
Introduction to Networks, Links, OSI Model

7 March 2010
Lecture 1

Slides Credits: Steve Zdancewic (UPenn)

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

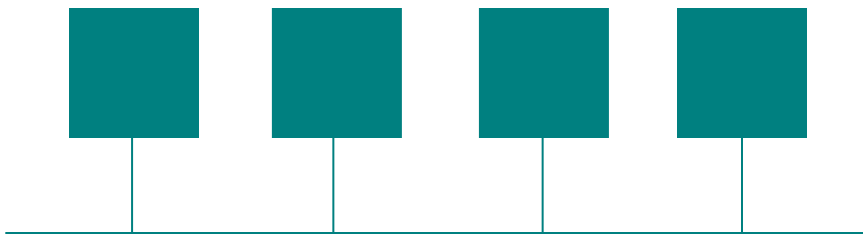
- Goal of a network is to get information from one place to another
 - Source
 - Destination
 - *Nodes or Hosts*
 - Network paths
 - Can be *direct* or *indirect*
 - Can be *static* or *dynamic*
- } Specified by an *address*

Connectivity: Direct Links

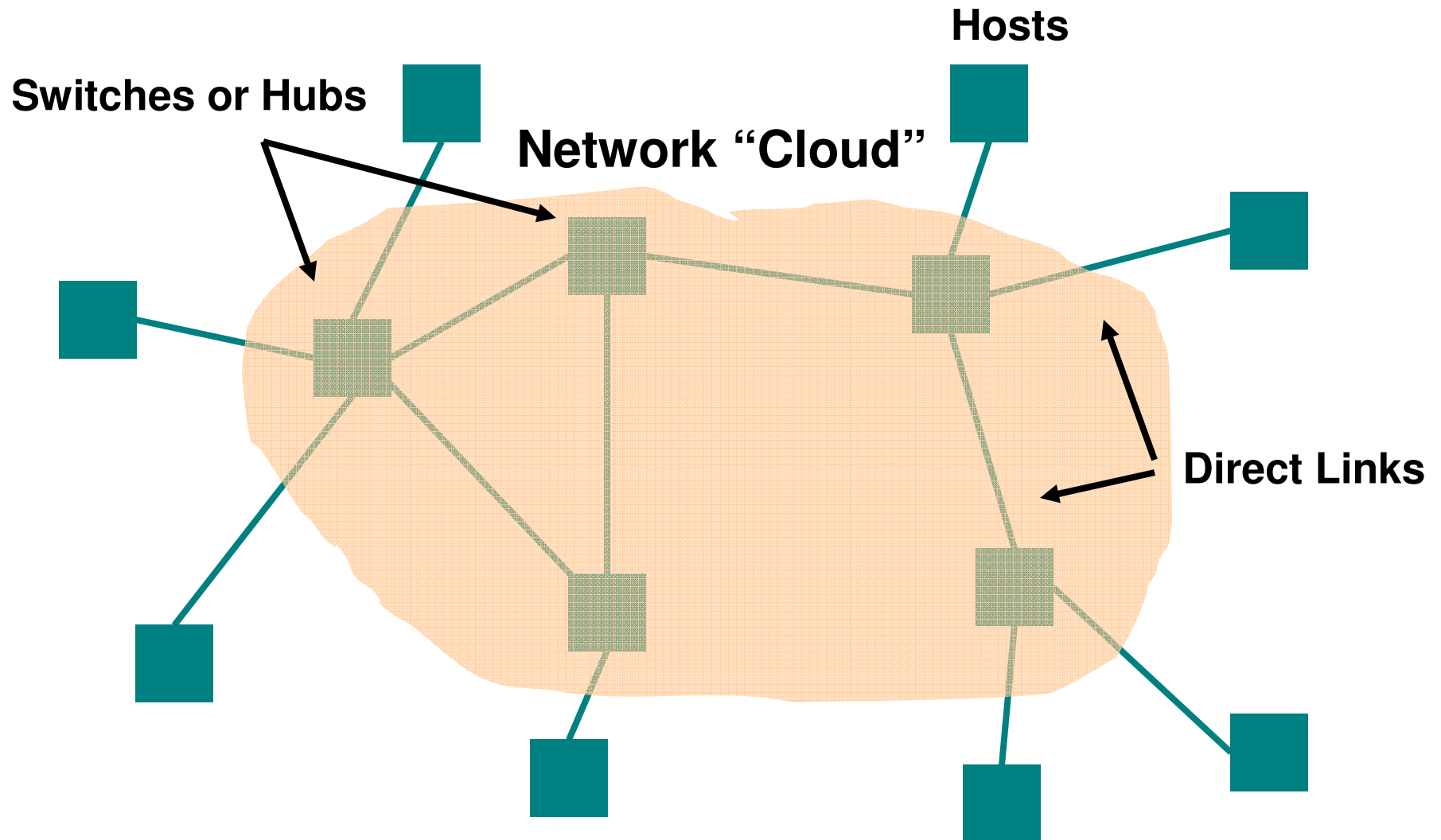
Point to Point
e.g. telephone



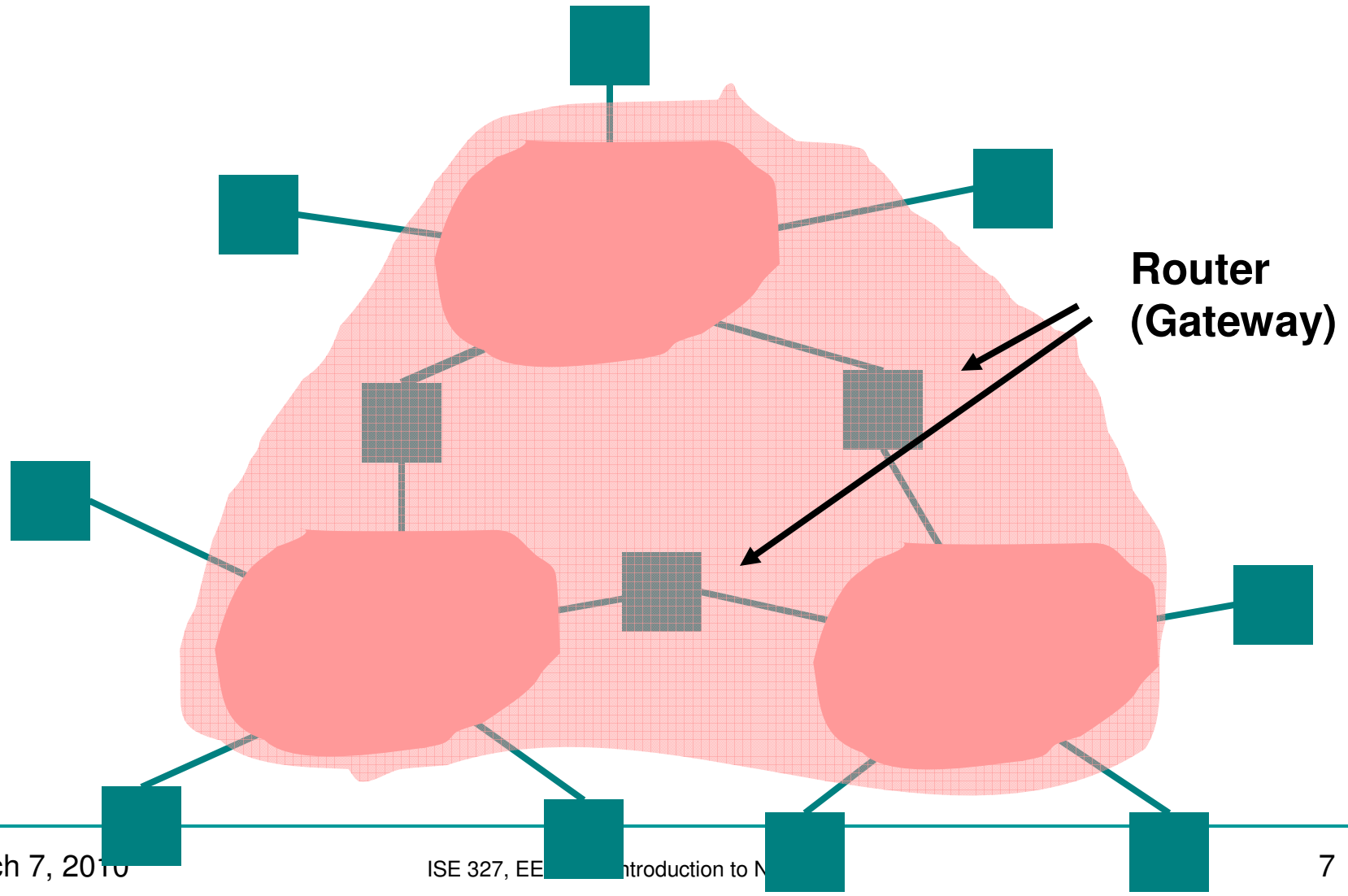
Multiple Access
e.g. Ethernet



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

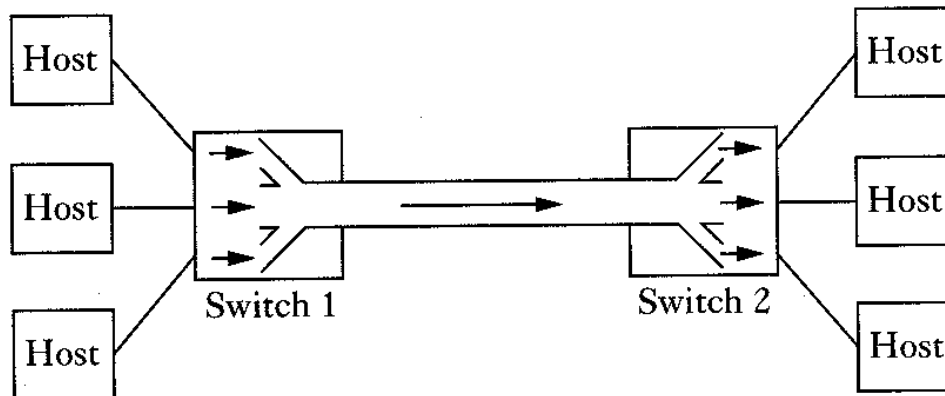


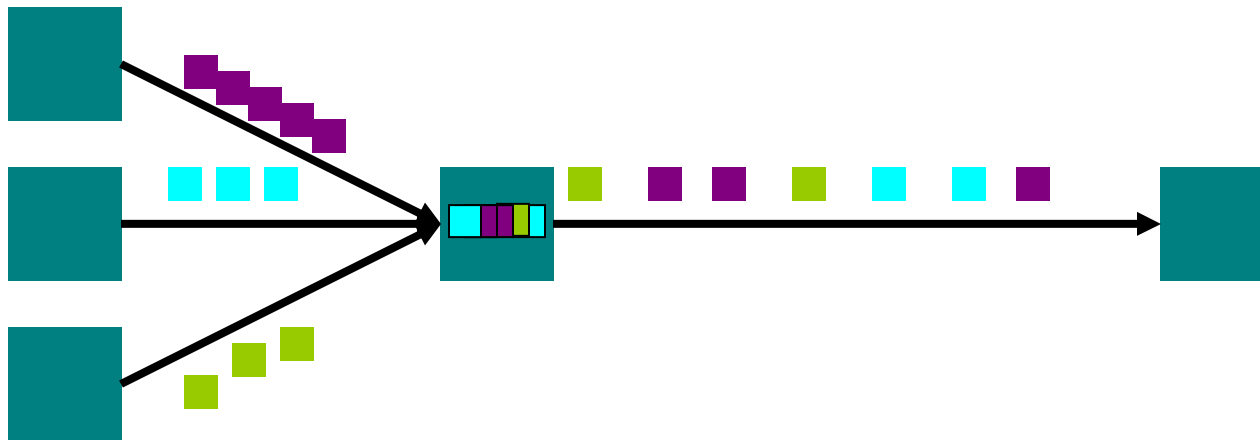
Figure 1.7 Multiplexing multiple logical flows over a single physical link.

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

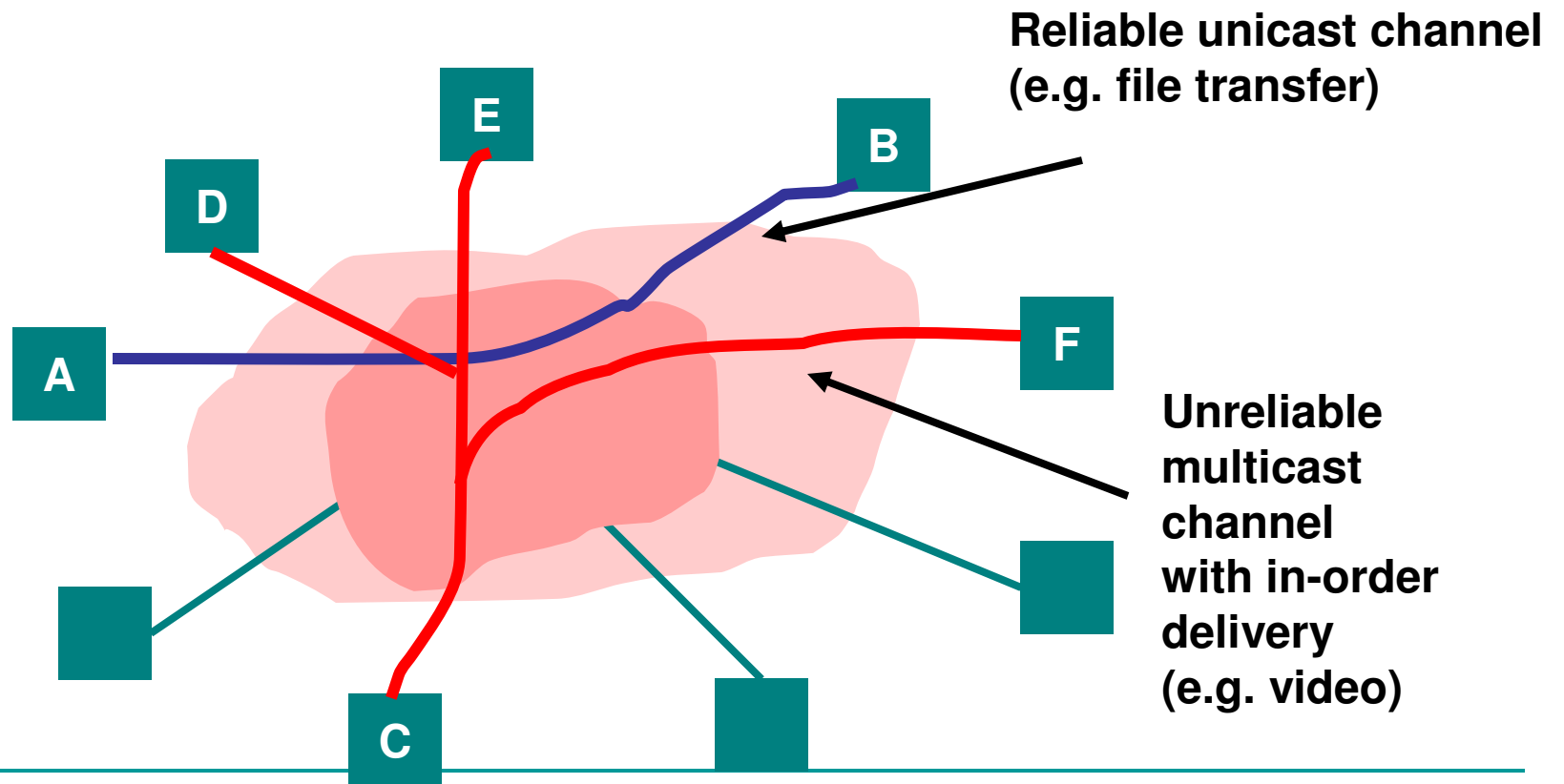
Statistical Multiplexing

- 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

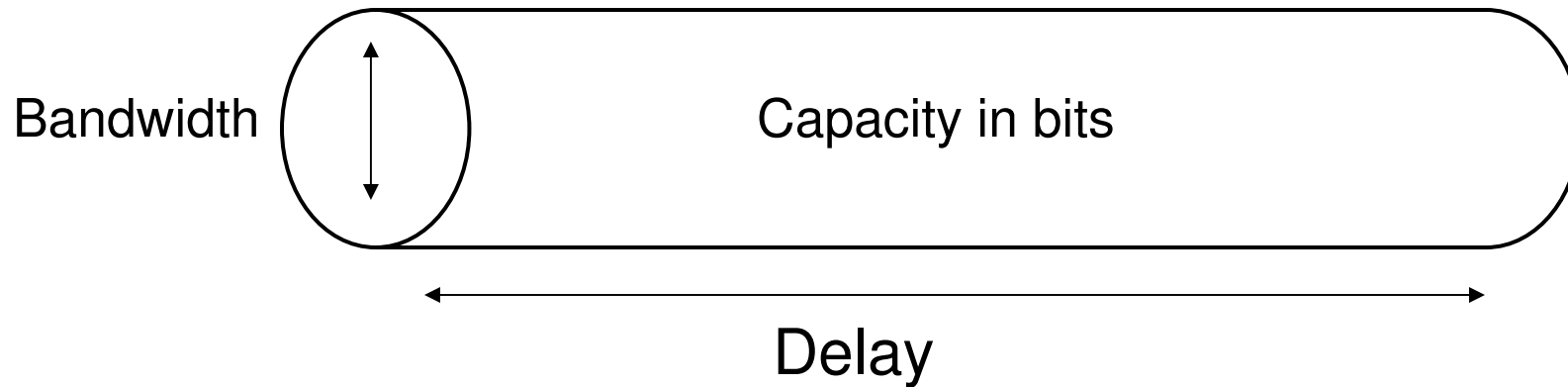
Performance

- *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

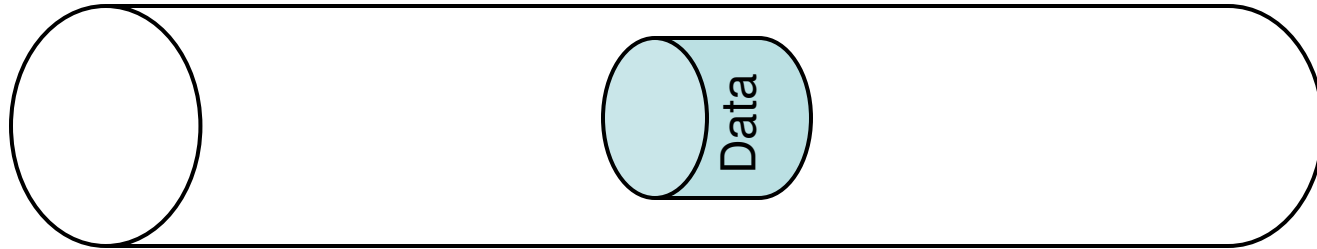
0

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

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

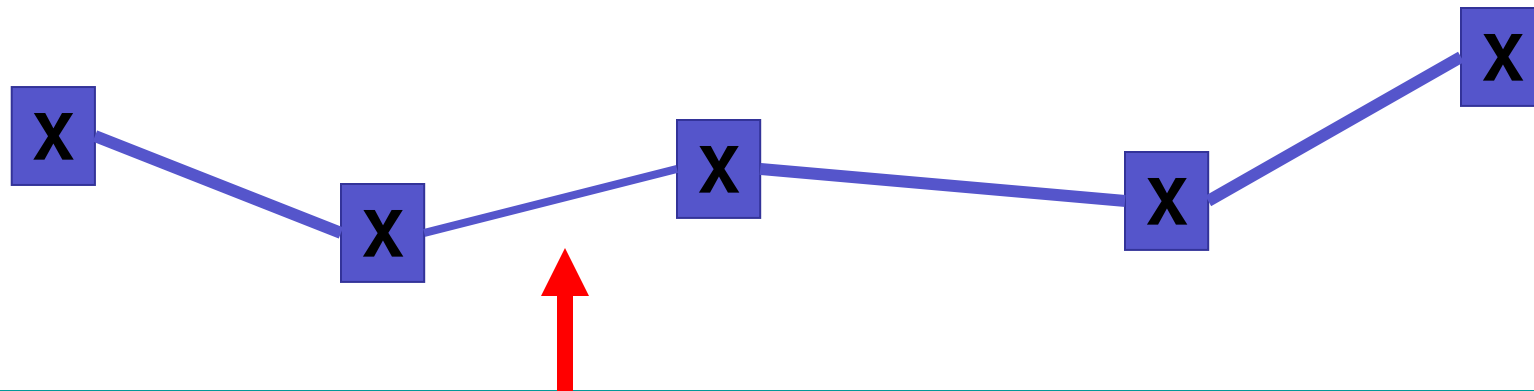
Data traveling through the link

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	3.5 min
100 Mbps	21 sec

Perceived Latency	
1 Mbps	210.1 sec
100 Mbps	21.1 sec

100 ms | 1 ms

210.001 sec .05%
21.001 sec 0.5%
0.8%

90%

The diagram illustrates the impact of bandwidth on perceived latency. It is divided into two sections by a red horizontal line. The top section, 'Transmit Time', shows that at 1 Mbps, it takes 3.5 minutes to transmit 25 MB, while at 100 Mbps, it takes only 21 seconds. The bottom section, 'Perceived Latency', shows that at 1 Mbps, the total perceived latency is 210.1 seconds, with a 100 ms delay accounting for 90% of the total. At 100 Mbps, the total perceived latency is 21.1 seconds, with a 1 ms delay accounting for 0.8% of the total. A blue circle highlights the 90% value.

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

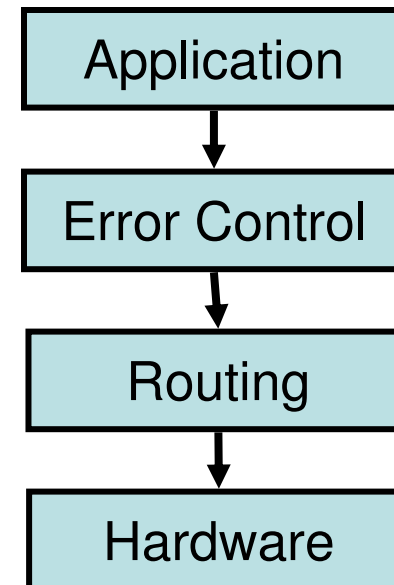
- Speed of light:
 - Vacuum : 3×10^8 m/sec
 - Copper or Fiber: 2×10^8 m/sec

Network Architecture

- General blueprints that guide the design and implementation of networks
- Goal: to deal with the complex requirements of a network
- Use *abstraction* to separate concerns
 - Identify the useful service
 - Specify the interface
 - Hide the implementation

Layering

- A result of abstraction in network design
 - A stack of services (layers)
 - Hardware service at the bottom layer
 - Higher level services are implemented by using services at lower levels
- Advantages
 - Decompose problems
 - Modular changes



Protocols

- A *protocol* is a specification of an interface between modules (often on different machines)
- Sometimes “protocol” is used to mean the implementation of the specification.

Interprocess communication

