
Introduction to Networks, Links, OSI Model

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Lecture 1

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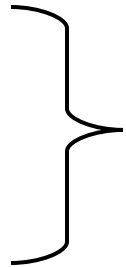
The Four Major Networks

- Telephone
 - Television
 - Radio
 - Internet (grew out of ARPANET—late 1960's)
 - Starting to see hybrids...
- } Special Purpose
- Computer networks
 - General purpose programmable hardware
 - Support many different applications

How to build such a network?

- Connectivity
- Efficient Resource Sharing
- Functionality
- Performance
- *Security*

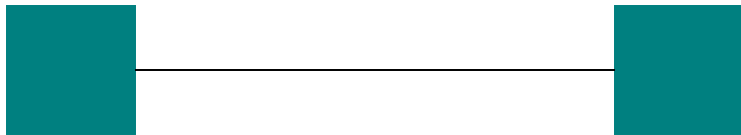
Requirement: Connectivity

- Goal of a network is to get information from one place to another
 - Source
 - Destination
 - *Nodes or Hosts*
 - Network paths
 - Can be *direct* or *indirect*
 - Can be *static* or *dynamic*
- Specified by an *address*
- 

Connectivity: Direct Links

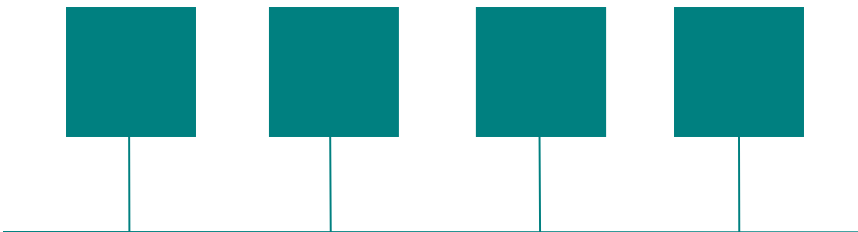
Point to Point

e.g. telephone

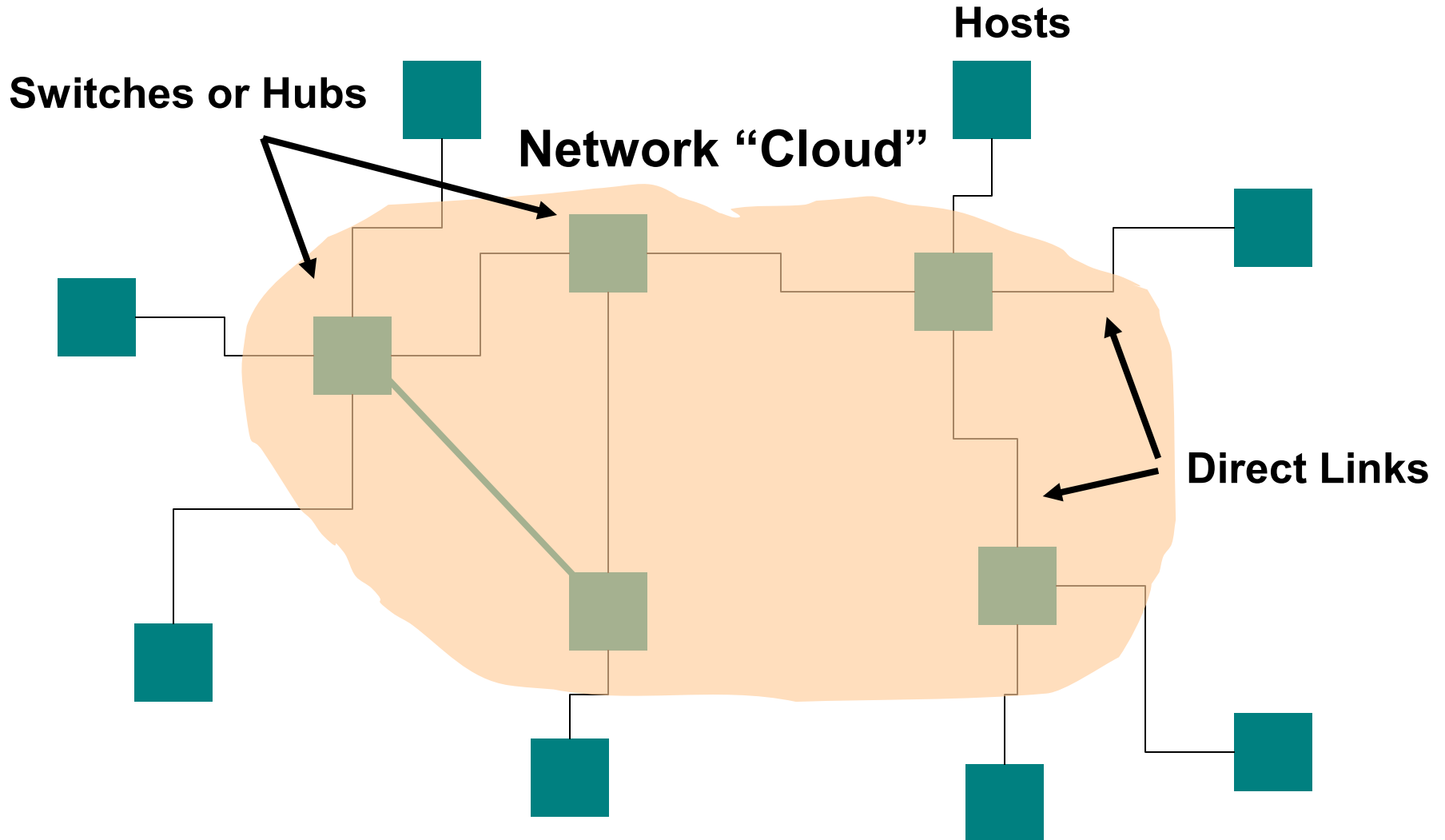


Multiple Access

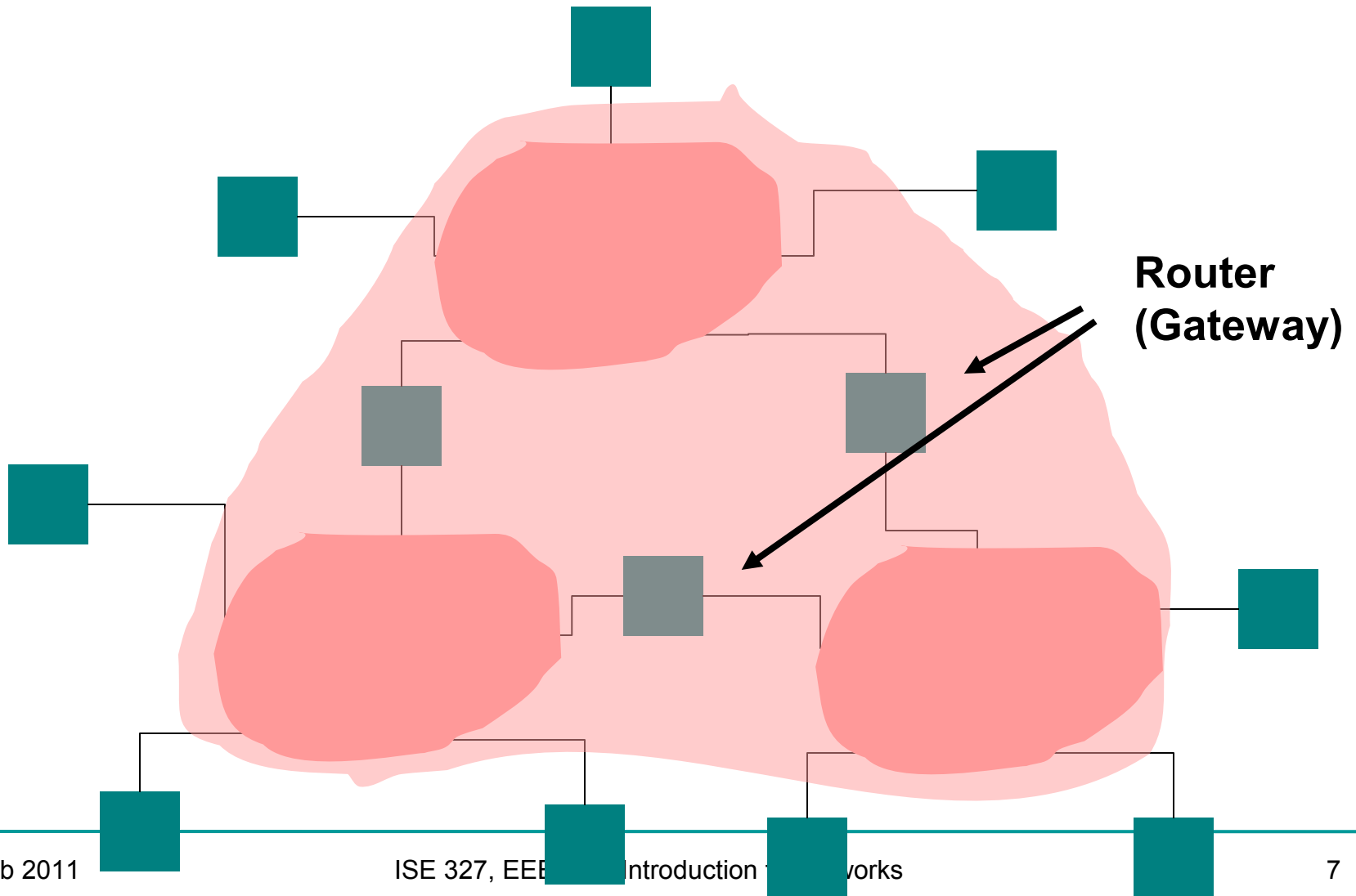
e.g. Ethernet



Connectivity: Switched Networks



Connectivity: Internetworks



Resource Sharing: Multiplexing

- How can multiple hosts share the network if they want to use it at the same time?
 - Sharing links
 - Sharing switches

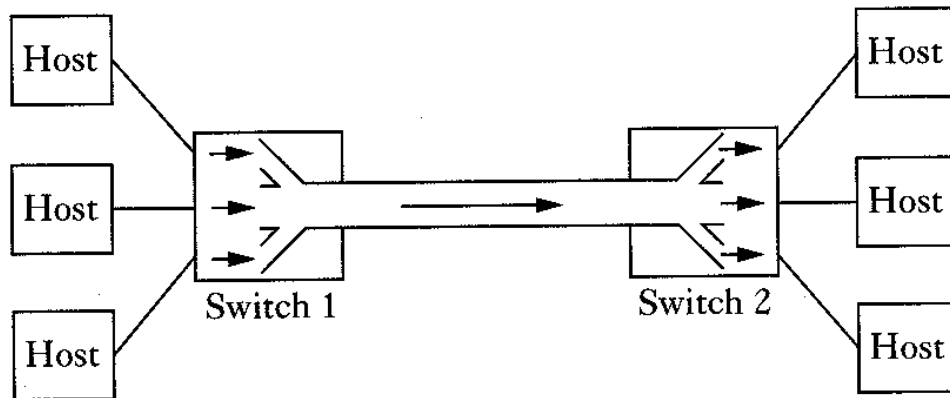


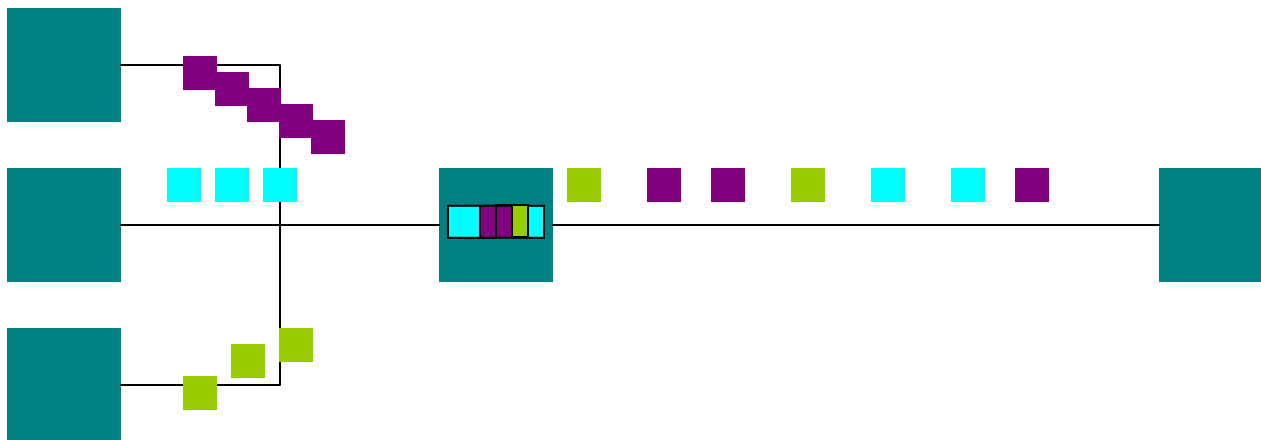
Figure 1.7 Multiplexing multiple logical flows over a single physical link.

Multiplexing: STDM & FDM

- Synchronous Time-division Multiplexing (STDM)
 - “Time sharing”
 - Divide time into equal sized quanta
 - Round-robin
- Frequency-division Multiplexing (FDM)
 - Transmit all flows at different frequencies
 - Radio or Television
- Limitations:
 - Wasted resources
 - Maximum # flows can't be changed

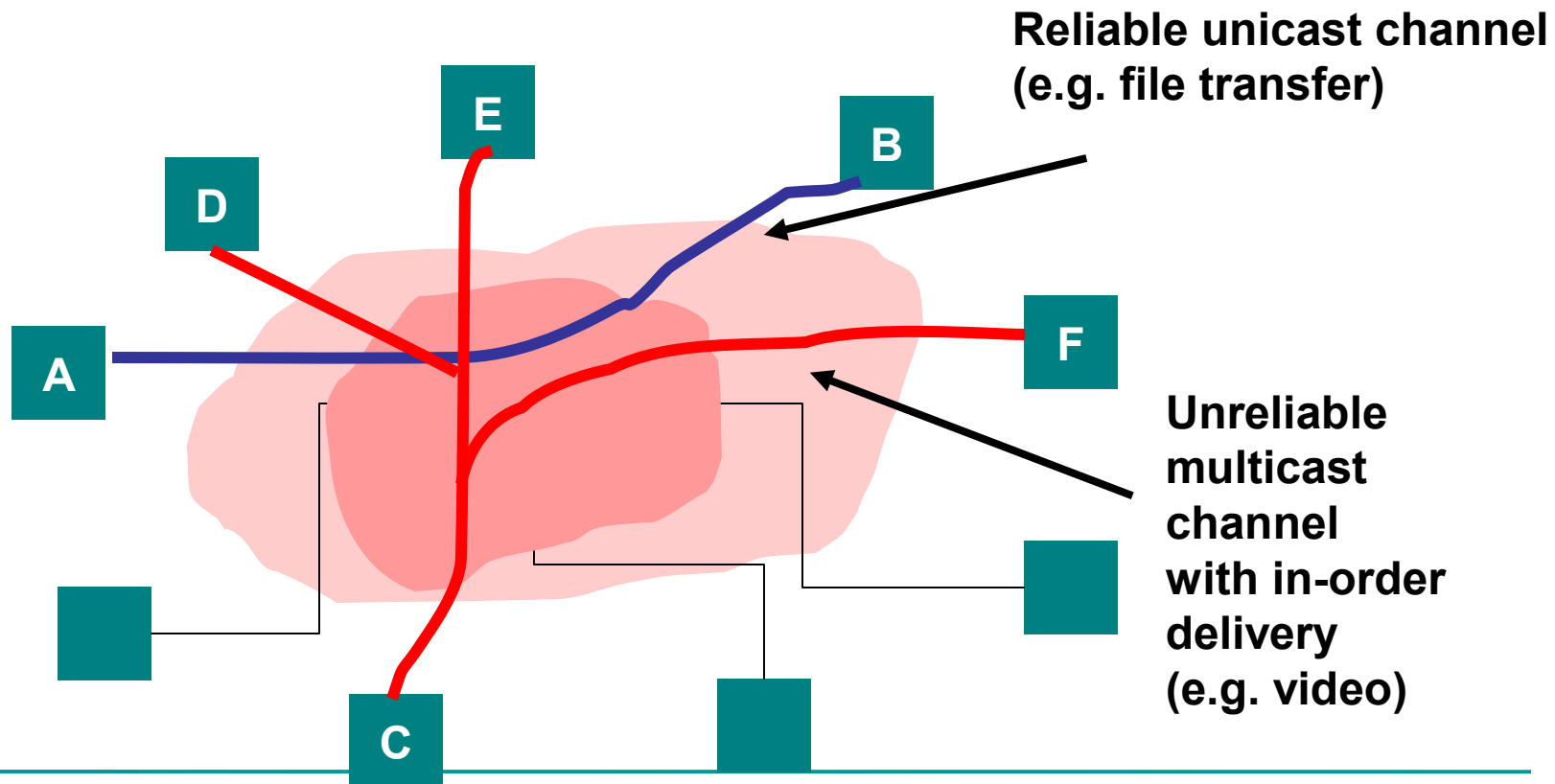
Statistical Multiplexing

- Data is partitioned into *packets*
- Routing decision is made per packet
- Better resource usage than STDM
- Fairness? Congestion?



Functionality

- Different applications require different services



Functionality & Dealing with Failure

- Fairness
- Congestion
- Quality of Service
- Bit or burst errors
- Link or node outages

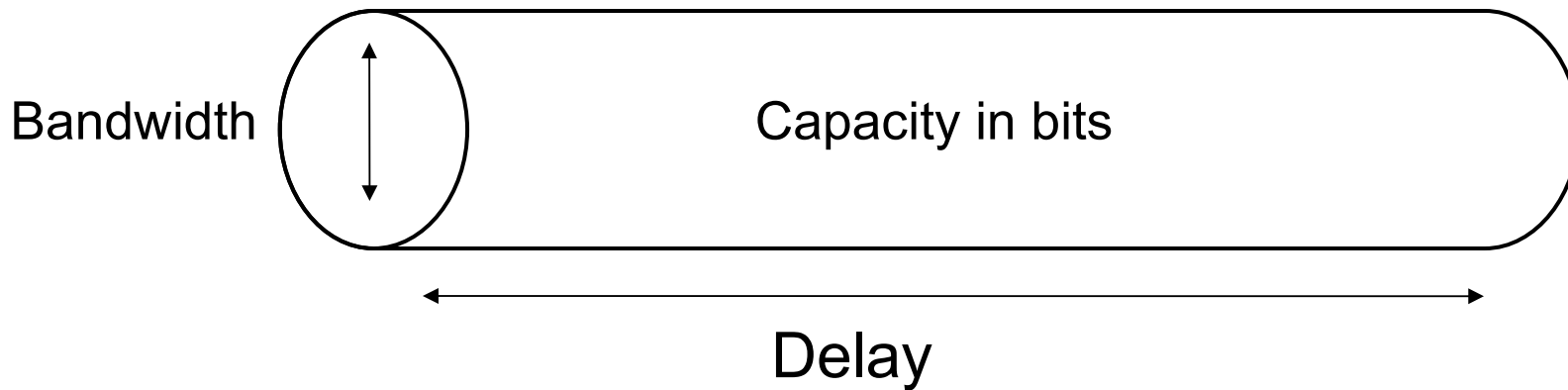
Performance

- *Bandwidth (throughput)*
 - The number of bits that can be transmitted over the network in a certain period of time.
 - Measured in bits/sec
- *Latency (delay)*
 - How long it takes a single bit to propagate from one end of the network to the other.
 - Measured in seconds
- *Round Trip Time (RTT)*
 - How long it takes for a bit to get from one end of the network to the other and back

Connectivity: Direct Link Technologies

Wired Ethernet	10, 100 Mbps, 1, 10 Gbps
SONET fiber up to 9.6 Gbps	Synchronous Optical Network
CATV 1-6 Mbps, asymmetric	Cable TV
ADSL Asymmetric Digital Subscriber Line	Downstream: 1.5-55.2 Mbps Upstream: 16-640 Kbps
ISDN Integrated Services Digital Network	64 Kbps * n with bonding
POTS Plain Old Telephone Service	56 Kbps
Wireless Ethernet	2, 11, 22, ... Mbps
Infrared IrDA	115 Kbps to 4 Mbps
CDPD Cellular Digital Packet Data	19.2 Kbps

Performance: Delay x Bandwidth



Delay x Bandwidth determines the number of bits that can be “in flight”.
For efficient resource usage: keep the pipe full.

Key Equations

- $\text{Latency} = \text{Propagation} + \text{Transmit} + \text{Queue}$
- $\text{Propagation} = \text{Distance} / \text{SpeedOfLight}$
- $\text{Transmit} = \text{Size} / \text{Bandwidth}$

Total Latency: Direct Link



Data moves through the link at the speed of light.

Time
0

Data ready to be sent

Total Latency: Direct Link



Data moves through the link at the speed of light.

Time

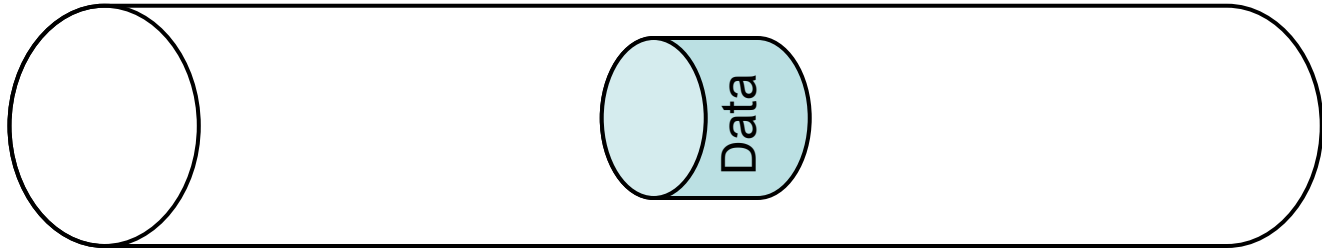
0

$t = \text{Size}/\text{Bandwidth}$

Data ready to be sent

Data in the link

Total Latency: Direct Link



Data moves through the link at the speed of light.

Time

0

$t = \text{Size}/\text{Bandwidth}$

$t+k$

Data ready to be sent

Data in the link

Data traveling through the link

Total Latency: Direct Link



Data moves through the link at the speed of light.

Time

0

$t = \text{Size}/\text{Bandwidth}$

$t+k$

$\text{prop} = \text{Distance}/\text{LightSpeed}$

Data ready to be sent

Data in the link

Data traveling through the link

First bit arrives at destination

Total Latency: Direct Link



Data moves through the link at the speed of light.

Time

0

$t = \text{Size}/\text{Bandwidth}$

$t+k$

$\text{prop} = \text{Distance}/\text{LightSpeed}$

$\text{prop} + t$

Data ready to be sent

Data in the link

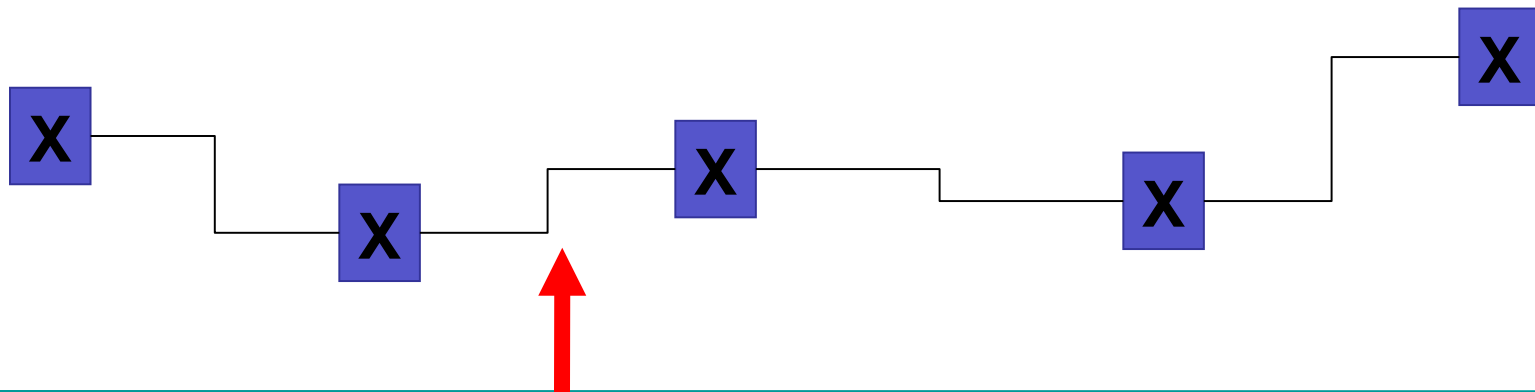
Data traveling through the link

First bit arrives at destination

Last bit arrives at destination

Paths Are Made of *Links*

- Links are interconnected by zero or more *network elements*, e.g., switches, routers, hubs, bridges, etc.
- Path delay is sum of link delays plus queuing (switching) delays
- Path throughput = *bottleneck link* throughput



Tradeoffs

- RTT from Hispin to UPenn is approx. 219ms
- 1.4 GHz workstation
 - 306.6 million cycles elapsed in that time
- Data compression
 - Trades machine cycles for bandwidth
- (Question: Why is RTT important?)

Bandwidth vs. Latency

- Which is the better deal:
 - Improve your *bandwidth* from 1 Mbps to 100 Mbps, or
 - Improve your *RTT* from 100 ms to 1 ms?
- The answer depends on what you need to send.

Latency Bound

- Send 1 byte

Transmit Time	
1 Mbps	8 μ s
100 Mbps	0.08 μ s

Perceived Latency	100 ms	1 ms	
1 Mbps	100.008 ms	1.008 ms	99%
100 Mbps	100.00008 ms	1.00008 ms	99%
	0.008%	0.8%	

Bandwidth Bound

- Send 25 mb

Transmit Time	
1 Mbps	209.7152 sec
100 Mbps	2.097152 sec

Perceived Latency	100ms	1ms	Difference
1 Mbps	209.8152 sec	209.7162 sec	0.047%
100 Mbps	2.197152 sec	2.098152	4.7%
	98.9%	98.99%	

Some Units and Measurements

- Mbps = 10^6 bits/sec
- byte = 8 bits
- KB = 2^{10} bytes (= 8,192 bits)
- MB = 2^{20} bytes (= 8,388,608 bits)
- ms = 10^{-3} seconds
- μ s = 10^{-6} seconds

- Speed of light:
 - Vacuum : 3×10^8 m/sec
 - Copper or Fiber: 2×10^8 m/sec