CS 352
Internet Technology

Lecture 2

http://www.cs.rutgers.edu/~sn624/352-S19

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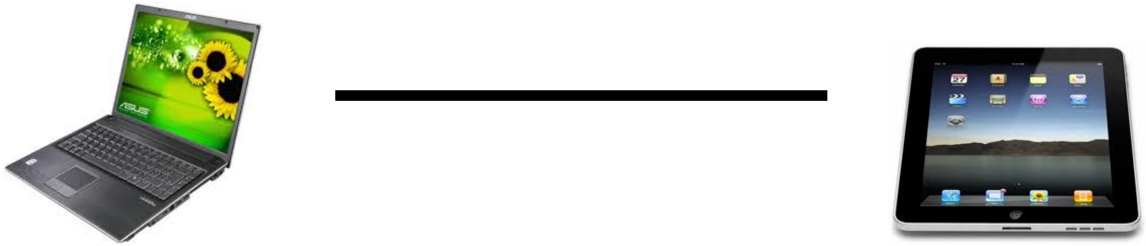
Some definitions

- Host: Machine running user application
- Packet: a unit of data transmission (ex: 1500 bits)
- Link: a physical communication channel between two or more machines
- Router: A machine that processes packets moving them from one link to another towards a destination
- Network: Collection of interconnected machines

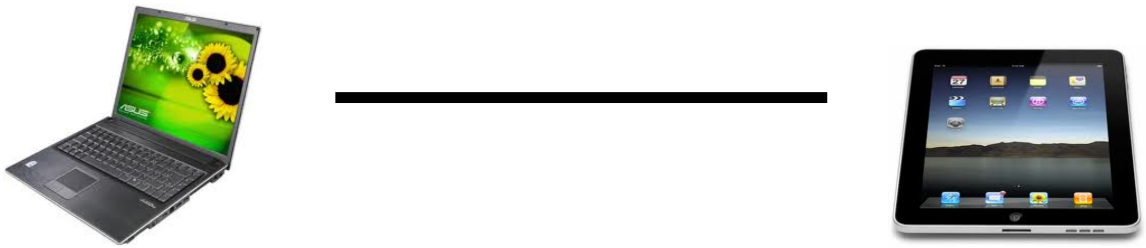
How do machines communicate?

How do machines communicate?

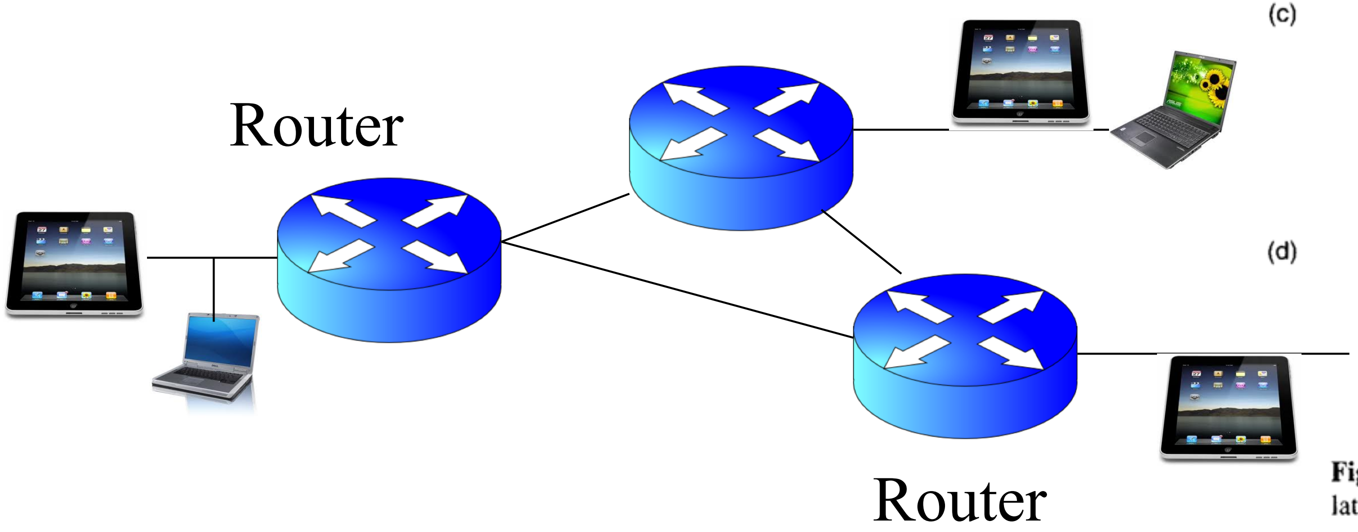
- With 1s and 0s
  - Computers only deal with 1s and 0s
  - So do networks
- How do we transmit 1s and 0s in a network?



Physical transmission on a single link



How about multi-link networks?



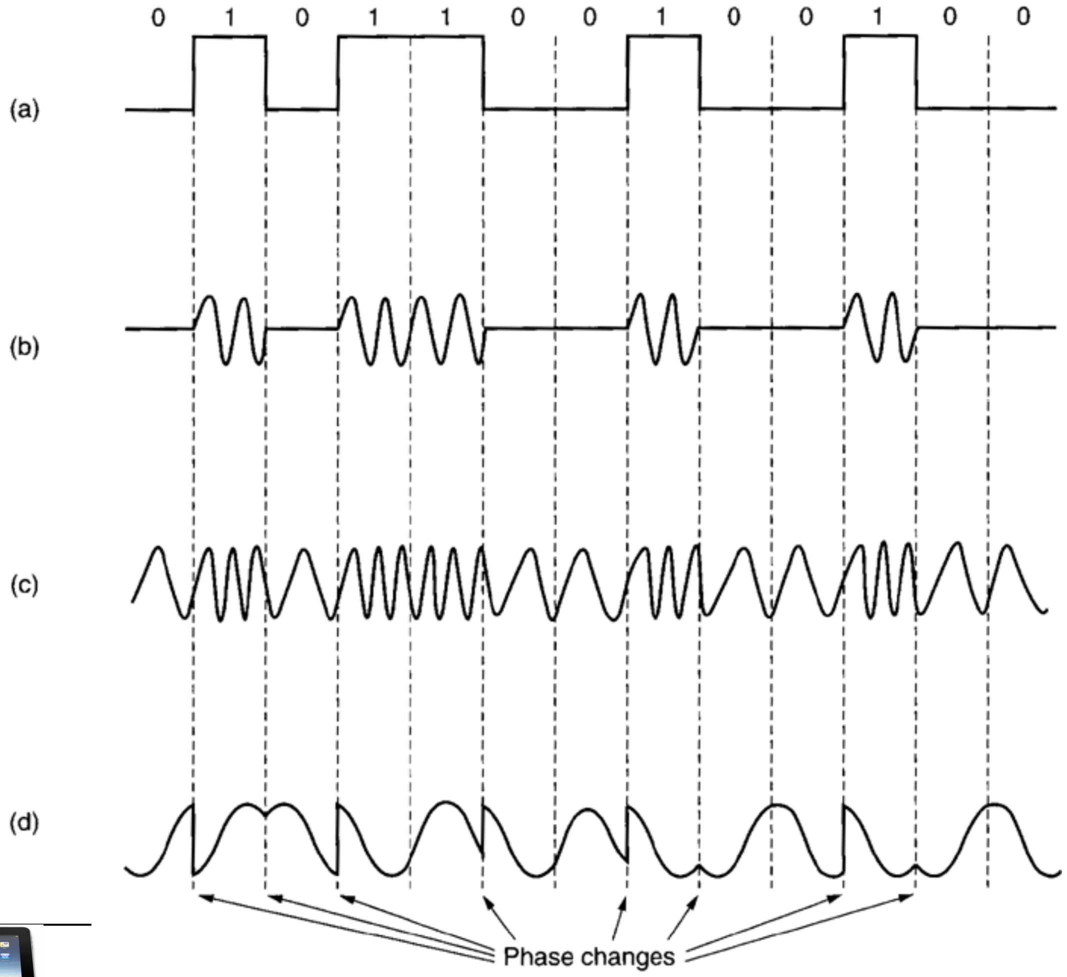


Fig. 2-18. (a) A binary signal. (b) Amplitude modulation. (c) Frequency modulation. (d) Phase modulation.

Switching schemes

Host applications transfer data containing many messages.

(1) Circuit Switching

(2) Message Switching (Store-and-Forward)

(3) Packet Switching (Store-and-Forward)

Circuit switching

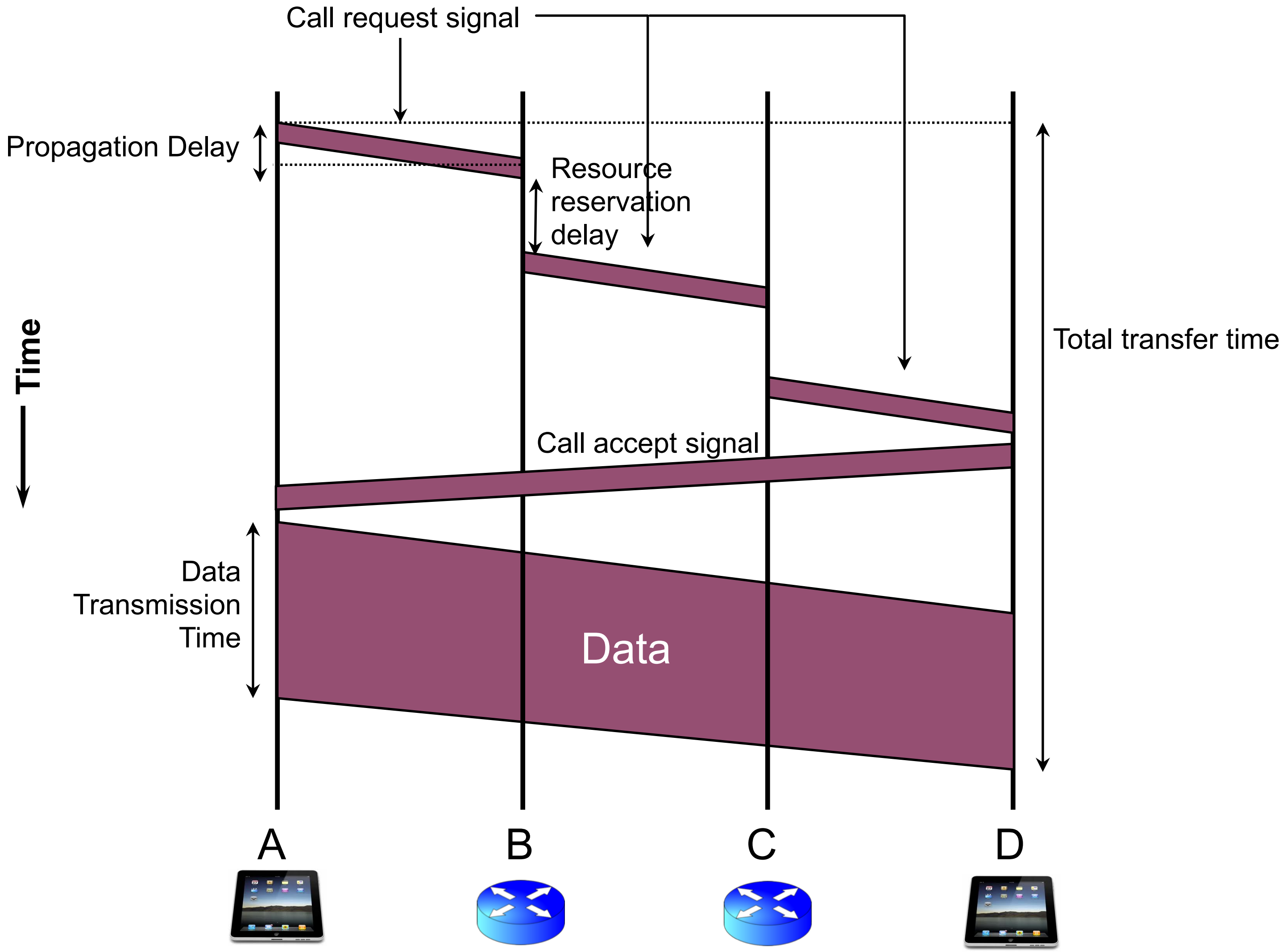
- Provides service by setting up the total path of connected lines from the origin to the destination

- Example: Telephone network

Circuit switching

1. Control message sets up a path from origin to destination
2. Return signal informs source that data transmission may proceed
3. Data transmission begins
4. Entire path remains allocated to the transmission (whether used or not)
5. When transmission is complete, source releases the circuit

Circuit switching



Message switching

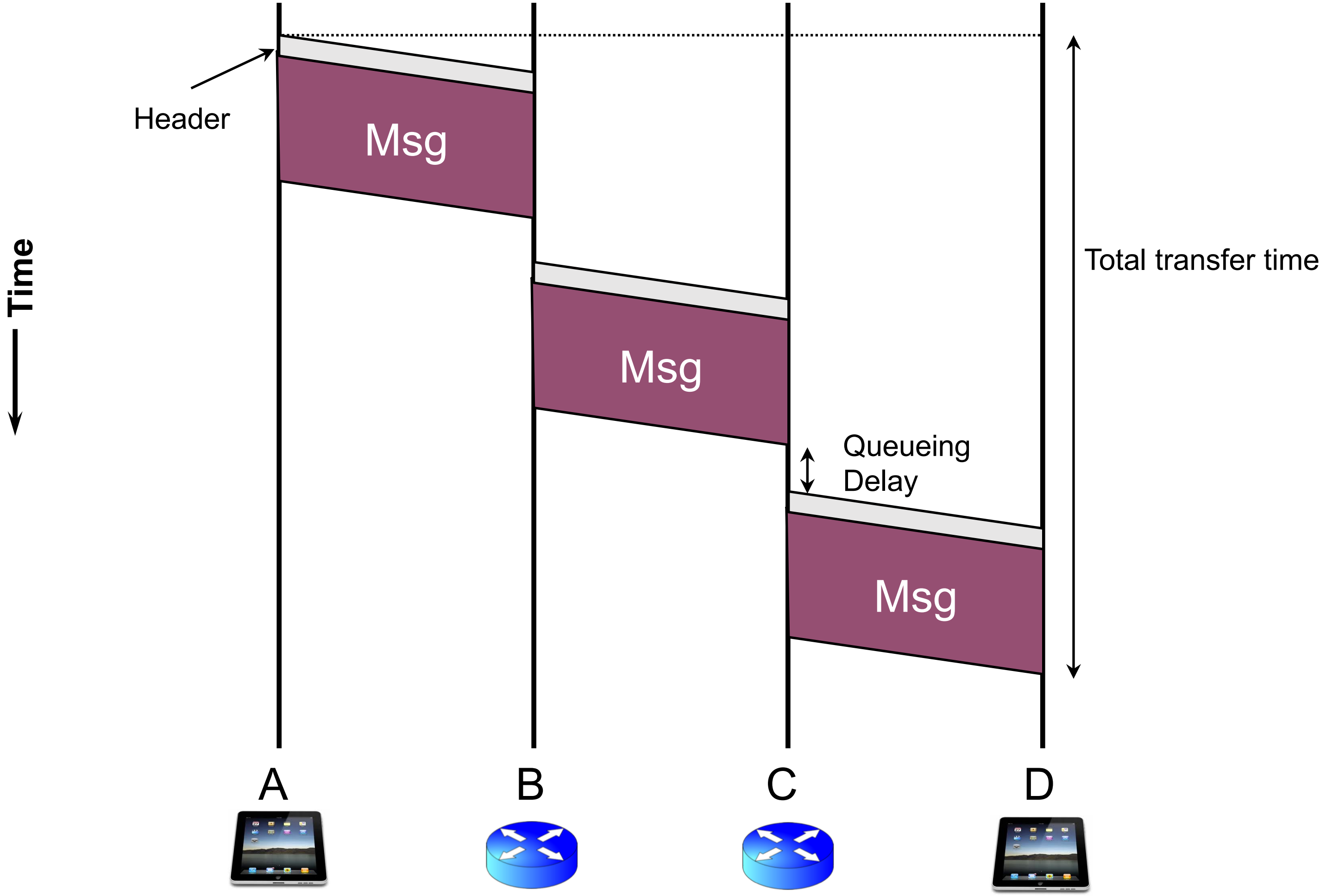
- Each message is addressed to a destination
- **Header:** metadata that denotes how to process a message
- The message “hops” from node to node through a network while allocating only one link at a time
  - Compare to circuit switching: all links reserved at the same time, regardless of use.
- Analogy: Postal service

Message switching

- When the entire message is received at a router, the next step in its journey is selected; if this selected channel is busy, the message waits in a **queue** until the channel becomes free

- **Store and forward** switching: router waits for all packet bits to arrive on incoming link before sending first bit on outgoing link
  - Compare to “cut–through” switching

Message Switching

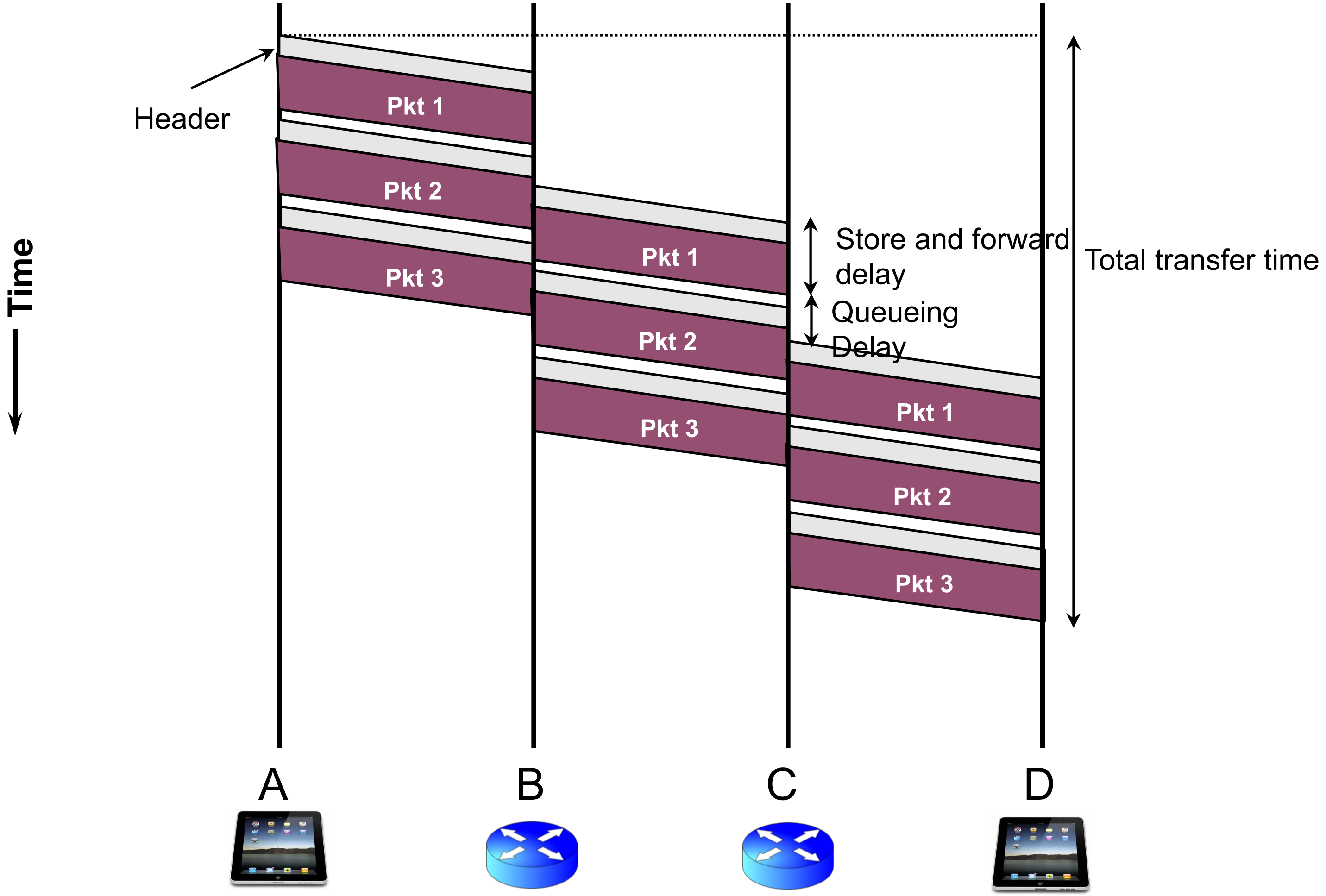


Packet switching

- Messages are split into smaller pieces called **packets**
  - Packets are numbered and addressed
  - Sent through the network one at a time

- **Pipelining:** different parts of a message concurrently transmitted over different links
  - Provides higher utilization of link resources

Packet switching



The Internet uses store-and-forward packet switching.

Some comparisons

(1) **Header Overhead** (what % of bits on the wire is metadata?)

Circuit < Message < Packet

(2) **Total Delay**

Short Bursty Messages:

Message < Circuit

Long Continuous Messages:

Circuit < Message

Telephone Network

- Connection-based
- Admission control
- Intelligence is "in the core network"
- Every service provided by the telephone company
- Traffic carried by relatively few, "well-known" communications companies

Internet

- Packet-based
- Best effort
- Intelligence is "at the endpoints"
- Services provided by anyone
- Traffic carried by many routers, operated by many service providers

Some definitions

- Packet length: size of a packet (bits or bytes)
- **Bandwidth**: For a single link, amount of data it can transmit per unit time (bits/second or Bytes/second or packets/second)
- **Propagation delay:** Time needed to move one bit across (second)
  - Imposed by the communication medium; depends on the effective link length
- **Packet transmission time:** for a single link, the time required to transmit an entire packet from a sender to a receiver (seconds)
  - Time between the first bit and last bit at the receiver
- **Total transfer time:** time from first bit@sender to last bit@receiver
  - propagation delay + transmission time for a single packet

Analogy: Conveyor belt

- Propagation delay = time for first box to travel the length of the belt
- Bandwidth = the number of boxes put on the belt per minute (“rate”)
- Suppose we have N boxes in one shipment
- Shipment transmission time = N / rate
    - The next box is put on the belt (1/rate) minutes after the last
- Total transfer time = transmission time + propagation delay

Protocols and Layering

Protocols: The “rules” of networking

- A protocol constitutes two things:

- *Message interface*: messages exchanged with a peer (ex: between two communicating hosts or routers)

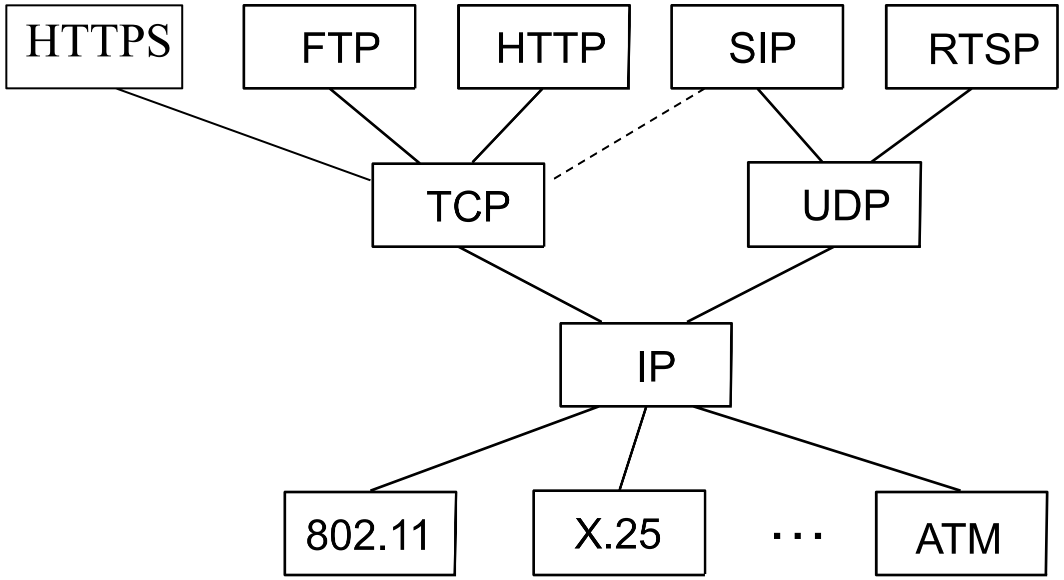
- *Actions:* operations on receiving (or not receiving) messages

- We use the term protocol to refer both to the specification and the implementation of these two notions.

The protocols of the Internet

- Defined by the Internet Engineering Task Force (IETF)
  - … through RFCs ("Request For Comments")

- **Layering** and **Hourglass Design**

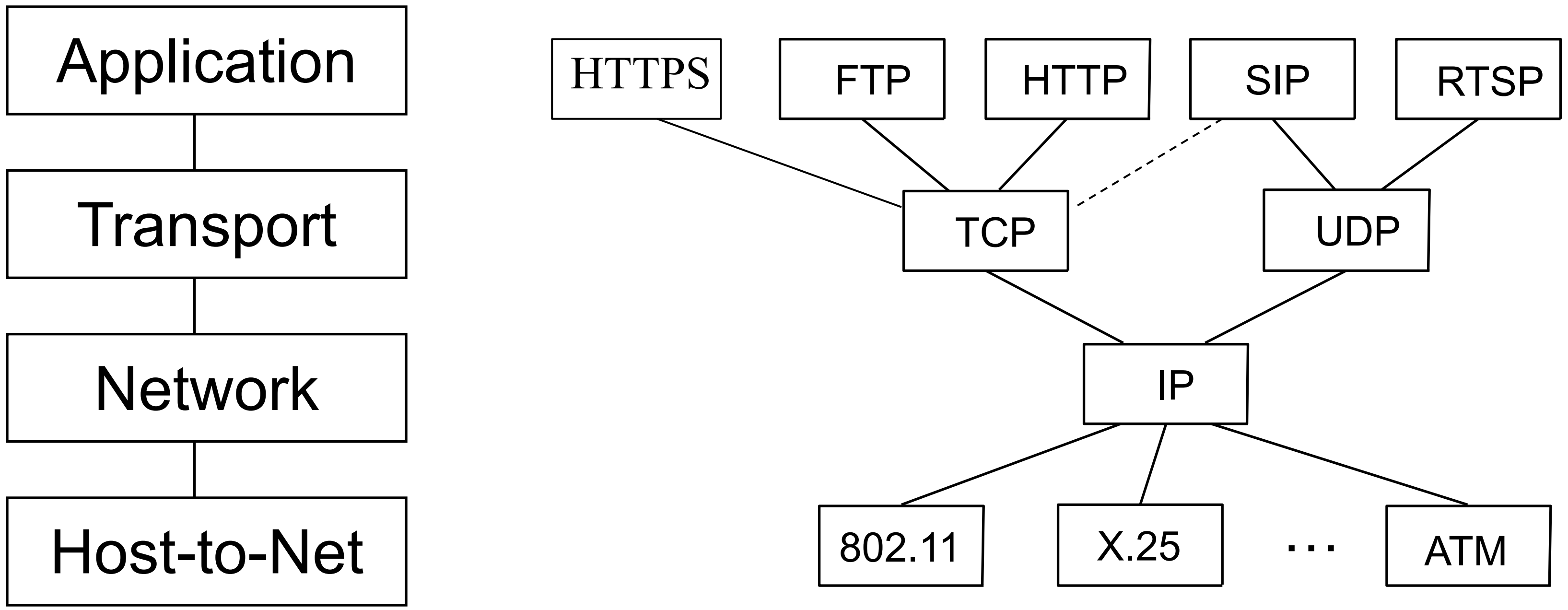


Layering

- Protocols at higher layers build on the ones at lower layers
- Layering is a form of **modularity**
  - Example: Break laundry up into washing and drying
  - A washer only washes; a dryer only dries
  - Each picks one task and does it very well

- Network communication is very complex
- Layering simplifies understanding, testing, maintaining
- Easy to improve or replace protocol at one layer
  - Without affecting other layers

TCP/IP Layering Architecture



Host-to-network layer: (a) Physical Layer

- The physical layer transmits the raw bit stream between two endpoints of a physical link
- Functions:
  - Modulation of bits over physical signals
  - Performing bit-serial or parallel signal transmission
  - Half- or Full-duplex transmission
- Concerns
  - How many pins does the network connector have?
  - How is physical connectivity set up or torn down?

Host-to-network layer: (b) Data Link Layer

- The data link layer provides the network layer with what appears to be an error-free link to the other side of the link

- Functions:
    - Provides reliable transfer of information between two adjacent nodes
    - Creates frames, or packets, from bits and vice versa
    - Provides frame-level error control

Network Layer

- Network layer protocols move (“route”) host data towards destination
- **Best effort**: network will try its best, but no guarantees.
- Network layer implemented differently on hosts and routers

- Functions:
  - Responsible for routing decisions
  - Routing may be fixed or dynamic

Transport Layer

- Handles host to host data transmission concerns
  - Almost fully implemented on hosts
  - Hides the details of the network from the application
    - Example: If we replace a point-to-point link with a satellite link, it doesn't affect the behavior of the upper layers

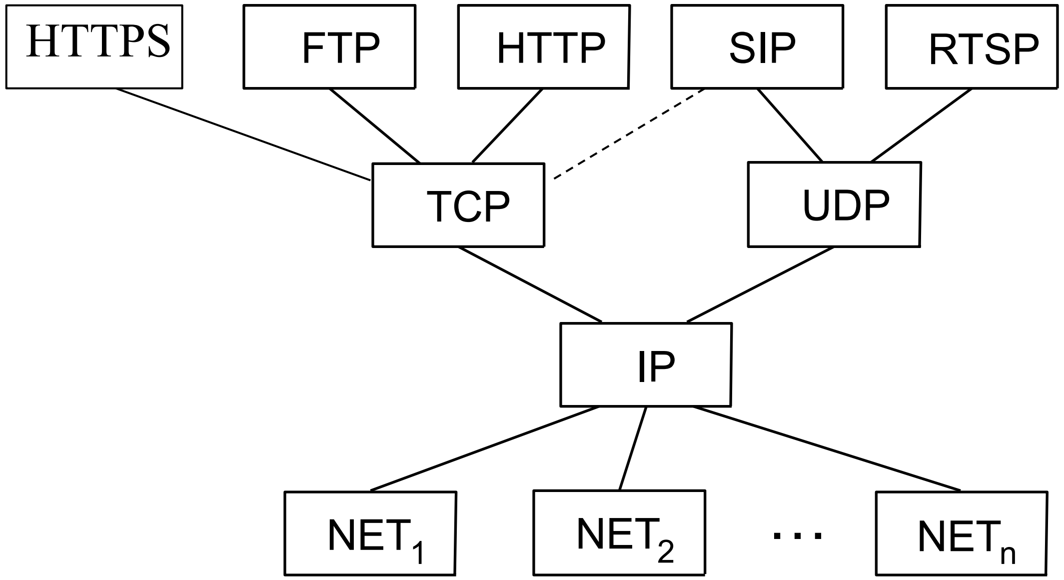
- Functions:
  - Reliable delivery: Packet retransmission upon loss
  - Ordered delivery: Reassemble packets in order at receiver
  - Flow control: Ensure that the receiving host isn't overwhelmed
  - Congestion control: Ensure that routers aren't overwhelmed

Application Layer

- Implements application-specific communication between hosts running applications of the same “type”
  - Ex: between your web browser and a web server (HTTP)
- Functions:
  - Provides session support and presentation support
  - Session state, encryption, encoding
- Examples:
  - FTP, HTTP, SMTP (email), SIP (Session Initiation Protocol)

Hourglass Design

- An artifact of the history of the Internet
  - Addressing a need to have diverse kinds of networks cooperate
- The *Internet Protocol* (IP) is the “glue” connecting different physical technologies, transports, and applications



Design principles of the Internet

- “multiplexed utilization of existing interconnected networks”

The Design Philosophy of the DARPA Internet Protocols

David D. Clark*
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(Originally published in Proc. SIGCOMM ‘88, Computer Communication Review Vol. 18, No. 4, August 1988, pp. 106–114)

Abstract

The Internet protocol suite, TCP/IP, was first proposed fifteen years ago. It was developed by the Defense Advanced Research Projects Agency (DARPA), and has been used widely in military and commercial systems. While there have been papers and specifications that describe how the protocols work, it is sometimes difficult to deduce from these why the

architecture into the IP and TCP layers. This seems basic to the design, but was also not a part of the original proposal. These changes in the Internet design arose through the repeated pattern of implementation and testing that occurred before the standards were set.

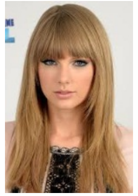
The Internet architecture is still evolving. Sometimes a new extension challenges one of the design principles, but in any case an understanding of the history of the

Design principles of the Internet

- Accommodate heterogeneity
  - Interoperate with different technologies, autonomous organizations
- Resilience to failure
  - Parts of the network must operate despite others failing
- Scale
  - Distributed management, networks of different sizes and host types
- Intelligence is at the endpoints (“the end-to-end argument”)
  - Much easier to engineer a network with fewer guarantees (best effort)
  - Hosts and applications share fate anyway

Backup slides

Issues at each layer


Application



Port#

Transport

End-to-end

Address

Network

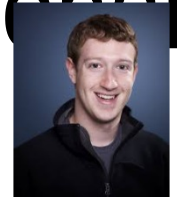
Routing

Link

Access



functionality at each layer

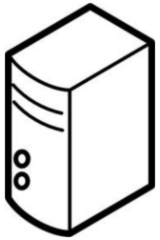


Application

Port#

Transport

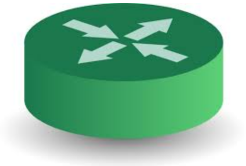
E-2-E



IP Address

Network

Routing



Link

Access

Internet Design Principles

- Scale
  - Protocols should work in networks of all sizes and distances
- Incremental deployment
  - New protocols need to be deployed gradually
- Heterogeneity
  - Different technologies, autonomous organizations
- End-to-end argument
  - Application requirements, to the extent possible should be delegated to the edges; application knows best
  - Encryption: Should the network provide as default or let applications or end points implement encryption on a need basis?

Measuring a Network's Performance

A Brief Introduction

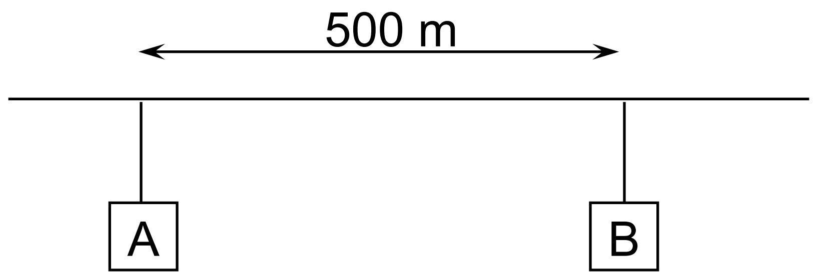
Some Definitions

- **Packet length**: size of a packet (units = bits or bytes)
- **Channel speed or bandwidth**: How fast the channel can transmit bits (units = bits/second or Bytes/second or packets/second)
- **Packet transmission time**: amount of time to transmit an entire packet (units = seconds)
- **Propagation delay**: Delay imposed by the properties of the link. Depends on the link's distance (units = seconds)
- Total transfer time =propagation delay + packet transmission time

Digression: Units

- **Bits** are the units used to describe an amount of data in a network
  - 1 kilobit (Kbit) = 1 x 10^3 bits = 1,000 bits
  - 1 megabit (Mbit) = 1 x 10^6 bits = 1,000,000 bits
  - 1 gigabit (Gbit) = 1 x 10^9 bits = 1,000,000,000 bits
- **Seconds** are the units used to measure time
  - 1 millisecond (msec) = 1 x 10^{-3} seconds = 0.001 seconds
  - 1 microsecond (μsec) = 1 x 10^{-6} seconds = 0.000001 seconds
  - 1 nanosecond (nsec) = 1 x 10^{-9} seconds = 0.000000001 seconds
- **Bits per second** are the units used to measure channel capacity/bandwidth and throughput
  - bit per second (bps)
  - kilobits per second (Kbps)
  - megabits per second (Mbps)
- Bytes (8 bits a byte) Mega bytes, Giga bytes, Tera bytes, Peta Bytes, Exa bytes

Example



packet length = 1500 bytes

channel capacity = 10 Mbps

propagation delay factor = 5 μsec/km

1. How long does it take a single bit to travel on the link from A to B?
2. How long does it take A to transmit an entire packet onto the link?

Propagation Delay

1. How long does it take a single bit to travel on the link from A to B of length 500 m with a prop. delay factor = 5 **μsec**/km ?

Another way to ask this question:

If it takes a signal 5 μsec to travel 1 kilometer, then how long does it take a signal to travel 500 meters?

$$\frac{5\ \mu sec}{1000\ m} = \frac{t}{500\ m}$$

Solving for t…

t = 2.5 μsec

Packet Transmission Time

2. How long does it take A to transmit an entire packet onto the link?

Relevant information: packet length = 1500 bytes
channel speed = 10 Mbps

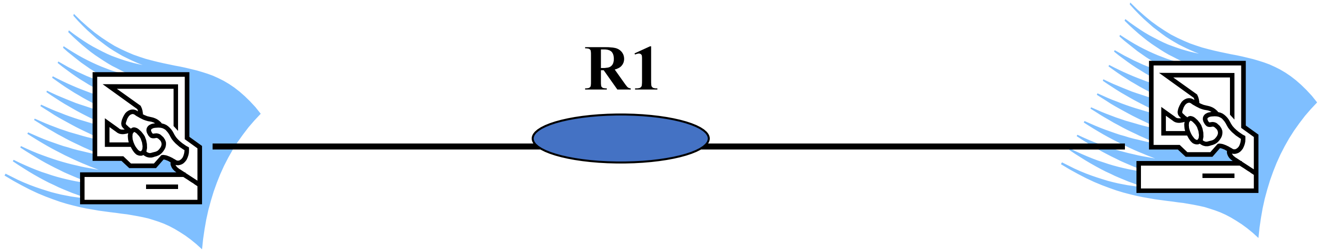
Another way to ask this question:

If the link can transmit 10 million bits in a second, how many seconds does it take to transmit 1500 bytes (8x1500 bits)?

$$\frac{10 \text{ Mbits}}{1 \text{ sec}} = \frac{1500 \text{ x } 8 \text{ bits}}{t}$$

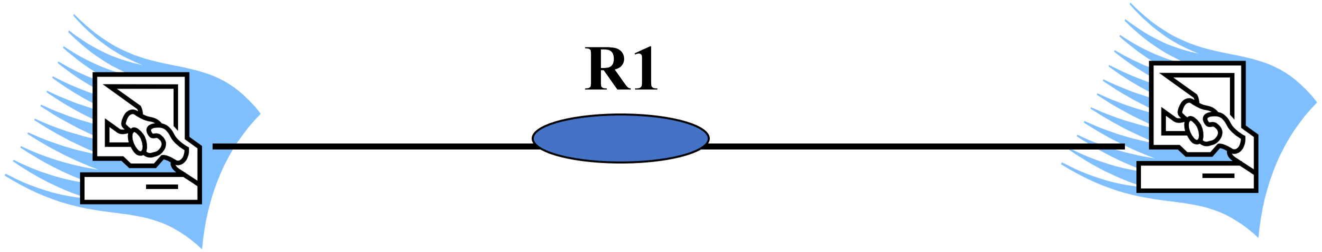
Solving for t…
t = 0.0012 sec (or 1.2 msec)

Message switching vs Packet switching



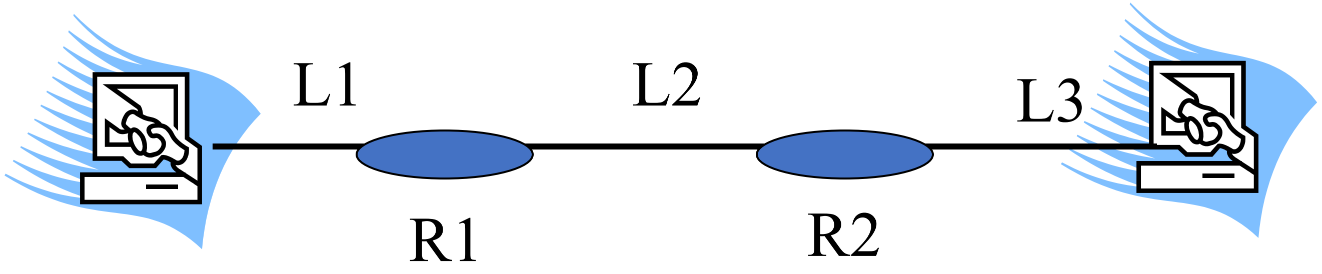
- Link speed is 1000 Bytes/sec. (ignore prop delay)
- Packet size is 100 Bytes, file size is 1000 Bytes
- Find total time to transfer the entire file under the two switching techniques
  - Msg switching
  - Packet switching

Message switching vs Packet switching



- Link speed is 1000 Bps. (prop delay for each link=10 msec)
- Packet size is 100 bytes, file size is 1000 bytes
- Find total time to transfer the entire file under the two switching techniques
  - Msg switching
  - Packet switching

Message switching vs Packet switching



- Link speed is 1000 Bytes per second . (ignore prop delay, ignore header overhead)
- Packet size is 100 Bytes, file size is 1000 Bytes
- Find total time to transfer the entire file under the two switching techniques