CS 352
Circuit & Packet Switching, Measurement & Layering

Lecture 2

http://www.cs.rutgers.edu/~sn624/352-F22

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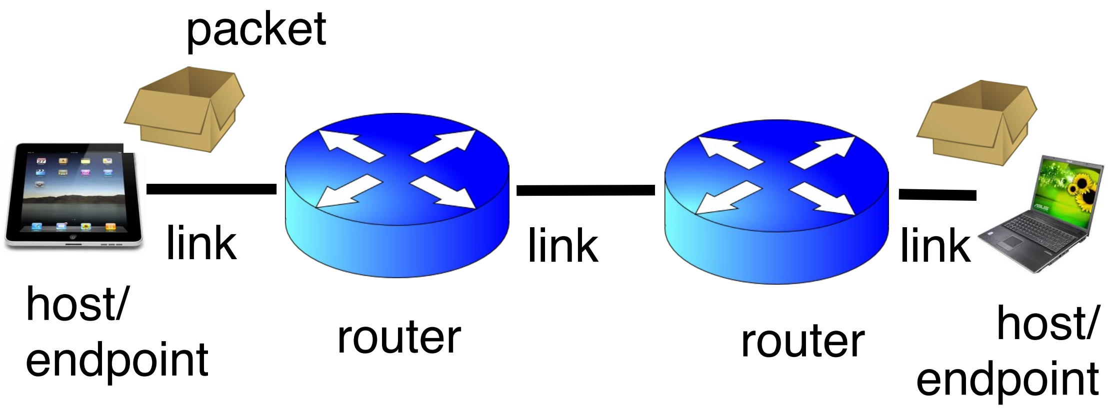
Review of definitions



- **Endpoint or Host:** Machine running user application
- **Packet:** a unit of data transmission (ex: 1500 bytes)
- **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
- **Address:** a unique name given to a machine (more later)

Today’s lecture

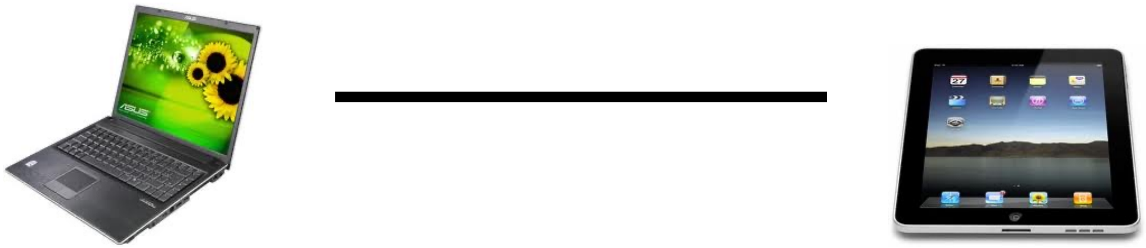
- Dive a bit deeper into how Internet communication works
  - Links: how does communication work physically?
  - Routers: how do they move data between links?
  - Endpoints: how is networking organized at endpoints?

- Understand how to measure the Internet

How do machines talk?

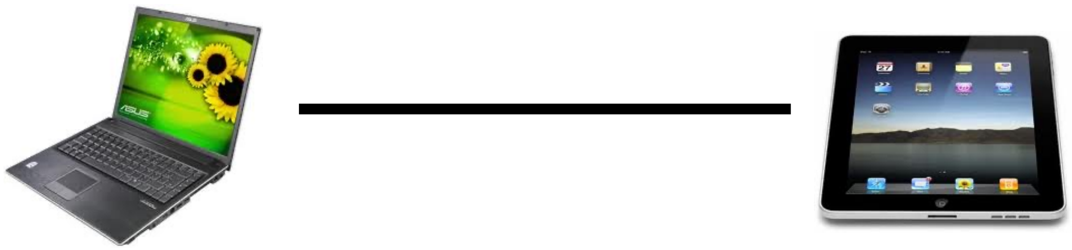
How do machines communicate?

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



Encoding and
Decoding problem.

Physical transmission on a single link



Physical signaling (light, AC voltages, etc.) are often analog

Convert bits to signals through modulation of the physical characteristics of signals: encoding

Convert signals back to digital by decoding physical signals

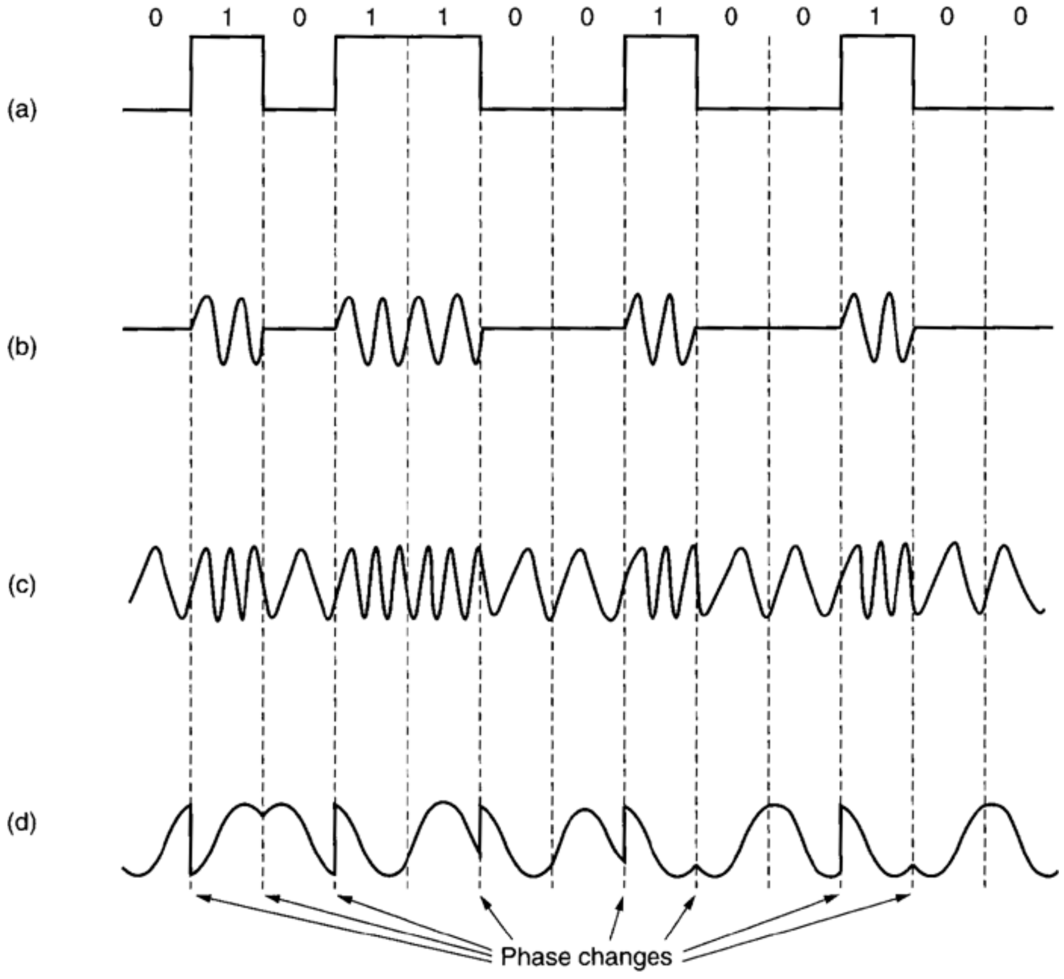
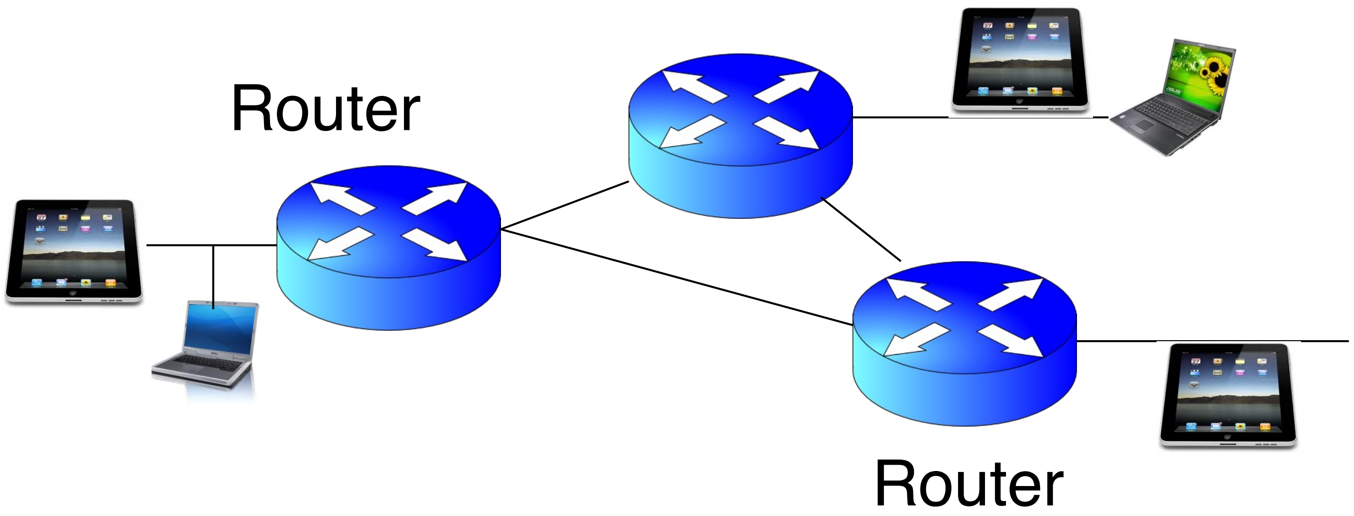


Fig. 2-18. (a) A binary signal. (b) Amplitude modulation. (c) Frequency modulation. (d) Phase modulation.

Routers and Multi-link networks



- Routers need a way to move data across links
- We use the term switching to denote physically moving data from one link to another
- There are different possibilities to switch data between links…

Switching schemes

Host applications transfer data containing many messages.

(1) Circuit Switching

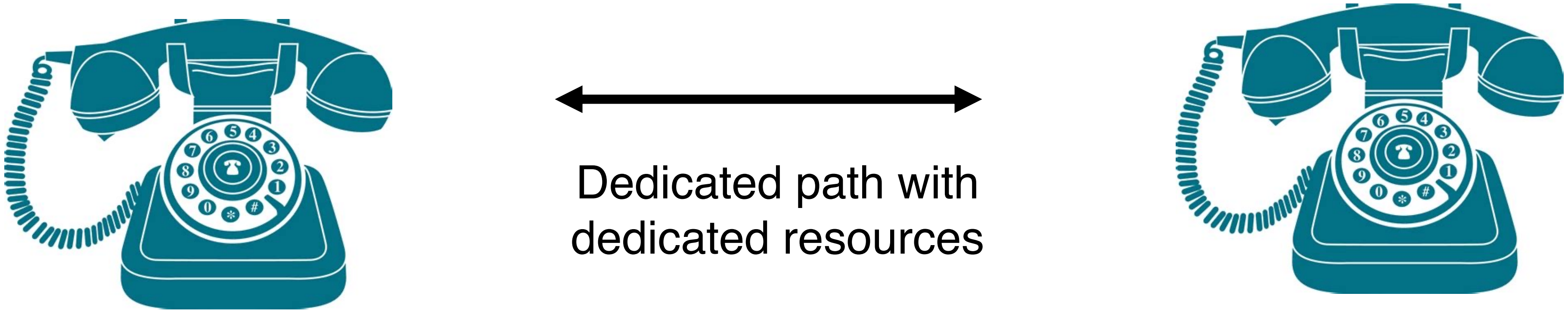
(2) Message Switching

(3) Packet Switching

Circuit switching

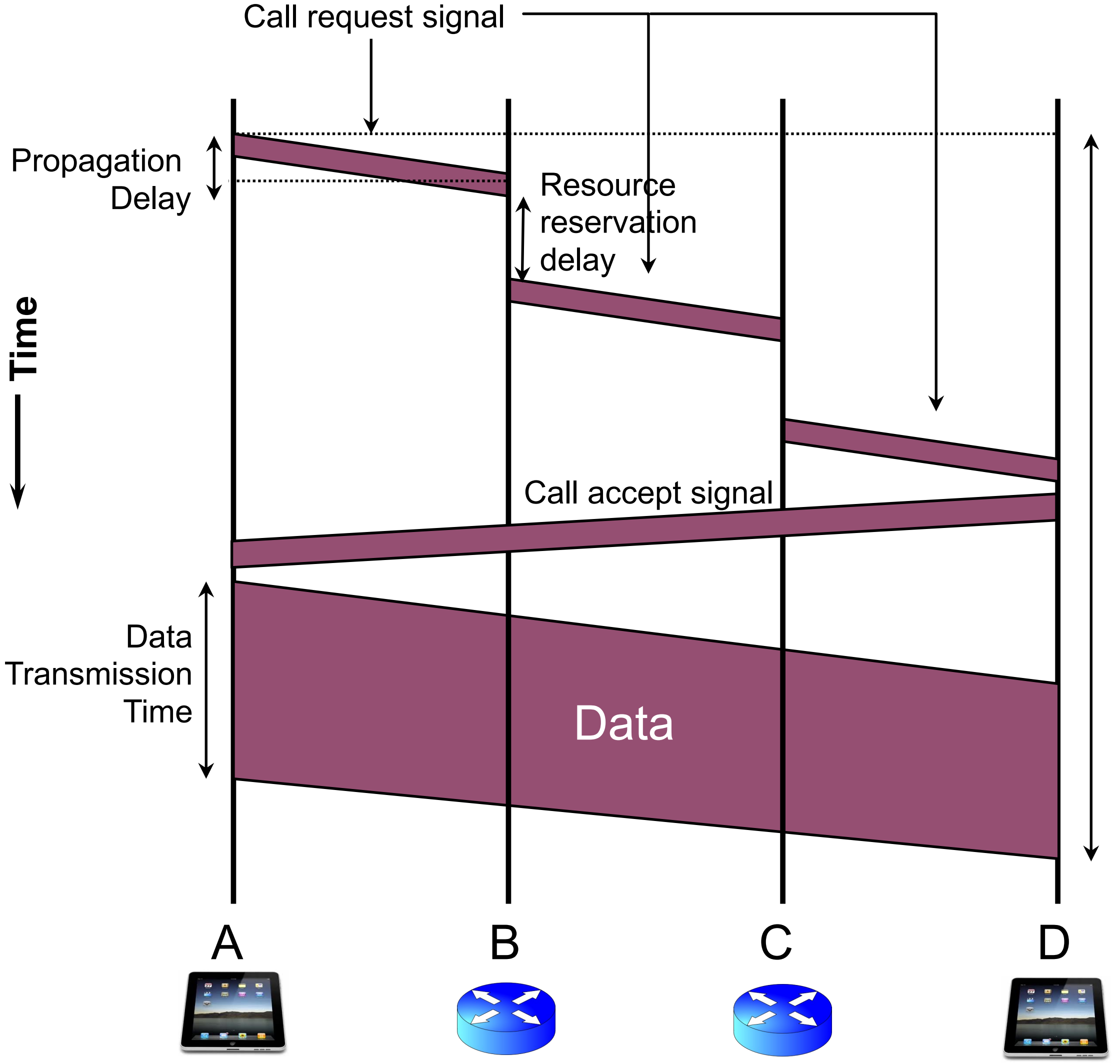
- Provides service by setting up the full path of connected links from the origin to the destination

- Example: Telephone network



Dedicated path with
dedicated resources

Circuit switching



1. Setup: Control message sets up a path from origin to destination
2. Accept 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

Message switching

- Each message is addressed to a destination

- Header: metadata that denotes how to process a message
  - Typically includes a destination address
- The message “hops” from node to node through a network while allocating only one link at a time
- (Compare to circuit switching, where all links are reserved at the same time, regardless of use.)
- Analogy: Postal service

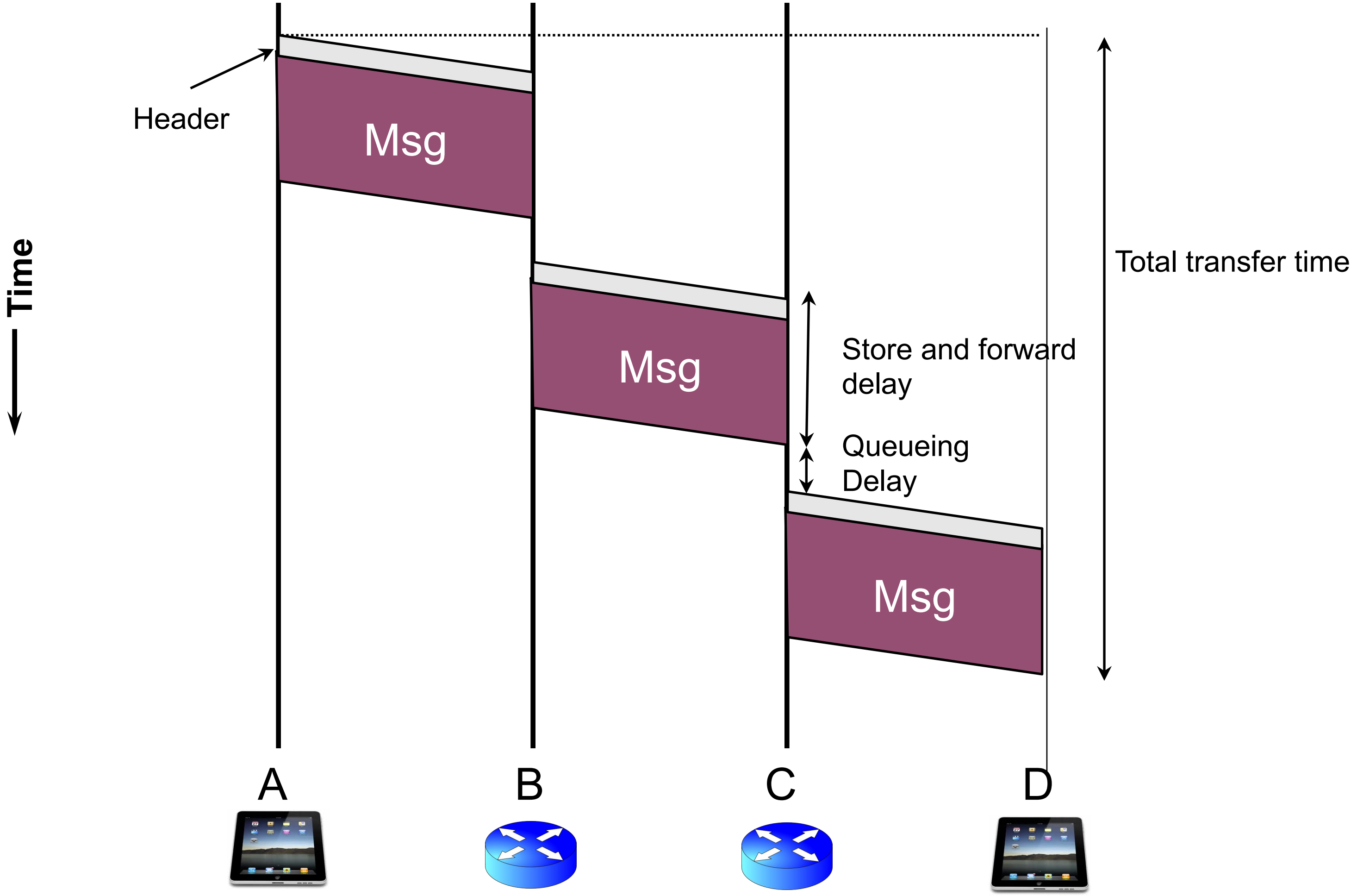
Message switching

- When the entire message is received at a router, the next step and link in its journey are selected (routing)

- If this selected link is busy, the message waits in a queue until the link becomes free

- Store and forward switching
    - Router waits for all bits of a message to arrive on incoming link before sending the first bit of the message on the outgoing link
    - Alternative: cut–through switching sends bits as they arrive

Message Switching

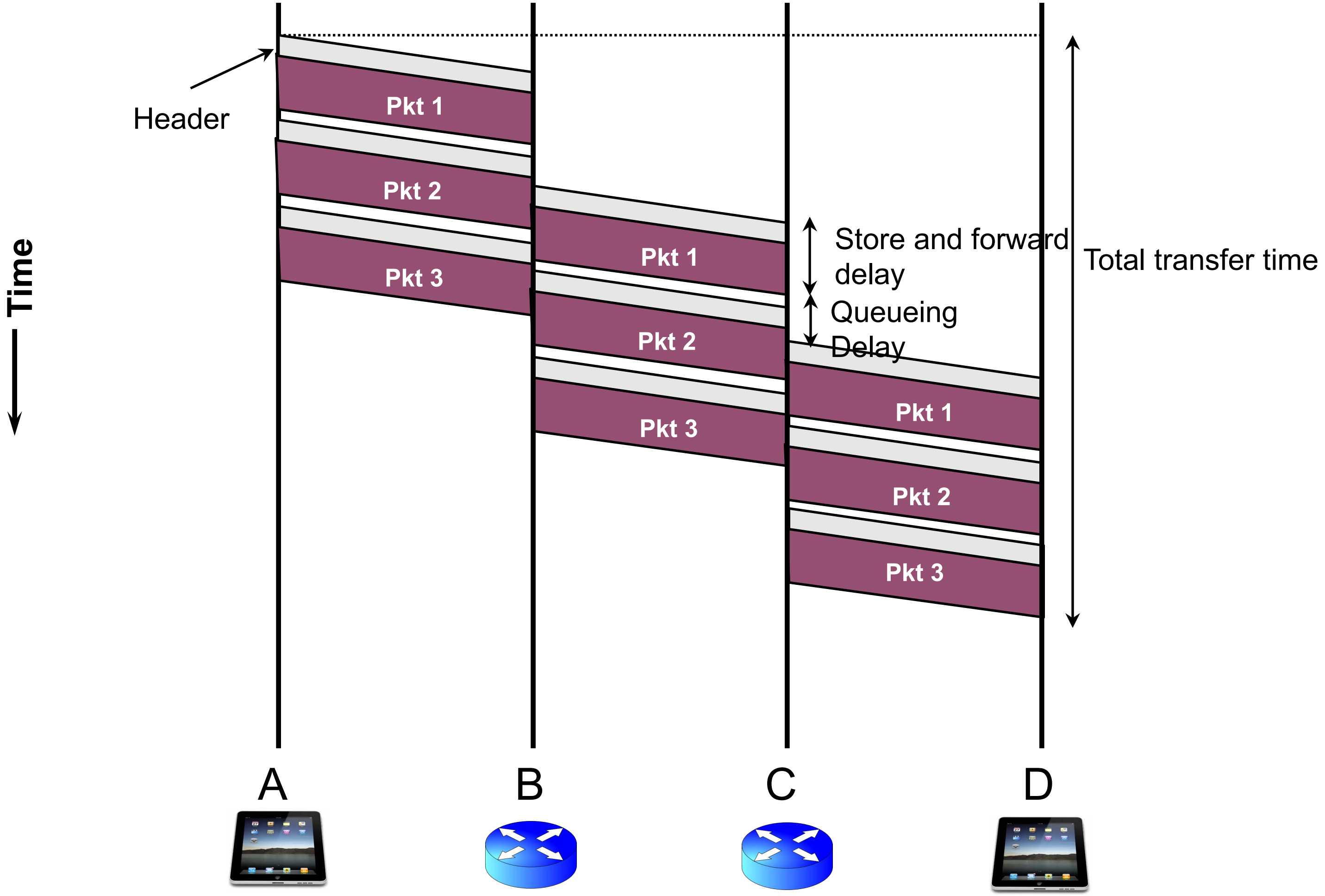


Packet switching

- Messages are split into smaller pieces called packets
  - Packets have a maximum length
  - Packets are numbered and addressed
  - Packets are 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.

Comparisons across switching tech

- Circuit switching incurs an initial delay to set up the path
  - Packet (and message) switching can start transmitting data right away

- Packet switching doesn't reserve resources for the conversation
  - Circuit switching does. Needs admission control
  - Packet switching makes resource reservation decisions per packet

- Fewer or no guarantees ➔ easier to build
  - Telephone networks are more reliable and harder to build

Comparisons across switching tech

(1) **Total Delay to transfer a message**

Short Bursty Messages:

Packet < Circuit

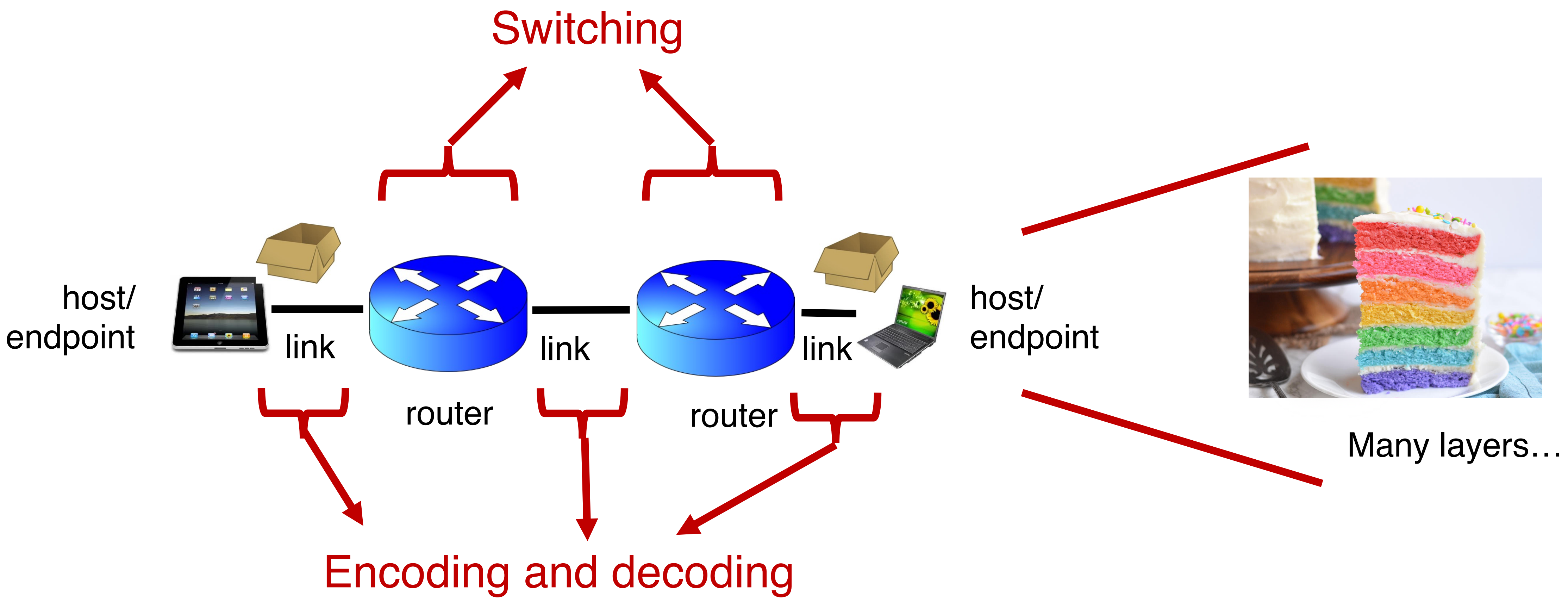
Long Continuous Messages:

Circuit < Packet

(2) Header overhead (what % of bits on the wire is metadata?)

If typical messages are larger than typical packets:

Packet > Message



Switching

host/
endpoint

link

router

link

router

link

host/
endpoint

Encoding and decoding

Many layers…

Layering and Protocols

Software/hardware organization at hosts

Application: useful user-level functions

Transport: provide guarantees to apps

Network: best-effort global pkt delivery

Link: best-effort local pkt delivery

Communication functions broken up and “stacked”

Each layer depends on the one below it.

Each layer supports the one above it.

The interfaces between layers are well-defined and standardized.

Internet software and hardware are arranged in layers.

Layering provides modularity

Each layer: well-defined function & interfaces to layers above & below it.

Functionality is implemented in protocols.

Protocols: The “rules” of networking

- Protocols consist of two things

- Message format
  - structure of messages exchanged with an endpoint

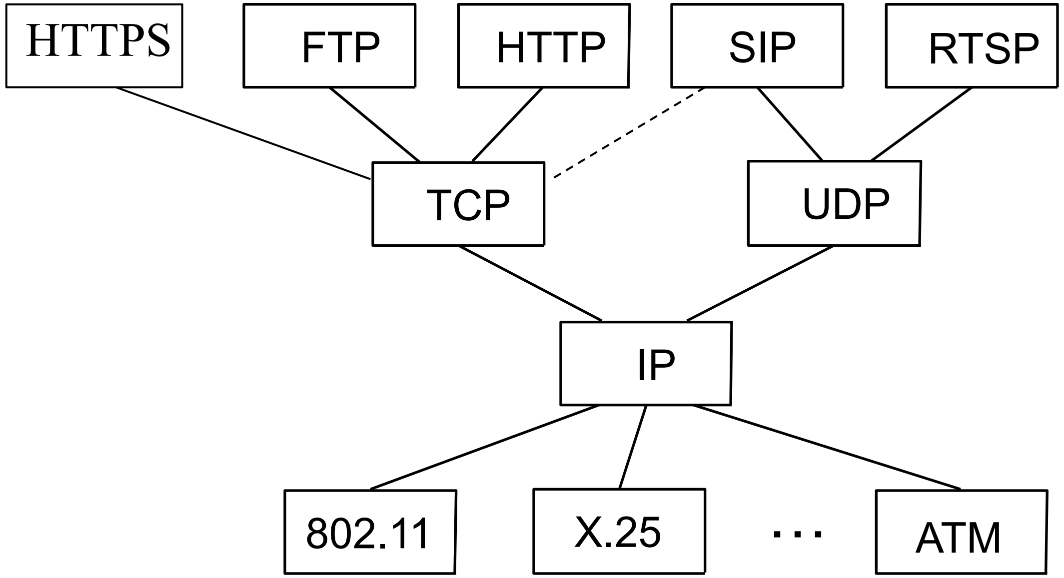
- Actions
  - operations upon receiving, or not receiving, messages

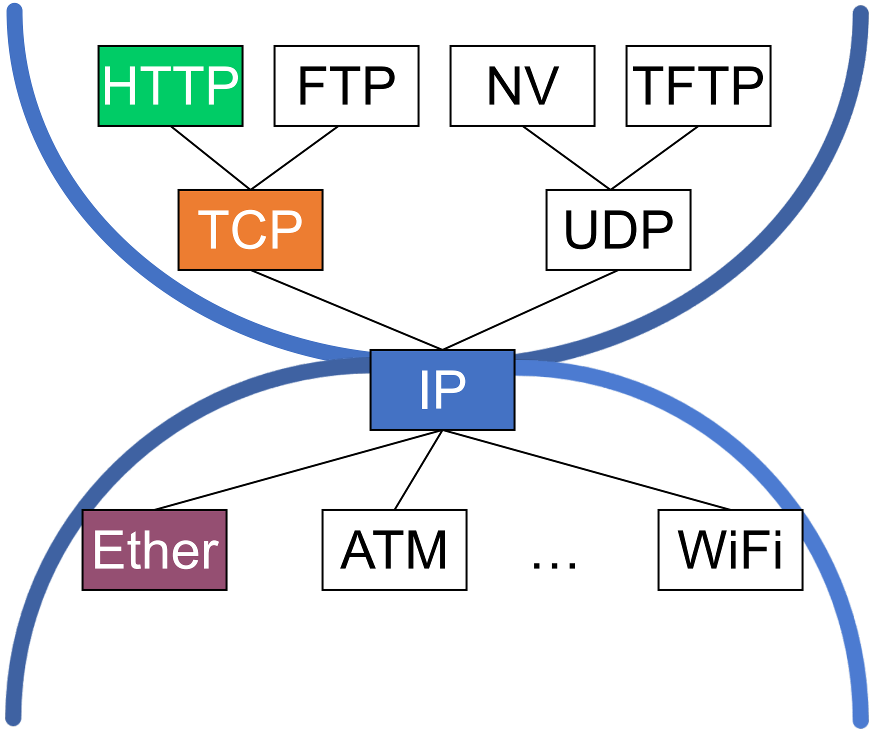
- Example of a Zoom conversation:
  - Message format: English words and sentences
  - Actions: when a word is heard, say “yes”; when nothing is heard for more than 3 seconds, say “can you hear me?”

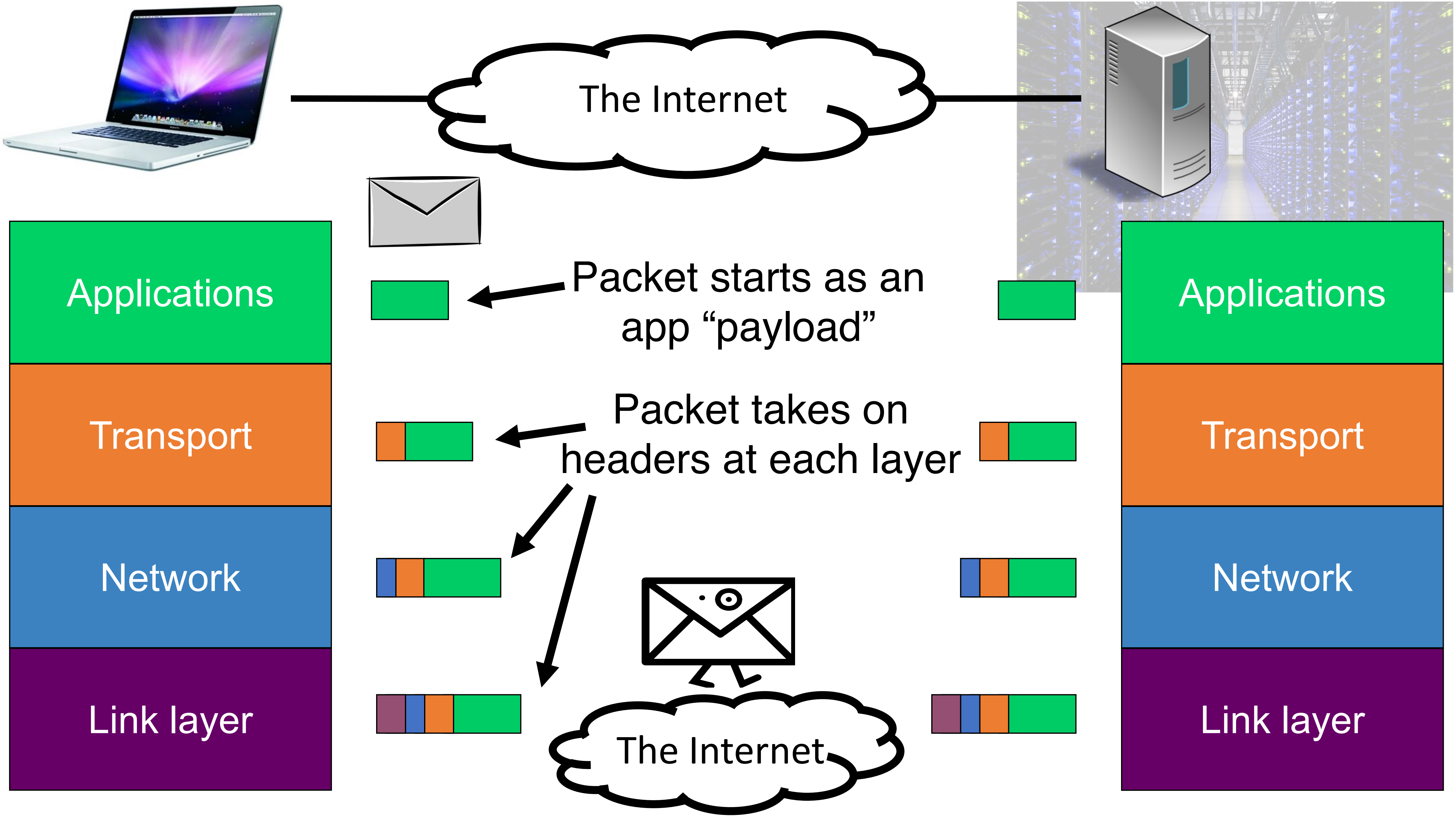
The protocols of the Internet

- Standardized by the Internet Engineering Task Force (IETF)
  - through documents called RFCs ("Request For Comments")

- Layering of protocols







The Internet

Applications

Transport

Network

Link layer

Packet starts as an app “payload”

Packet takes on headers at each layer

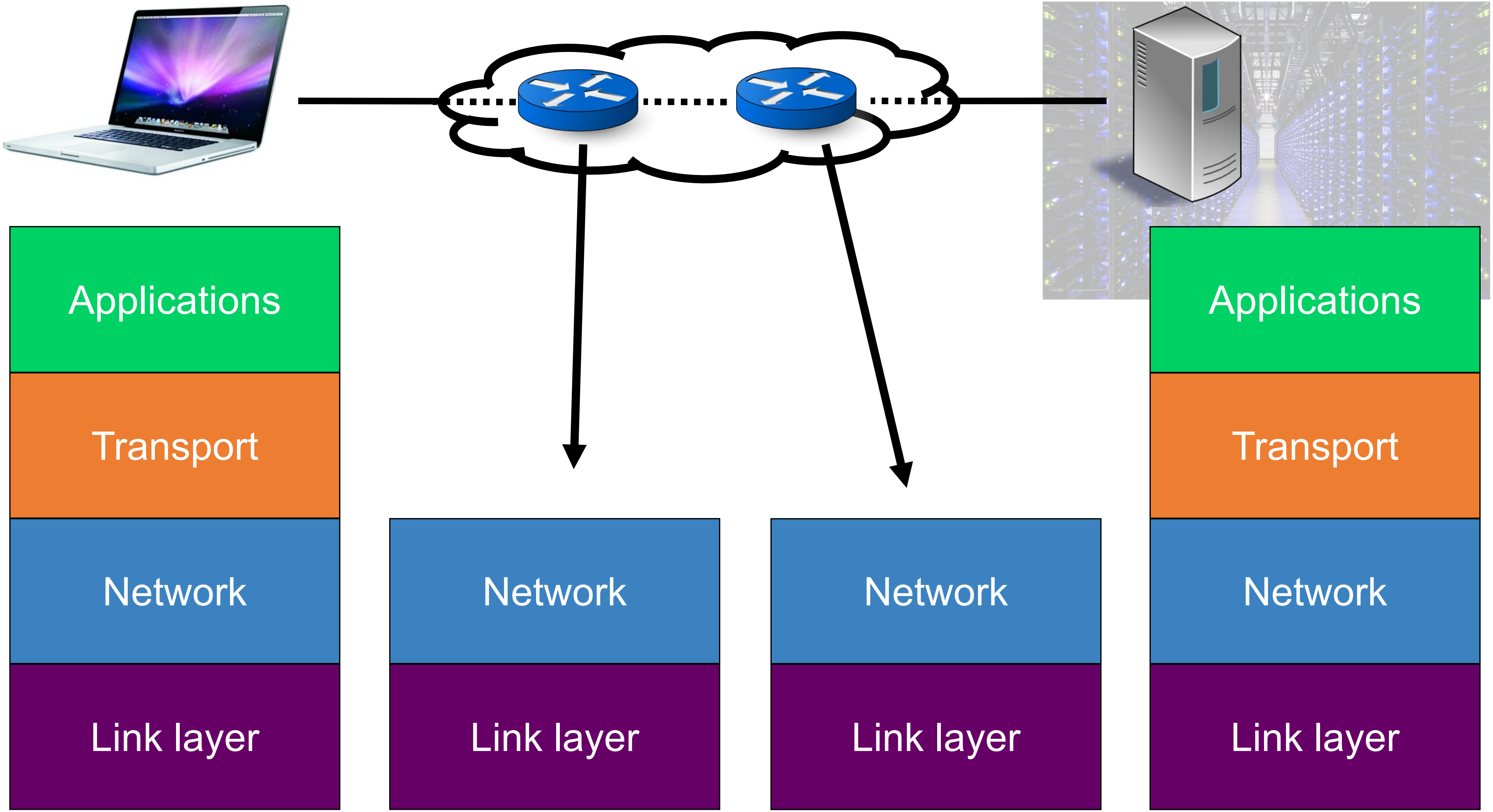
The Internet

Applications

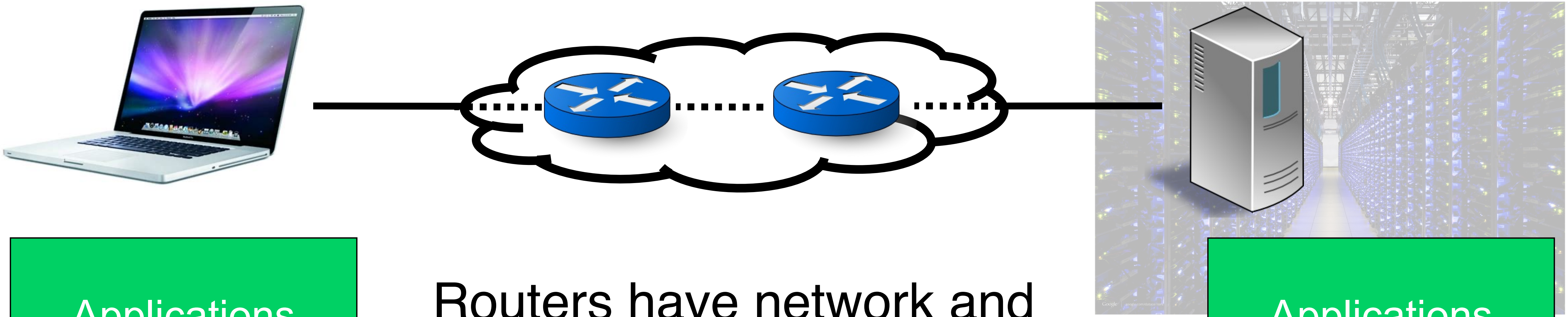
Transport

Network

Link layer



Applications			Applications
Transport			Transport
Network	Network	Network	Network
Link layer	Link layer	Link layer	Link layer



Routers have network and link layers too!

Applications			Applications
Transport			Transport
Network	Network	Network	Network
Link layer	Link layer	Link layer	Link layer

Layering

- Communication over the Internet is a complex problem.
- Layering simplifies understanding, testing, maintaining
- Easy to improve or replace protocol at one layer without affecting others

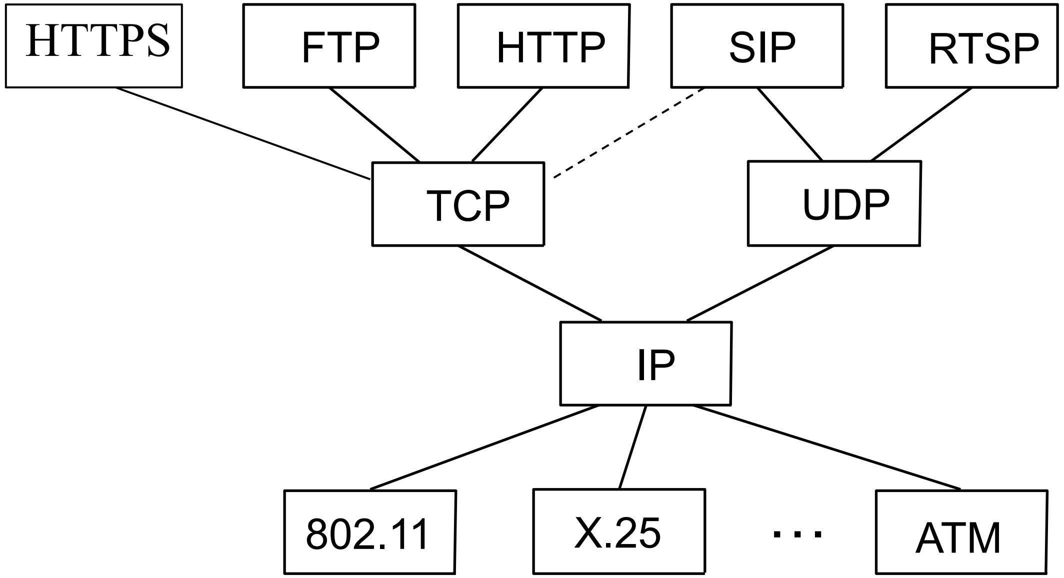
This course has layers

Application

Transport

Network

Host-to-Net

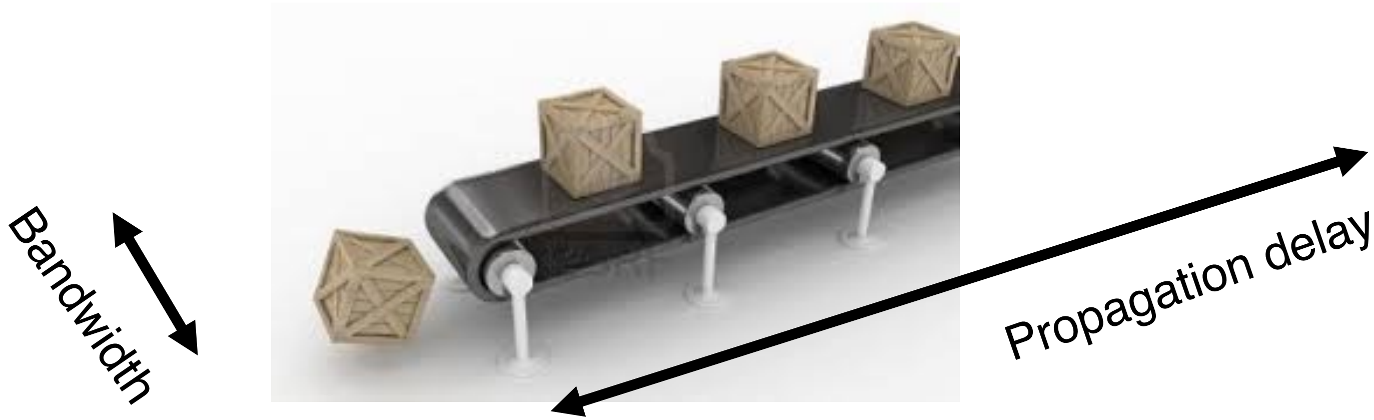


Measuring Networks
(including the Internet)

Some definitions

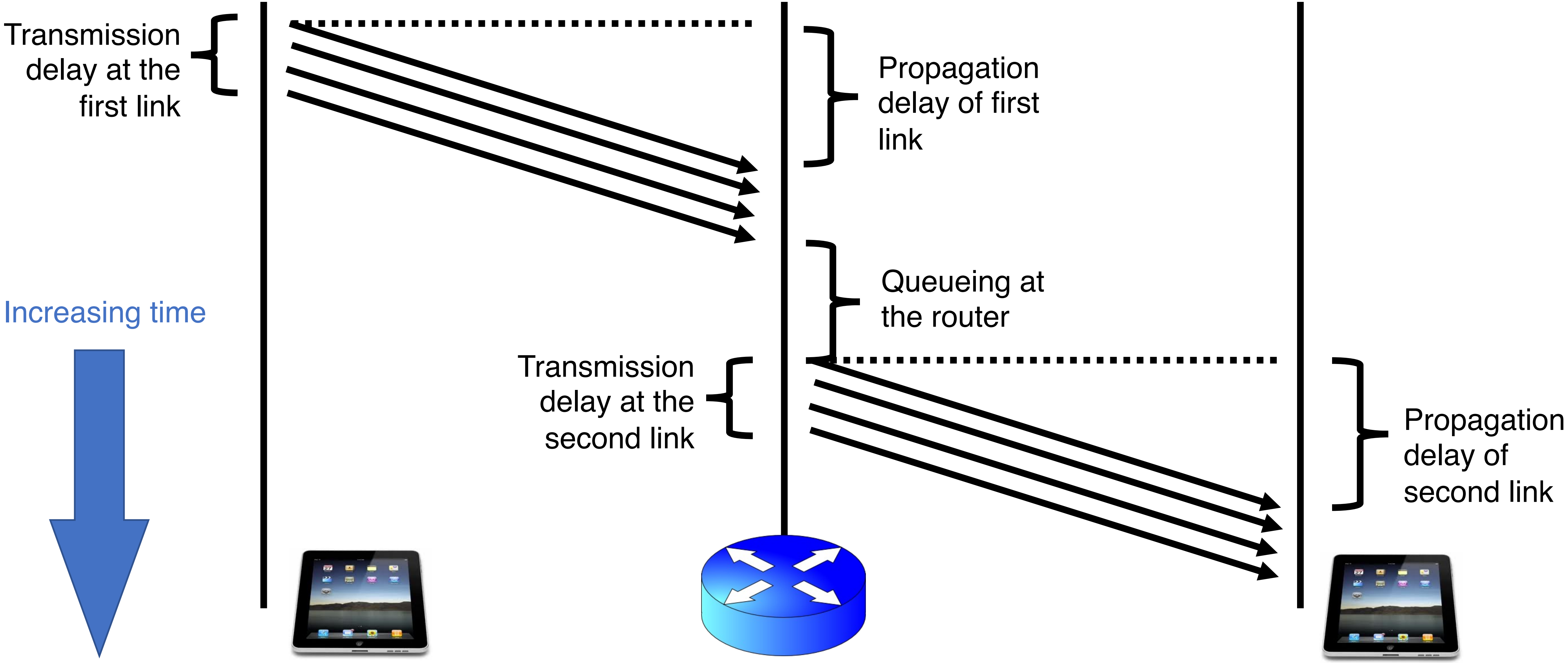
- Packet size: length of a packet (bits or bytes), incl. header and data
- Bandwidth: For a single link, amount of data it can transmit per unit time (bits/second or Bytes/second or packets/second)
- Propagation delay: Time needed to move one bit across (second)
  - Imposed by the communication medium; depends on the link “length”
- Transmission delay: Time from first bit@sender to last bit@sender
  - Determined by link bandwidth and packet size
- Queueing delay: Time that a packet waits for transmission
  - Determined by contention for the link
- Total packet delay: time from first bit@sender to last bit@receiver
  - propagation delay + queueing delay + transmission delay for a single packet

An 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

Visualizing the components of delay



Transmission delay at the first link

Propagation delay of first link

Queueing at the router

Increasing time

Transmission delay at the second link

Propagation delay of second link

Bandwidth and delay demo

- Throughput (related to bandwidth)
  - `iperf –s` # at the destination
  - `iperf –c <destination>` # at the source,
  - e.g., `iperf –c localhost`

- (total) delay
  - `ping <destination>`
  - e.g., `ping google.com`

- (Don’t just watch; you can try it!)