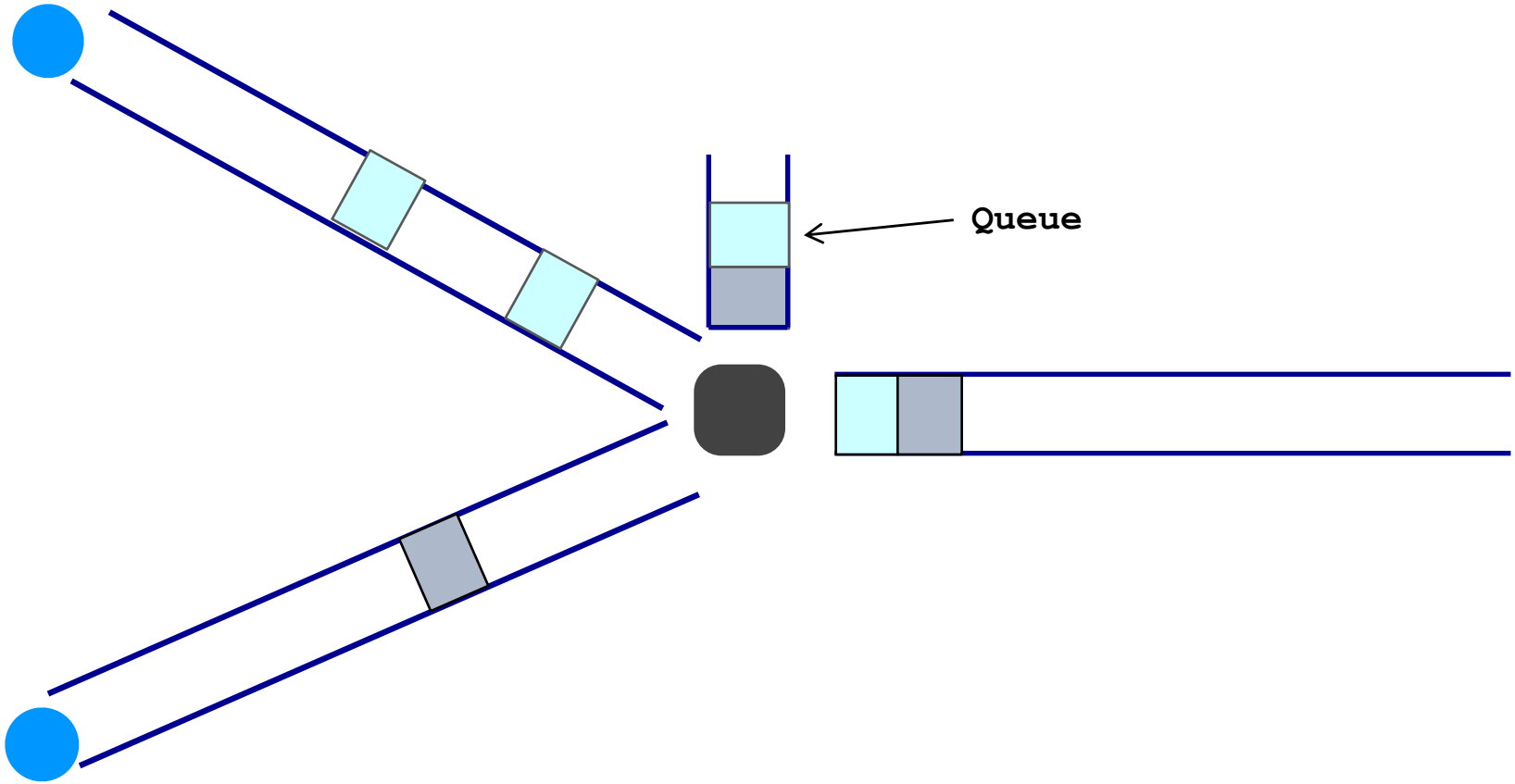
Transient Overload

Not a rare event!

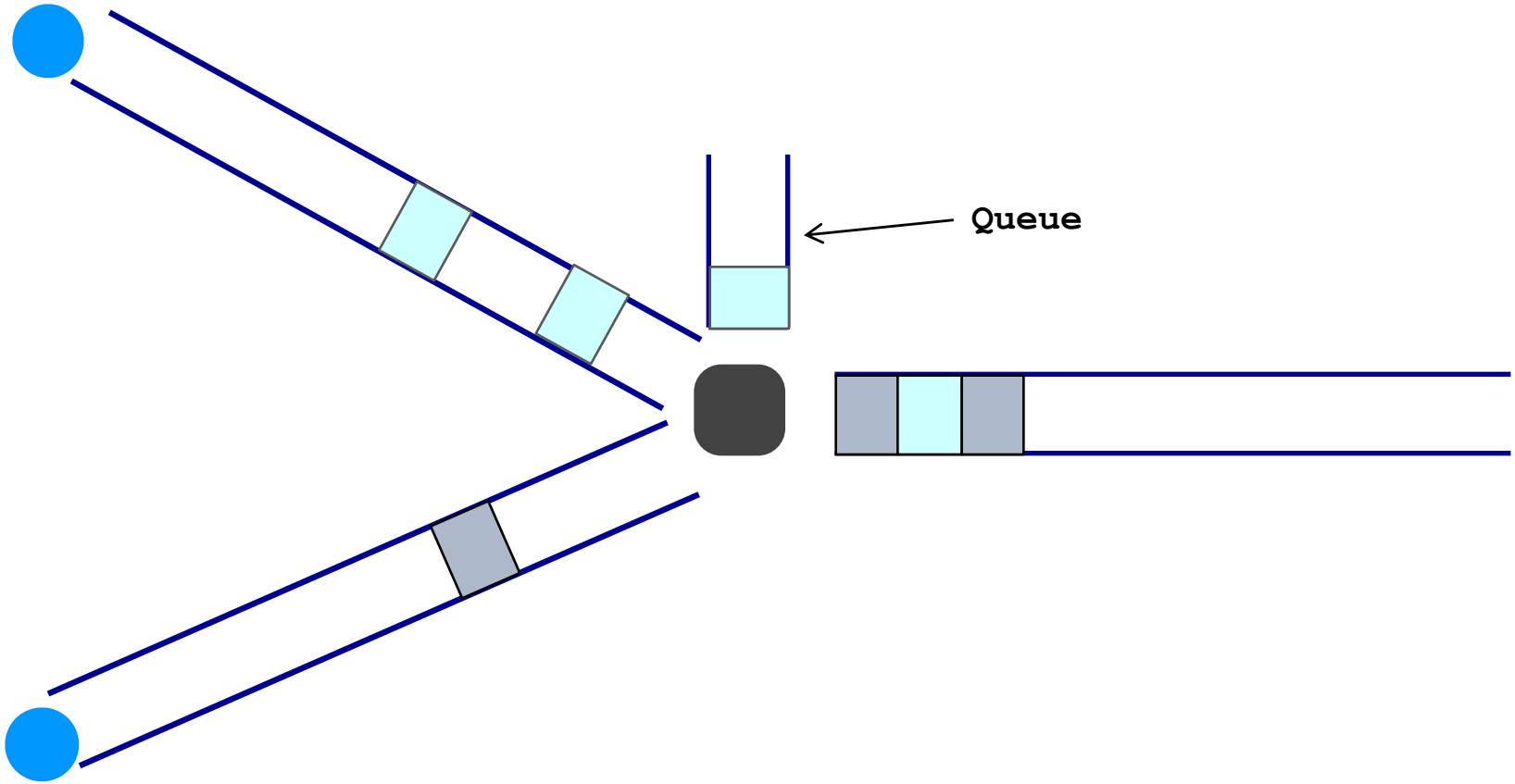
Queuing delay: “pipe” view



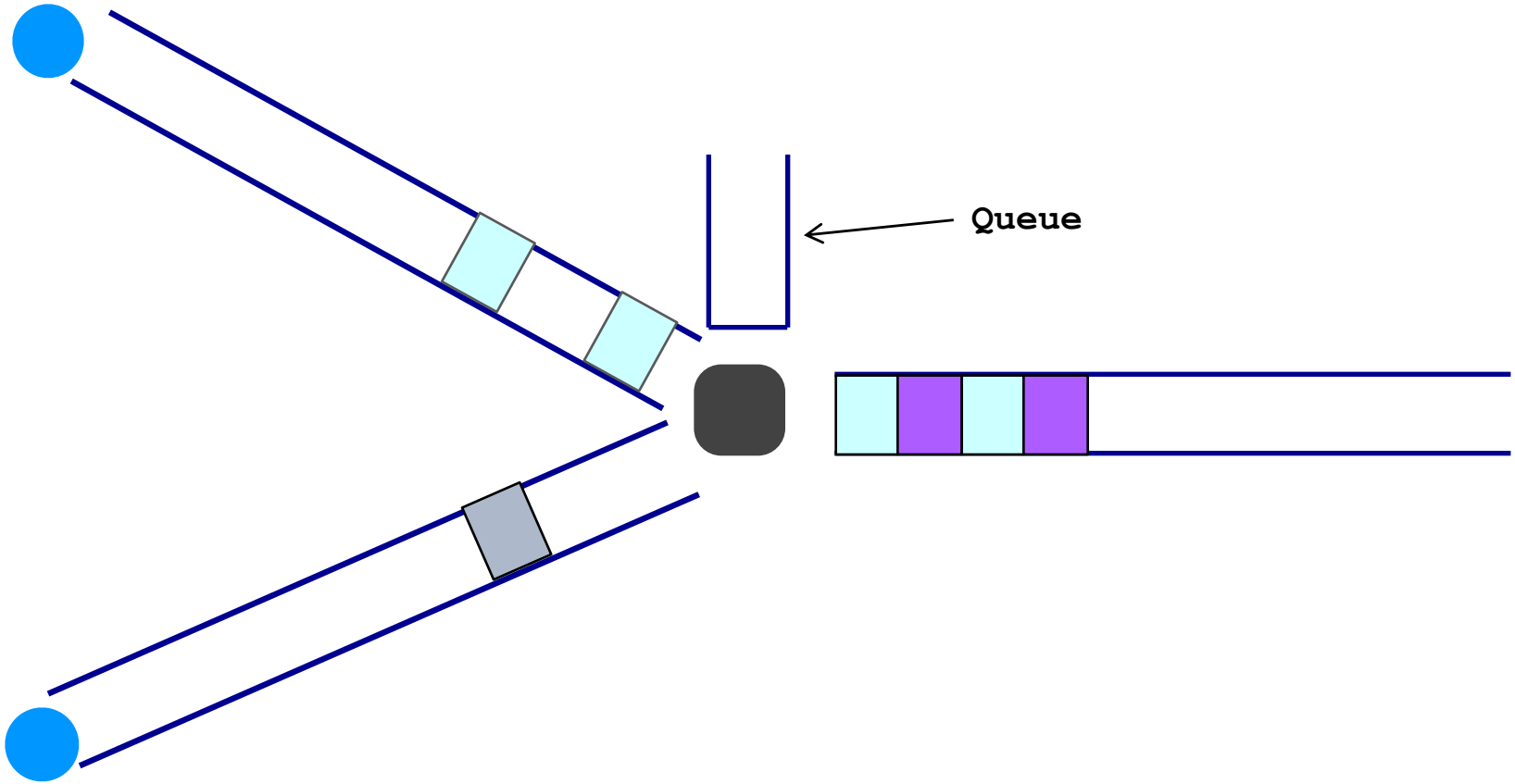
Queuing delay: “pipe” view



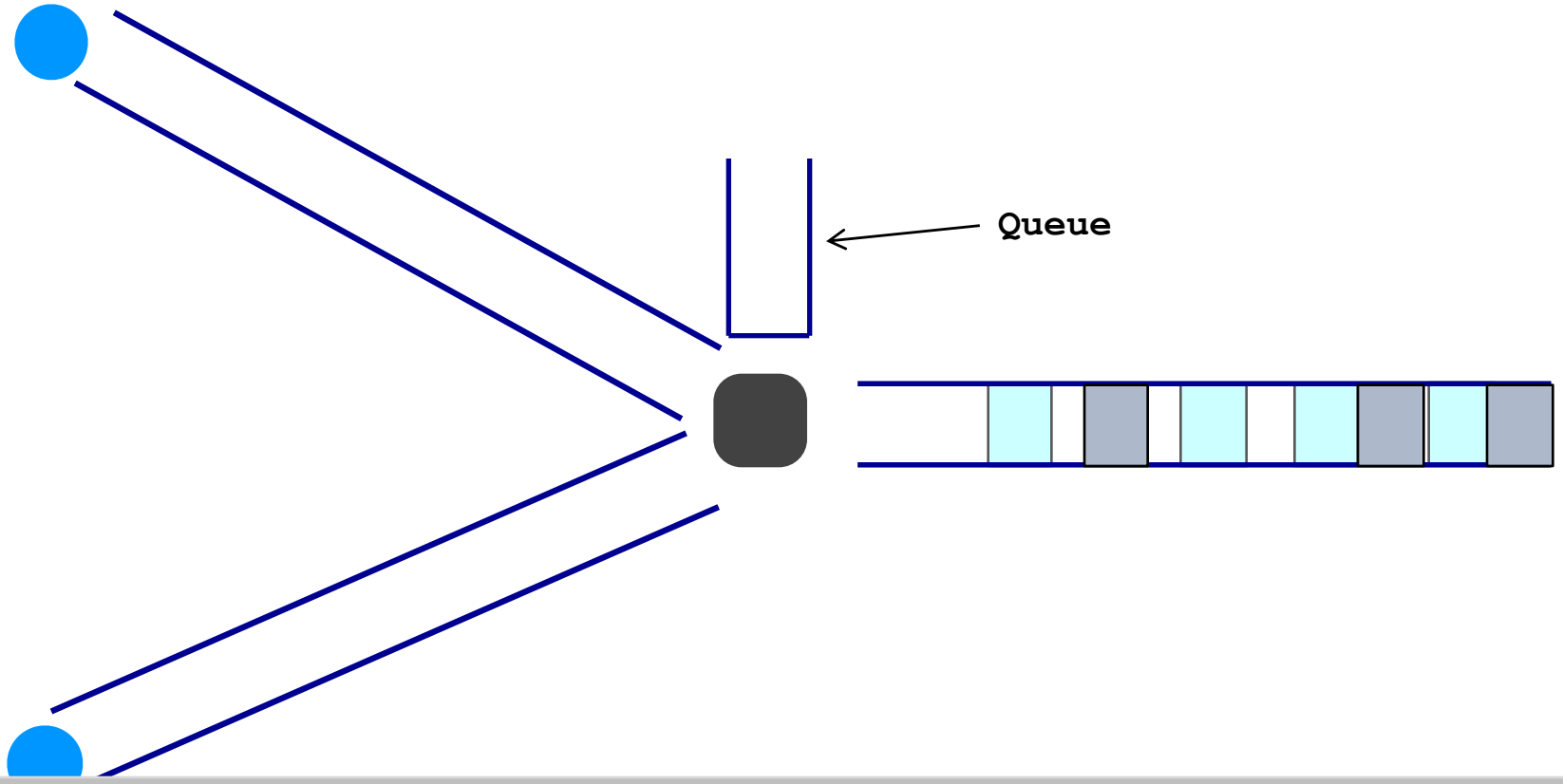
Queuing delay: “pipe” view



Queuing delay: “pipe” view

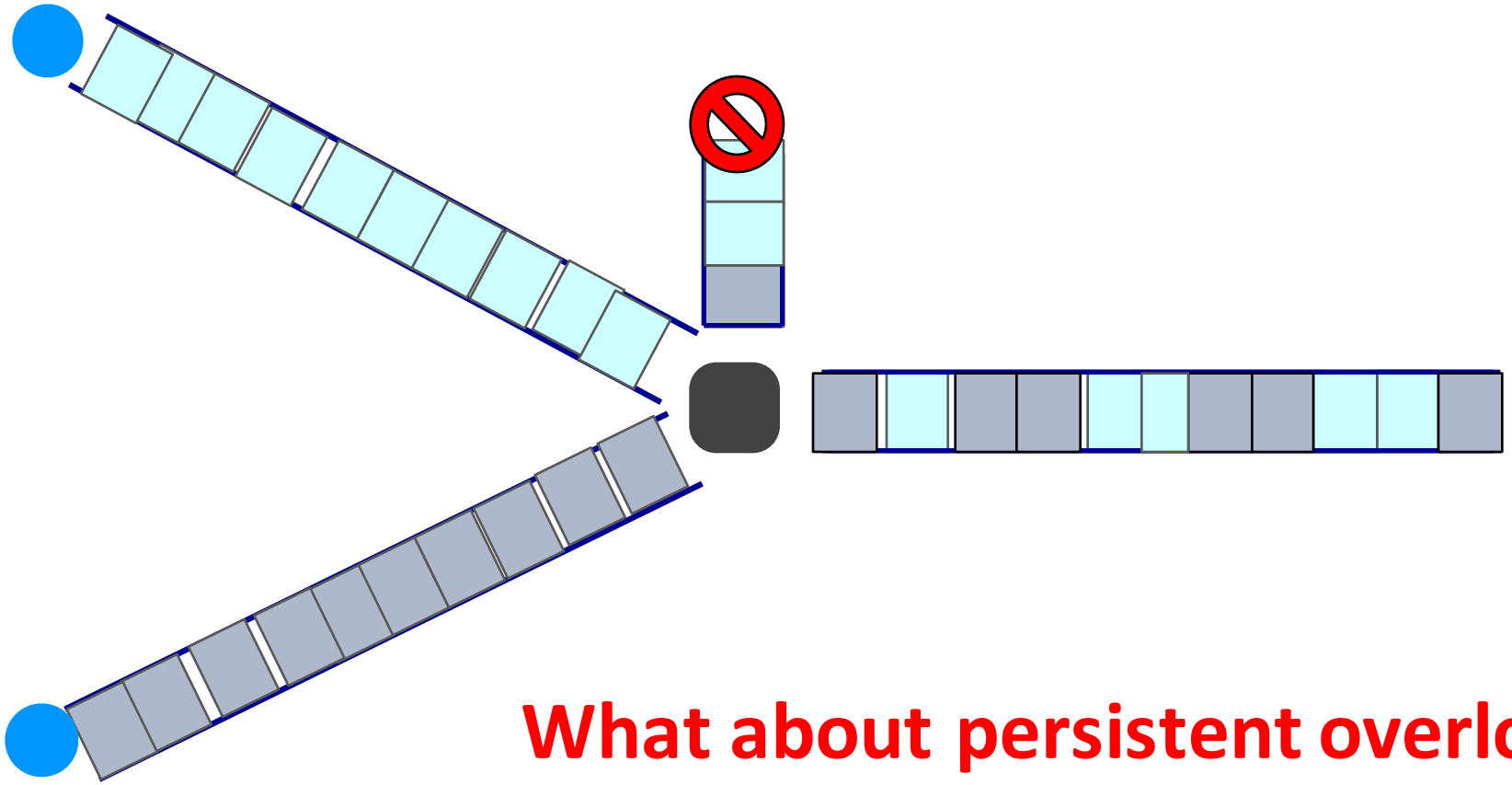


Queuing delay: “pipe” view



Queues absorb transient bursts but introduce queuing delay

Queuing delay: “pipe” view

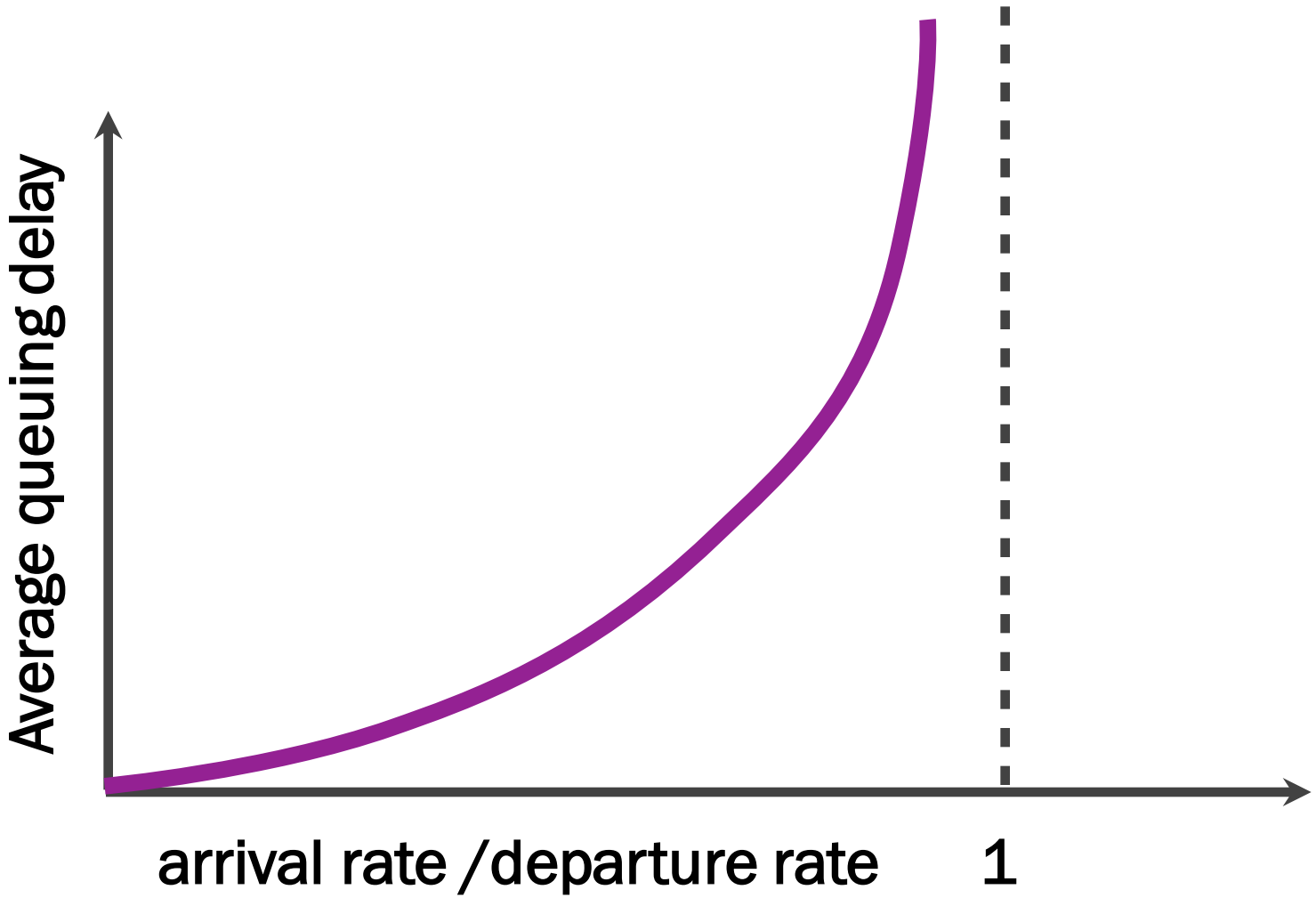


What about persistent overload?

Will eventually drop packets (“loss”)

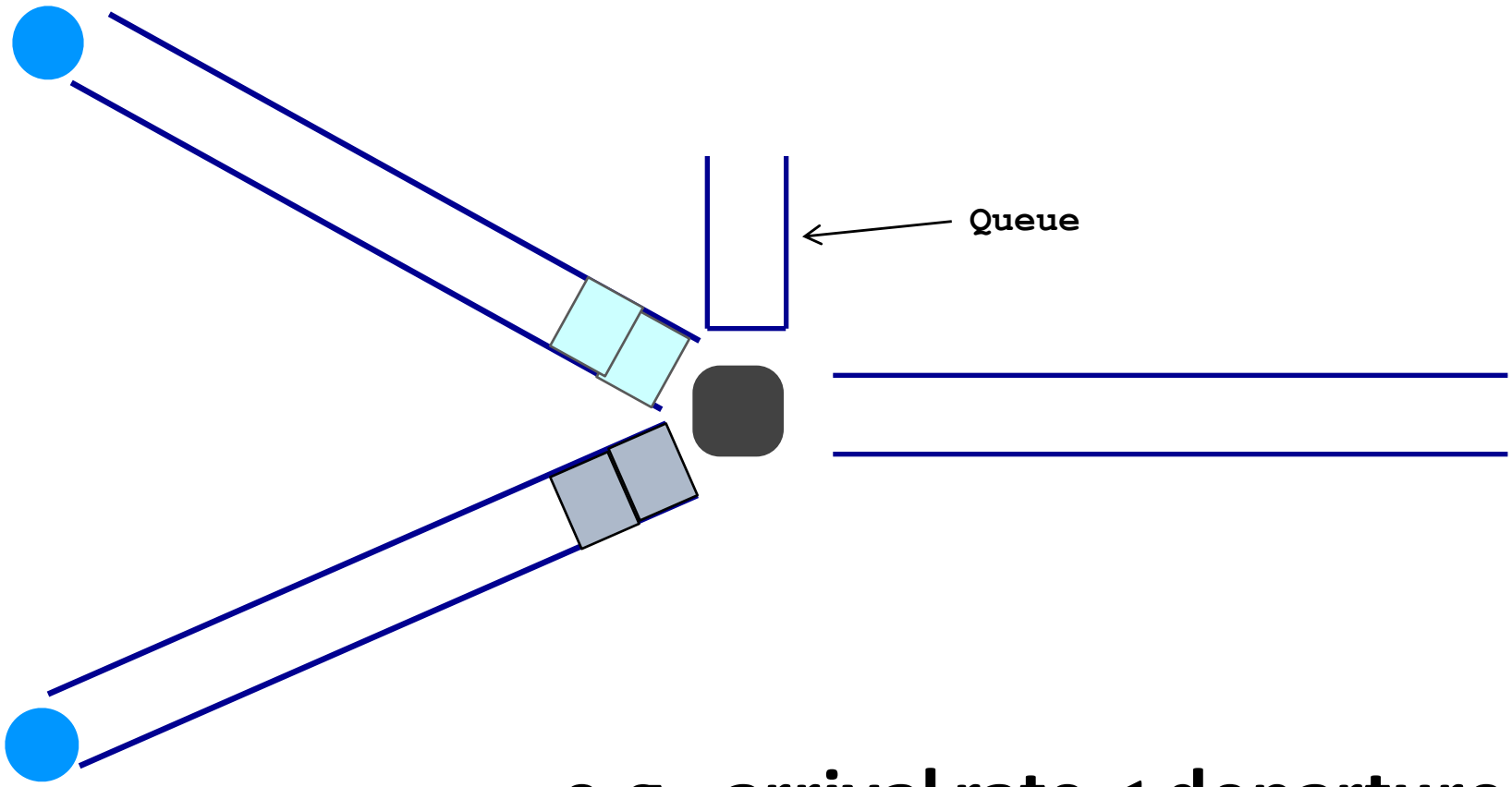
Queuing delay

- If arrival rate > departure rate
  - *approaches infinity (assuming an infinite buffer)*


Average queuing delay
arrival rate /departure rate
1

Queuing delay

- If arrival rate > departure rate
  - *approaches infinity (assuming an infinite buffer)*
  - *in practice, finite buffer → loss*
- If arrival rate < departure rate



e.g., arrival rate < departure rate

Queuing Delay

- If arrival rate > departure rate
  - *approaches infinity (assuming an infinite buffer)*
  - *in practice, finite buffer → loss*
- If arrival rate < departure rate
  - *depends on burst size*

Queuing Delay

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

- Depends on traffic pattern

Queuing Delay

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

- Depends on traffic pattern

- Characterized with statistical measures
  - *average queuing delay*
  - *average arrival rate*
  - *average departure rate*

Basic Queuing Theory Terminology

- Arrival process: how packets arrive
  - *Average rate A*
- 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)

$$L = A \times W$$

- 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?

- typically assume this is negligible

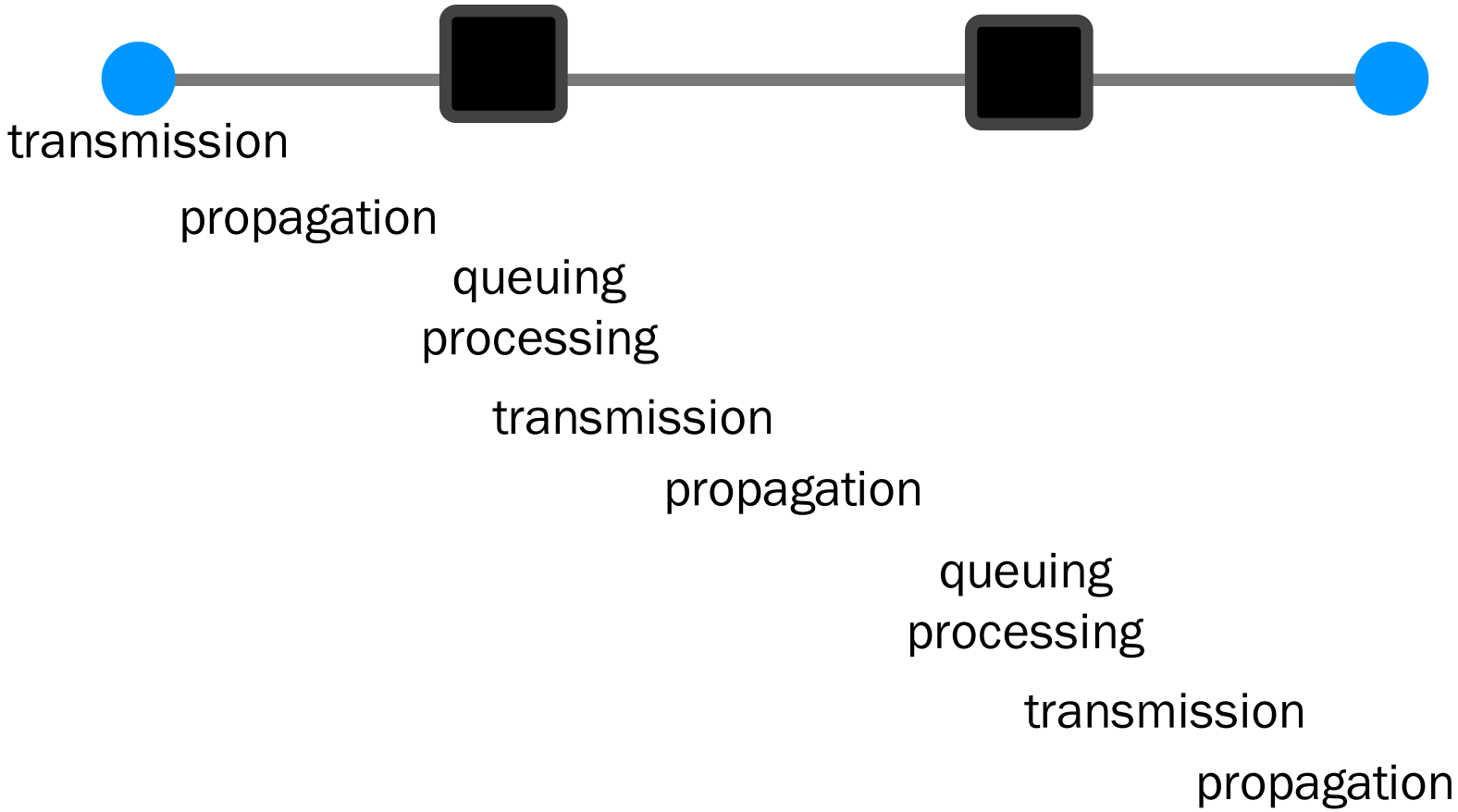
Delay

- Consists of four components
  - *transmission delay*
  - *propagation delay*
  - *queuing delay*
  - *processing delay*

due to link properties

due to traffic mix and switch internals

End-to-end Delay

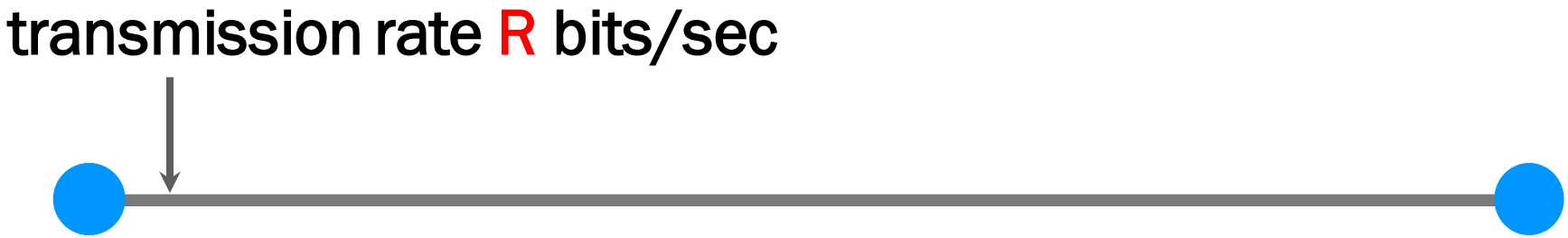


Loss

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

Throughput

- *At what rate is the destination receiving data from the source*
  - Data size / transfer time

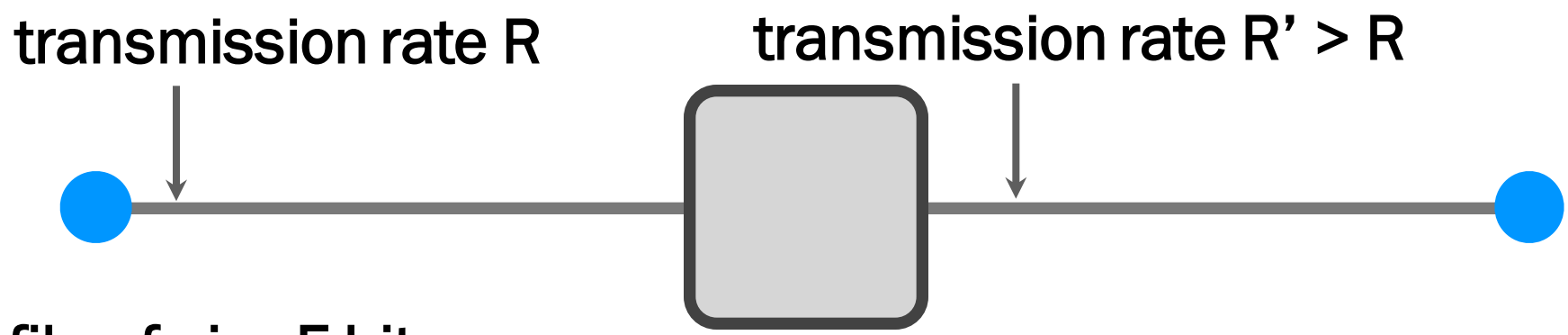


file of size F bits

packets of size L bits

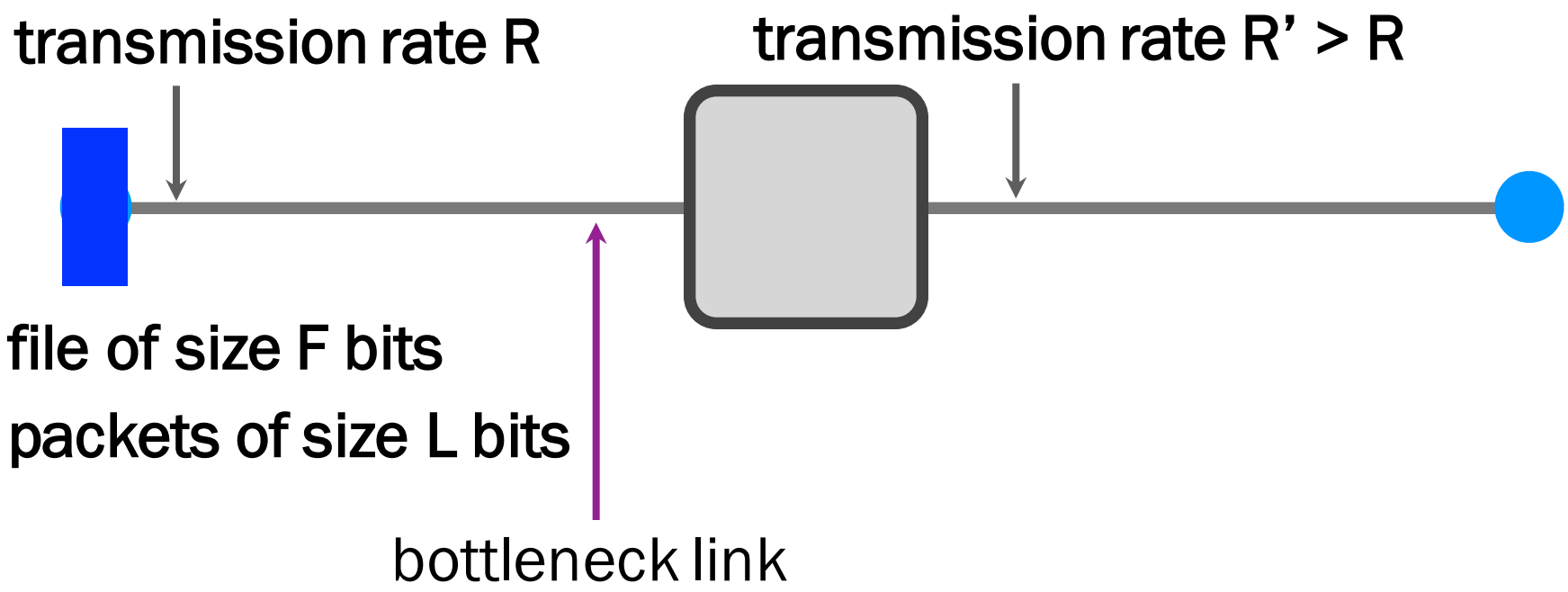
Transfer time = F/R + propagation delay

Average throughput = R



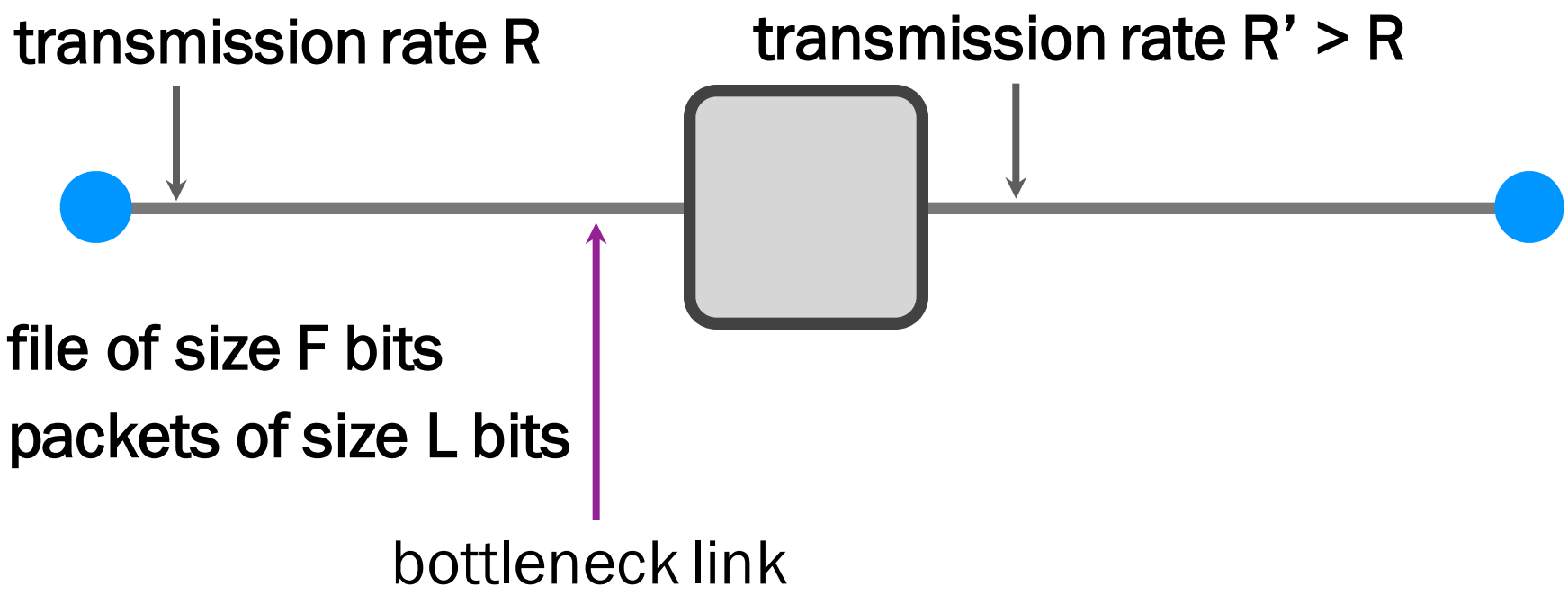
file of size F bits

packets of size L bits

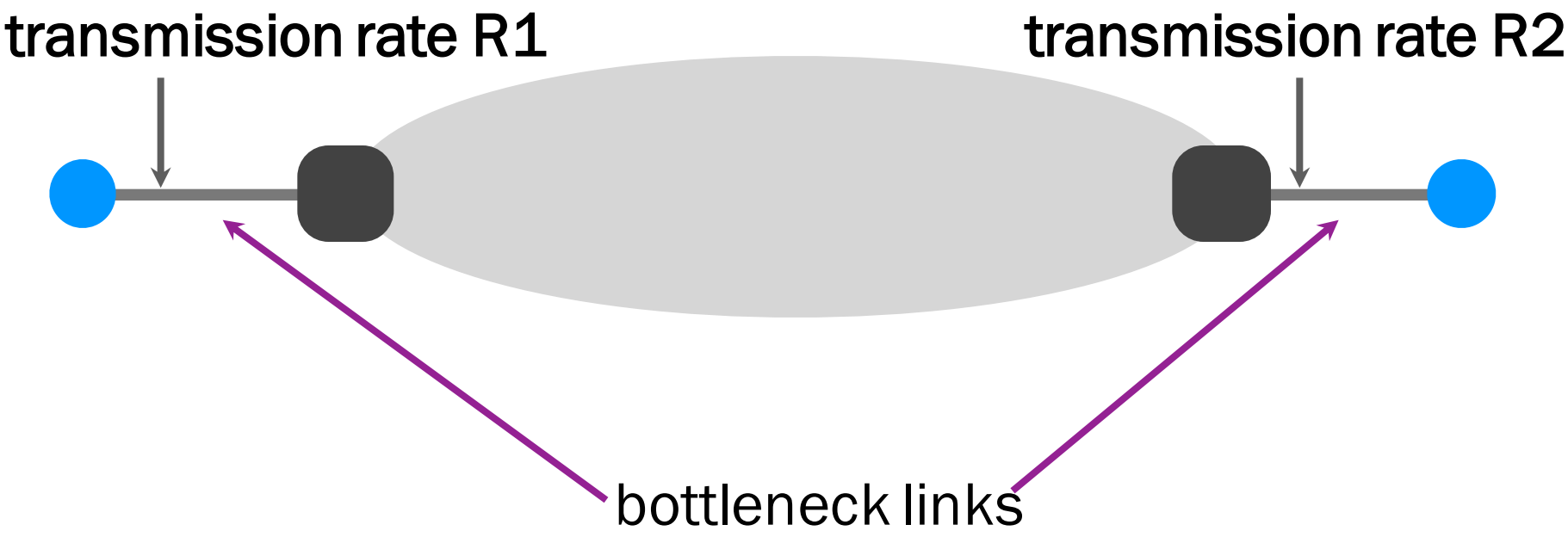


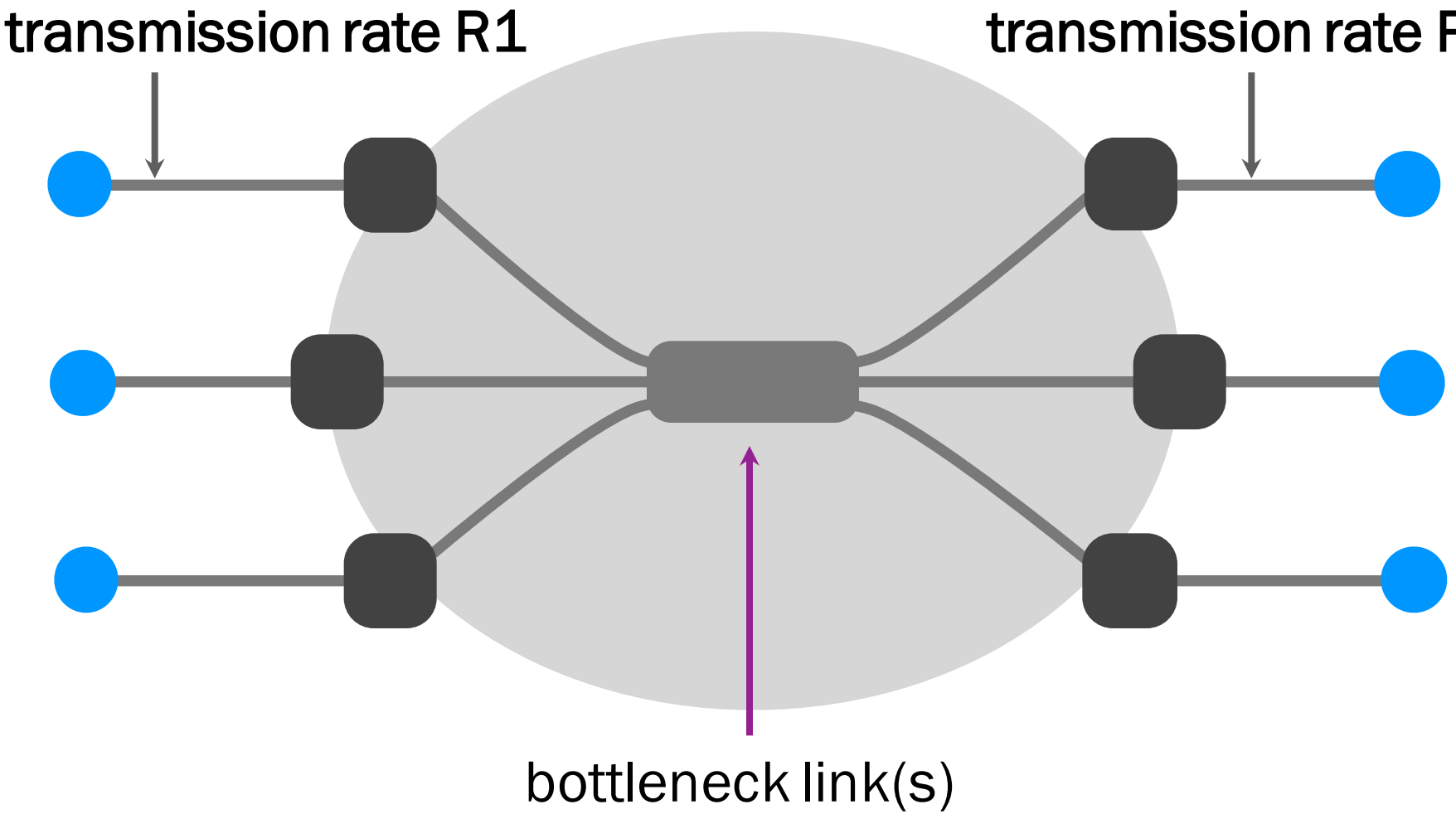
Transfer time = F/R + propagation delay + L/R'

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



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


transmission rate R1
transmission rate R2
bottleneck links


transmission rate R1
transmission rate R2
bottleneck link(s)

Throughput

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

- Later in the quarter
  - *TCP throughput, application-level throughput, etc.*
  - *throughput vs. "goodput"*

Plan of attack

- What is a network made of?
- How is it shared?
- How do we evaluate a network?
- How is communication organized?

Three steps

- Decompose the problem into tasks
- Organize these tasks
- Assign tasks to entities (who does what)

Inspiration…

- CEO A writes letter to CEO B
  - *Folds letter and hands it to administrative aide*
- Aide:
  - *Puts letter in envelope with CEO B's full name*
  - *Takes to FedEx*
- FedEx Office
  - *Puts letter in larger envelope*
  - *Puts name and street address on FedEx envelope*
  - *Puts package on FedEx delivery truck*
- FedEx delivers to other company

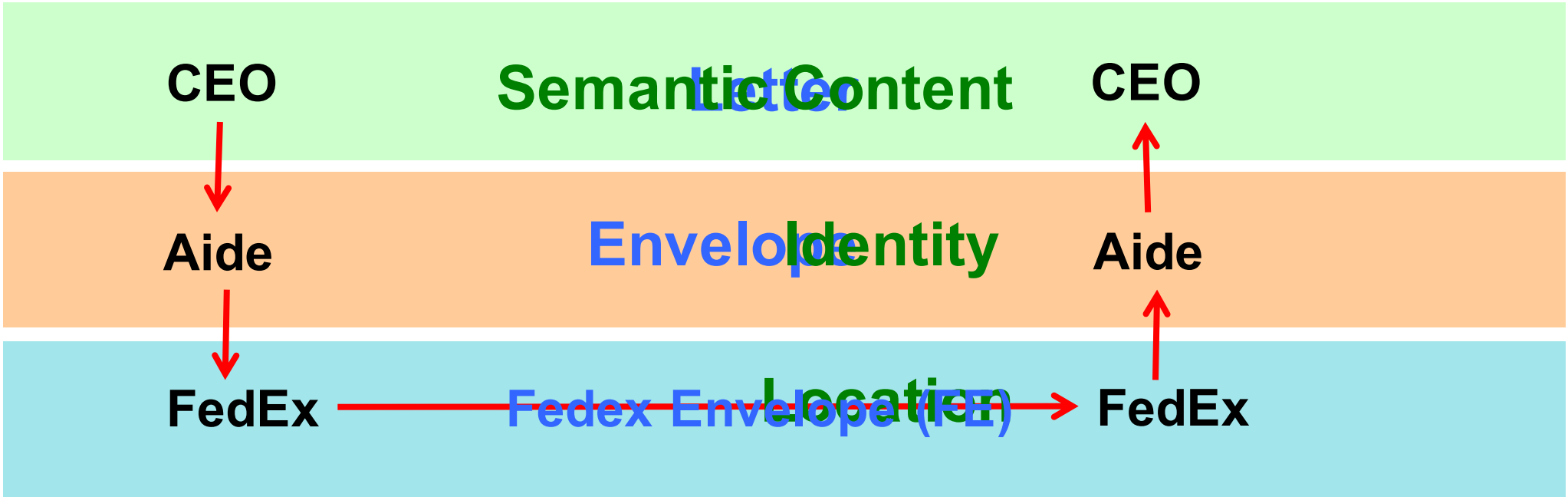
Dear Marissa,

Let's talk merger...

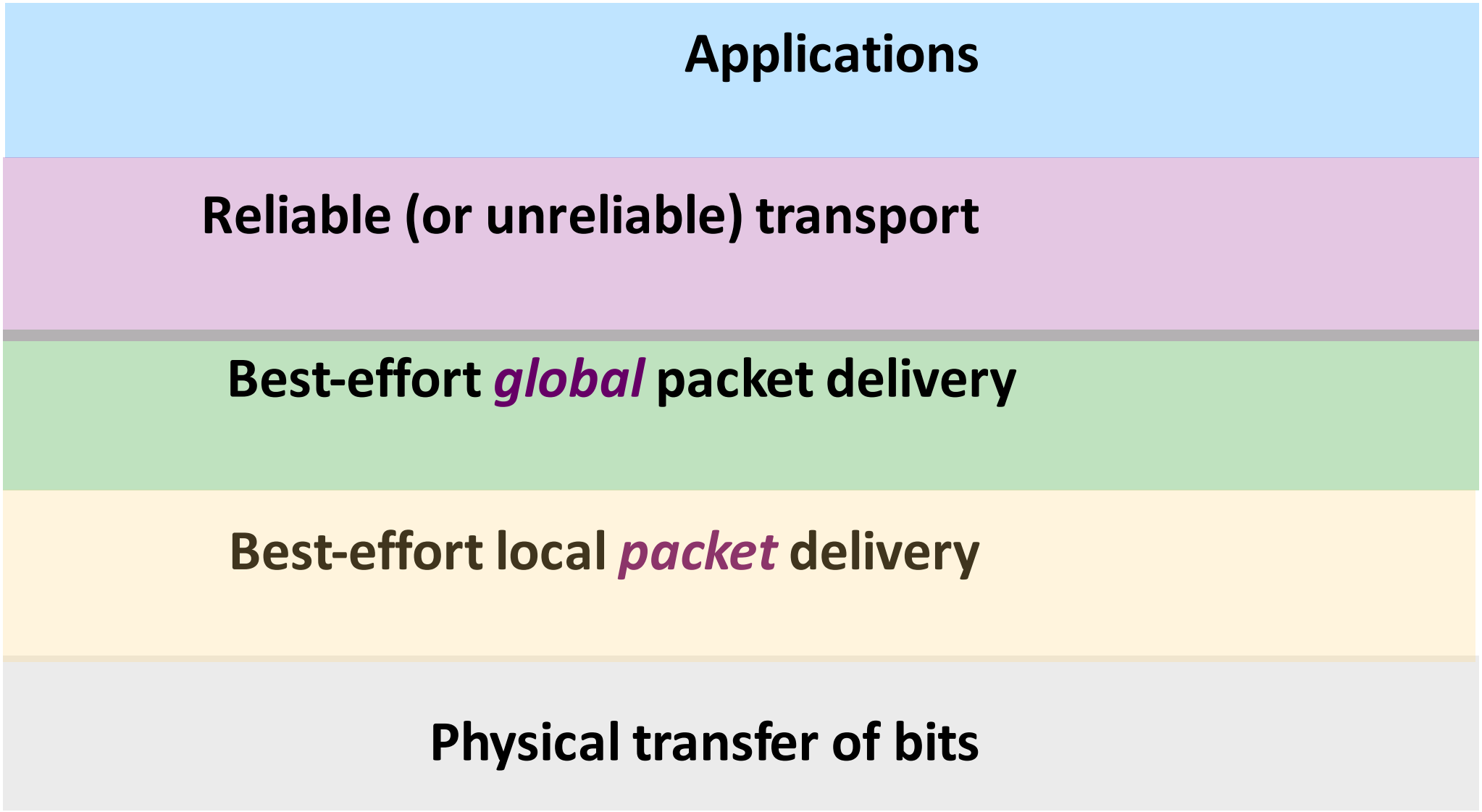
-Jim

The Path of the Letter

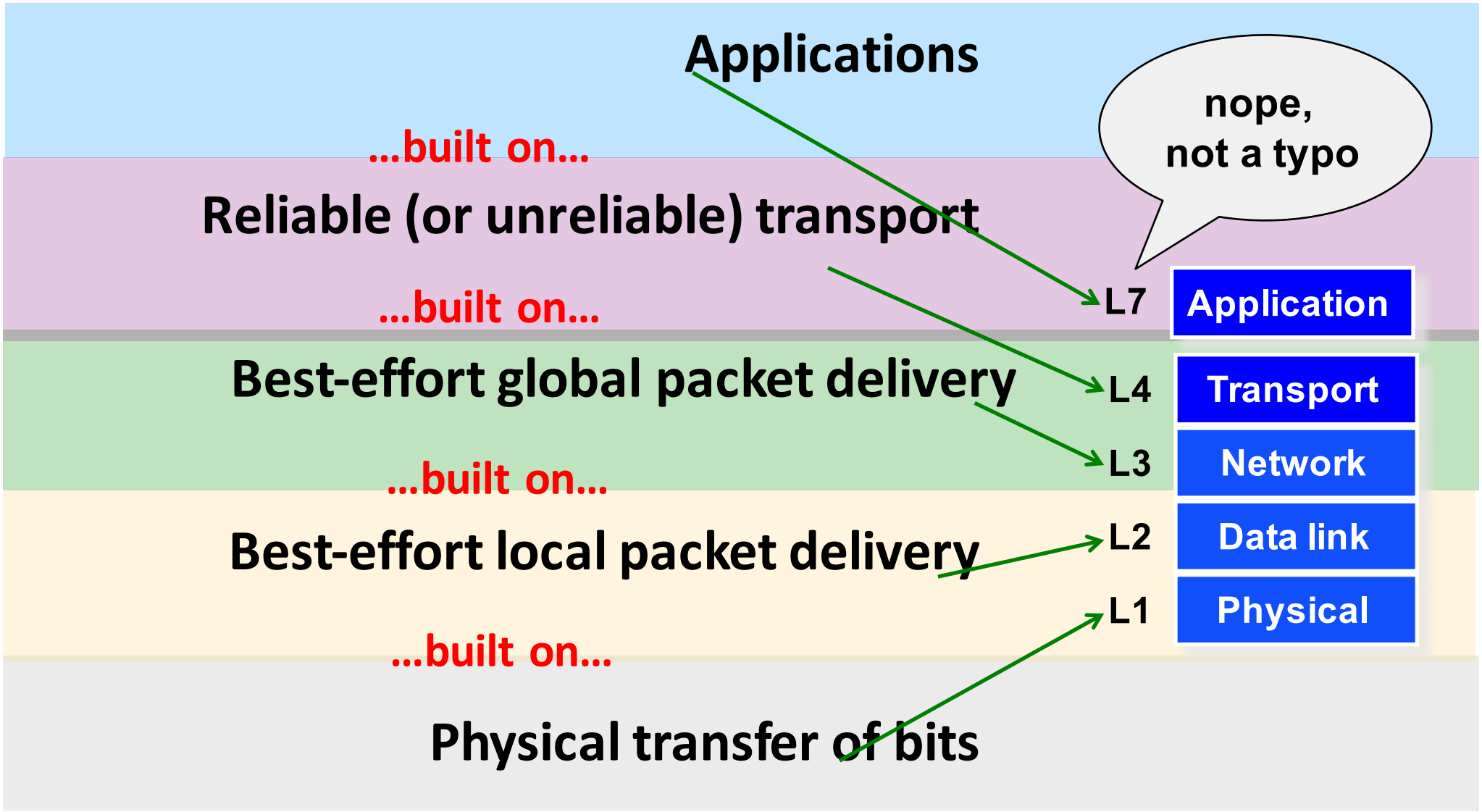
- "Peers" in the same layer understand the same things
- No one else needs to
- Lowest level has most packaging



In the Internet: decomposition



In the Internet: organization



In the context of the Internet

Open Systems Interconnect (OSI) model developed by ISO included two additional layers that are often implemented as part of the application