Introduction to Computer Networks

COSC 4377

Lecture 7

Spring 2012

February 8, 2012

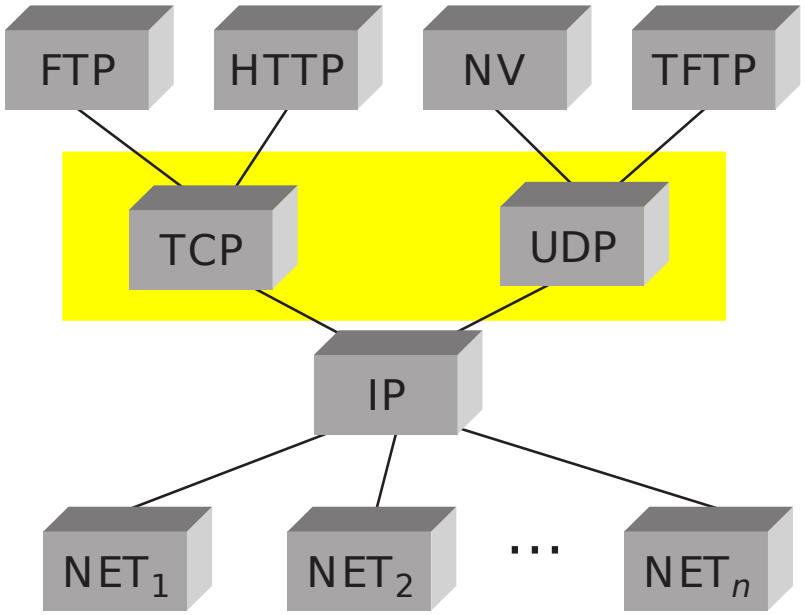
Announcements

- HW3 due today
- Start working on HW4
- HW5 posted
- In-class student presentations
- No TA office hours this week
  - Makeup hours next week

Today's Topics

- Transport Protocols
  - UDP
  - TCP
  - EWMA

Transport Layer



- Transport protocols sit on top of network layer and provide
  - Application-level multiplexing (“ports”)
  - Error detection, reliability, etc.

Error Detection

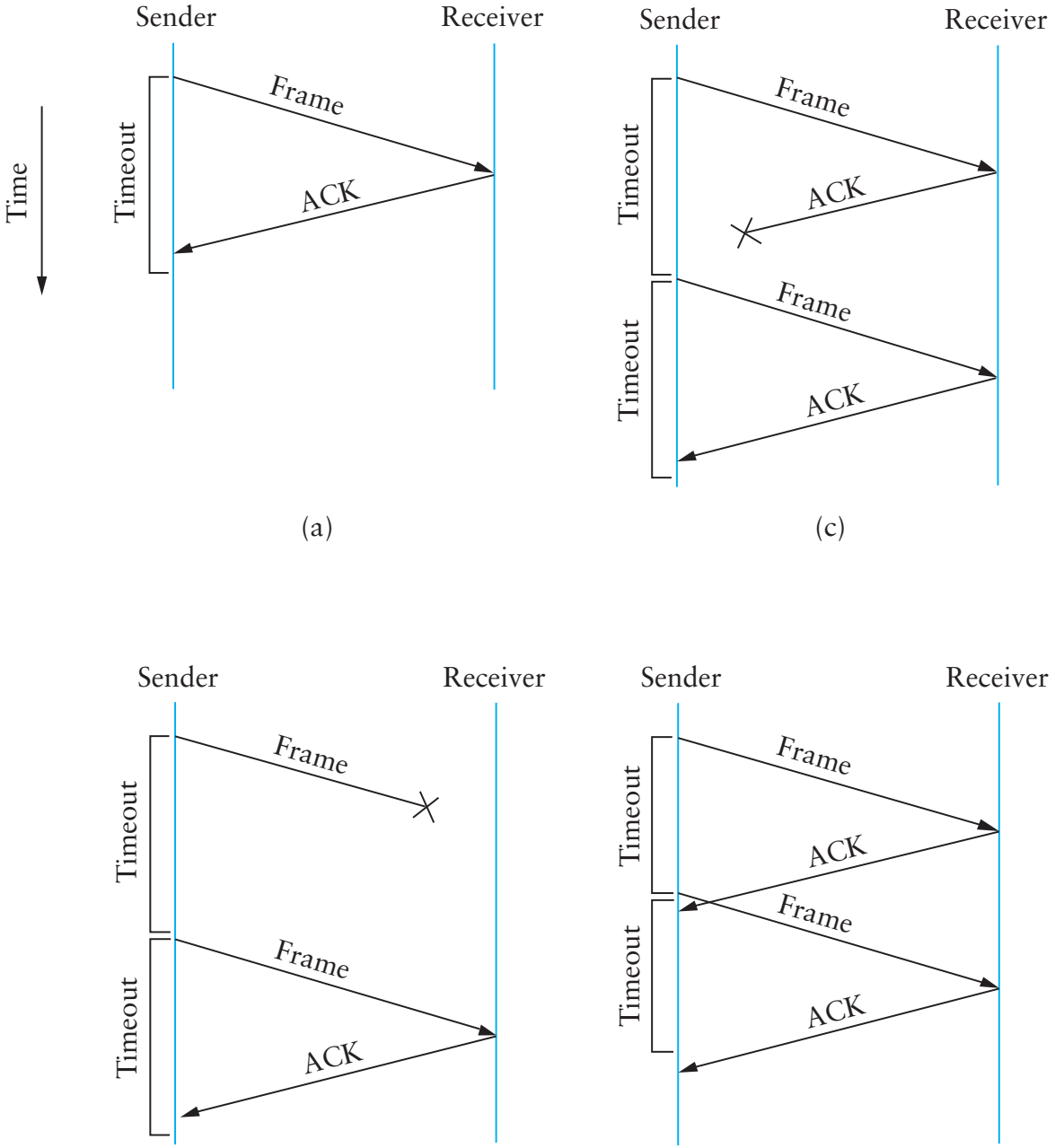
- Idea: add redundant information to catch errors in packet
- Three examples:
  - Parity
  - Internet Checksum
  - CRC

Reliable Delivery

- Error detection can discard bad packets
- Problem: if bad packets are lost, how can we ensure reliable delivery?
  - Exactly-once semantics = at least once + at most once

At Least Once Semantics

- How can the sender know packet arrived *at least once*?
  - Acknowledgments + Timeout
- Stop and Wait Protocol
  - S: Send packet, wait
  - R: Receive packet, send ACK
  - S: Receive ACK, send next packet
  - S: No ACK, timeout and retransmit

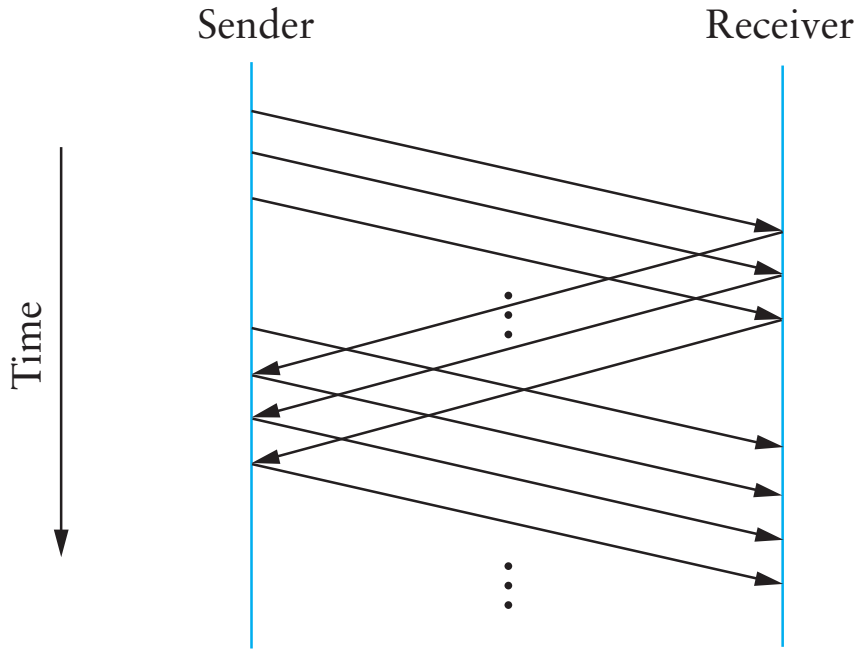

Sender
Receiver
Time
Timeout
Frame
ACK
(a)
Sender
Receiver
Timeout
Frame
ACK
Timeout
Frame
ACK
(c)
Sender
Receiver
Timeout
Frame
Timeout
Frame
ACK
(b)
Sender
Receiver
Timeout
Frame
ACK
Timeout
Frame
ACK
(d)

Stop and Wait Problems

- Duplicate data
- Duplicate acks
- Can’t fill pipe
- Difficult to set the timeout value

Sliding Window Protocol

- Still have the problem of keeping pipe full
  - Generalize approach with > 1-bit counter
  - Allow multiple outstanding (unACKed) frames
  - Upper bound on unACKed frames, called *window*

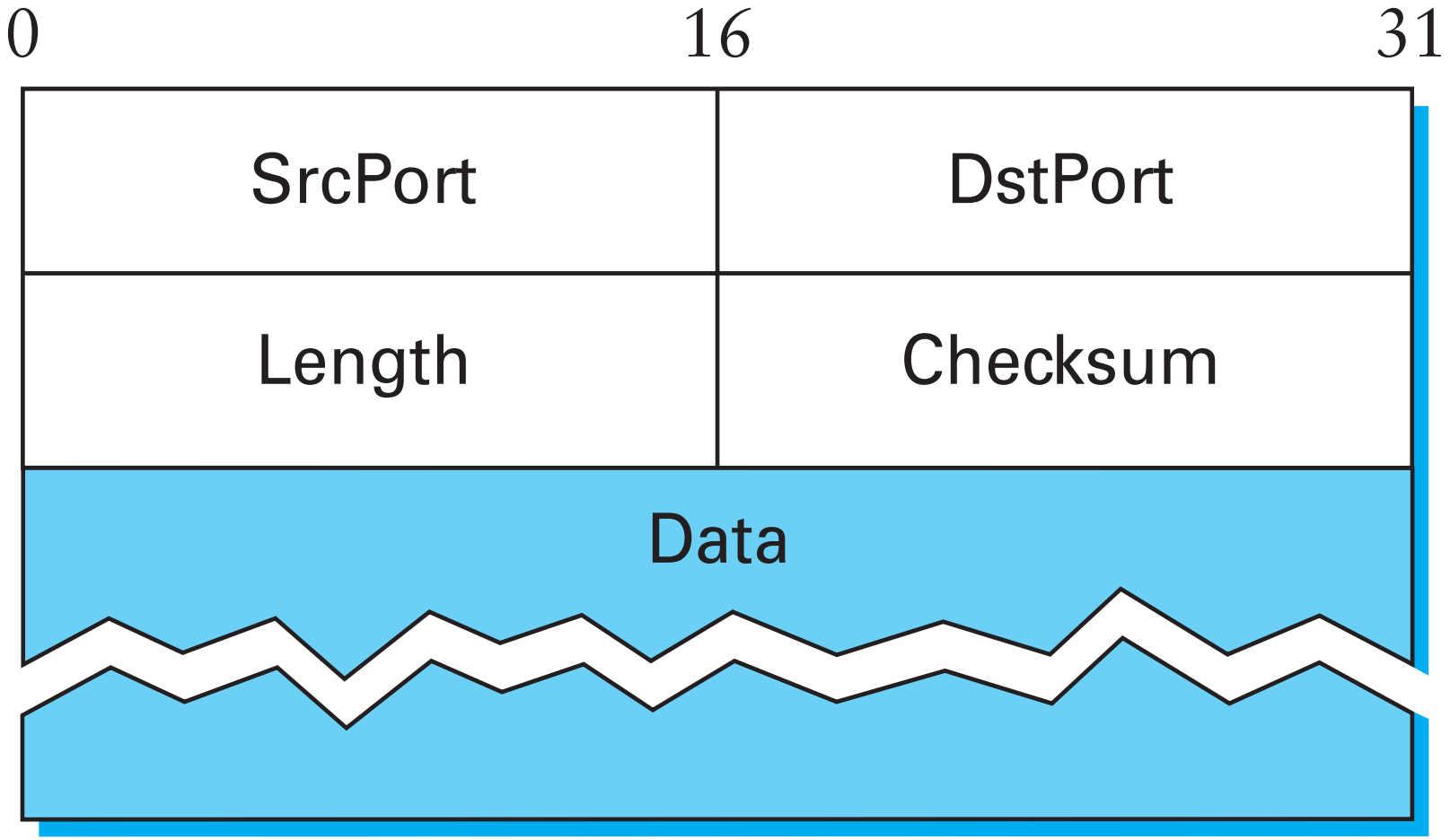


UDP – User Datagram Protocol

- Unreliable, unordered datagram service
- Adds multiplexing, checksum
- End points identified by *ports*
  - Scope is an IP address (interface)
- Checksum aids in error detection

http://en.wikipedia.org/wiki/User_Datagram_Protocol

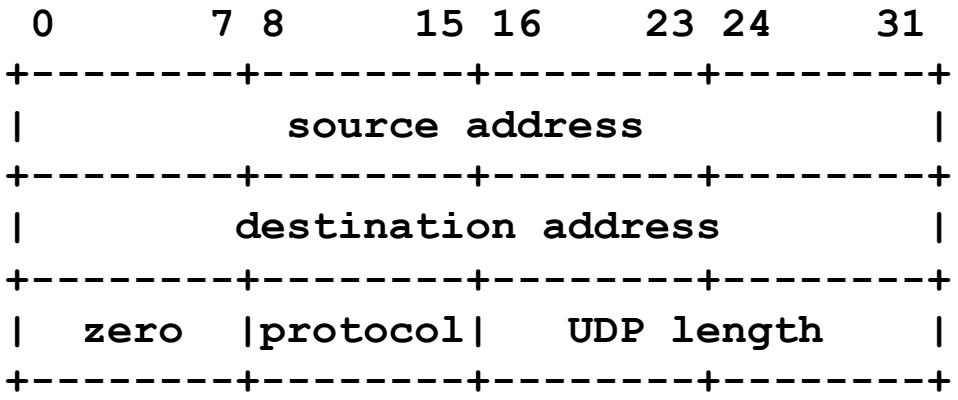
UDP Header



UDP Checksum

- Uses the same algorithm as the IP checksum
  - Set Checksum field to 0
  - Sum all 16-bit words, adding any carry bits to the LSB
  - Flip bits to get checksum (except 0xffff->0xffff)
  - To check: sum whole packet, including sum, should get 0xffff
- How many errors?
  - Catches any 1-bit error
  - Not all 2-bit errors
- Optional in IPv4: not checked if value is 0

Pseudo Header



- UDP Checksum is computer over *pseudo-header* prepended to the UDP header
  - For IPv4: IP Source, IP Dest, Protocol (=17), plus UDP length
- Benefits? Problem?
  - Is UDP a layer on top of IP?

http://www.postel.org/pipermail/end2end-interest/2005-February/004616.html

Next Problem: Reliability

Problem	Mechanism
Dropped Packets	Acknowledgments + Timeout
Duplicate Packets	Sequence Numbers
Packets out of order	Receiver Window
Keeping the pipe full	Sliding Window (Pipelining)

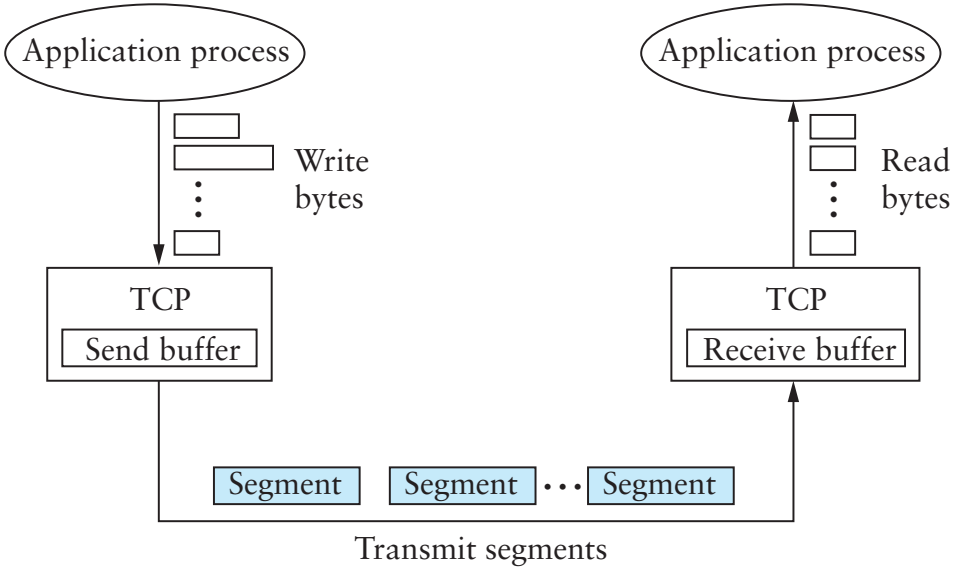
Transport Layer Reliability

- Extra difficulties
  - Multiple hosts
  - Multiple hops
  - Multiple potential paths
- Need for connection establishment, tear down
  - Analogy: dialing a number versus a direct line
- Varying RTTs
  - Both across connections and *during* a connection
  - Why do they vary? What do they influence?

Extra Difficulties (cont.)

- Out of order packets
  - Not only because of drops/retransmissions
  - Can get very old packets (up to 120s), must not get confused
- Unknown resources at other end
  - Must be able to discover receiver buffer: flow control
- Unknown resources in the network
  - Should not overload the network
  - But should use as much as safely possible
  - Congestion Control (next class)

TCP – Transmission Control Protocol

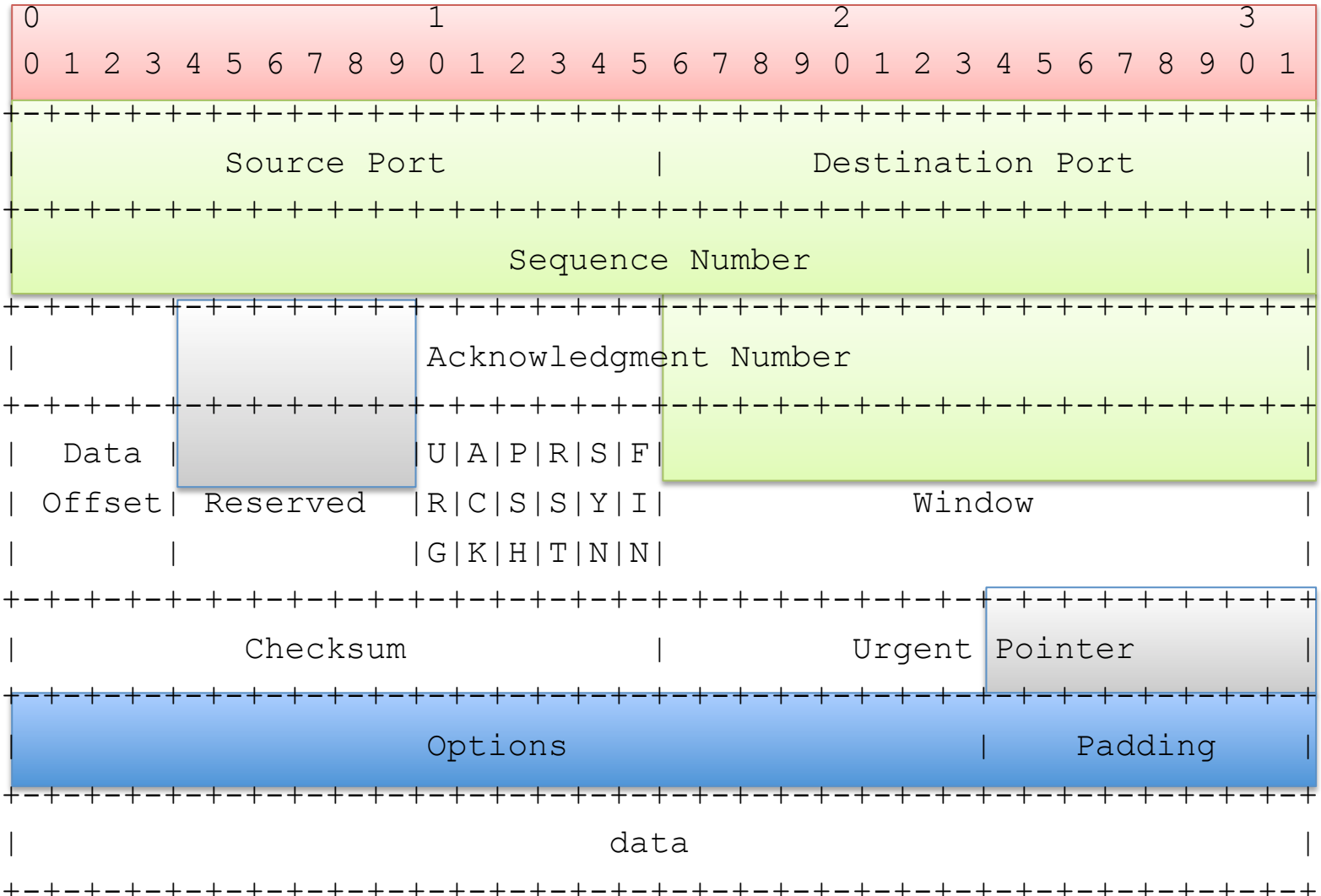


- Service model: “reliable, connection oriented, full duplex byte stream”
  - Endpoints: <IP Address, Port>
- Flow control
  - If one end stops reading, writes at other eventually stop/fail
- Congestion control
  - Keeps sender from overloading the network (next lecture)

TCP

- Specification
  - RFC 793 (1981), RFC 1222 (1989, some corrections), RFC 5681 (2009, congestion control), …
- Was born coupled with IP, later factored out
  - We talked about this, don't always need everything!
- End-to-end protocol
  - Minimal assumptions on the network
  - All mechanisms run on the end points
- Alternative idea:
  - Provide reliability, flow control, etc, link-by-link
  - Does it work?

TCP Header


0 1 2 3
0 1 2 3 4 5 6 7 8 9 0 1 2 3 4 5 6 7 8 9 0 1 2 3 4 5 6 7 8 9 0 1
Source Port
Destination Port
Sequence Number
Acknowledgment Number
Data Offset
Reserved
U|A|P|R|S|F|
R|C|S|S|Y|I|
G|K|H|T|N|N|
Window
Checksum
Urgent Pointer
Options
Padding
data

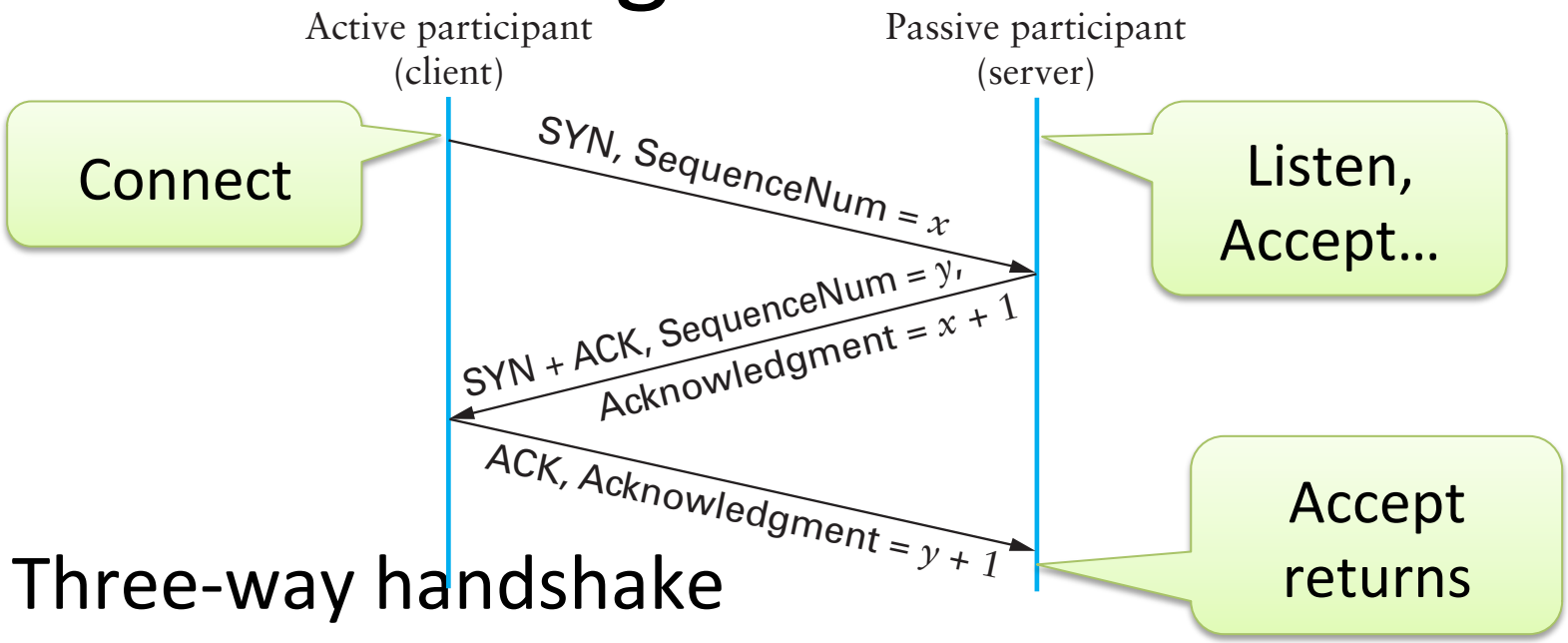
Header Fields

- Ports: multiplexing
- Sequence number
  - Correspond to *bytes*, not packets!
- Acknowledgment Number
  - Next expected sequence number
- Window: willing to receive
  - Lets receiver limit SWS (even to 0) for flow control
- Data Offset: # of 4 byte header + option bytes
- Flags, Checksum, Urgent Pointer

Header Flags

- URG: whether there is urgent data
- ACK: ack no. valid (all but first segment)
- PSH: push data to the application immediately
- RST: reset connection
- SYN: synchronize, establishes connection
- FIN: close connection

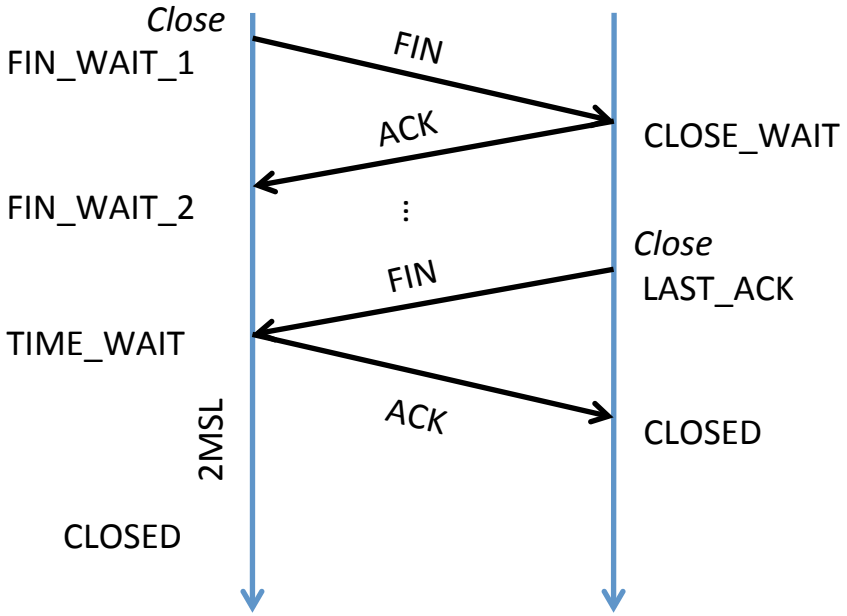
Establishing a Connection



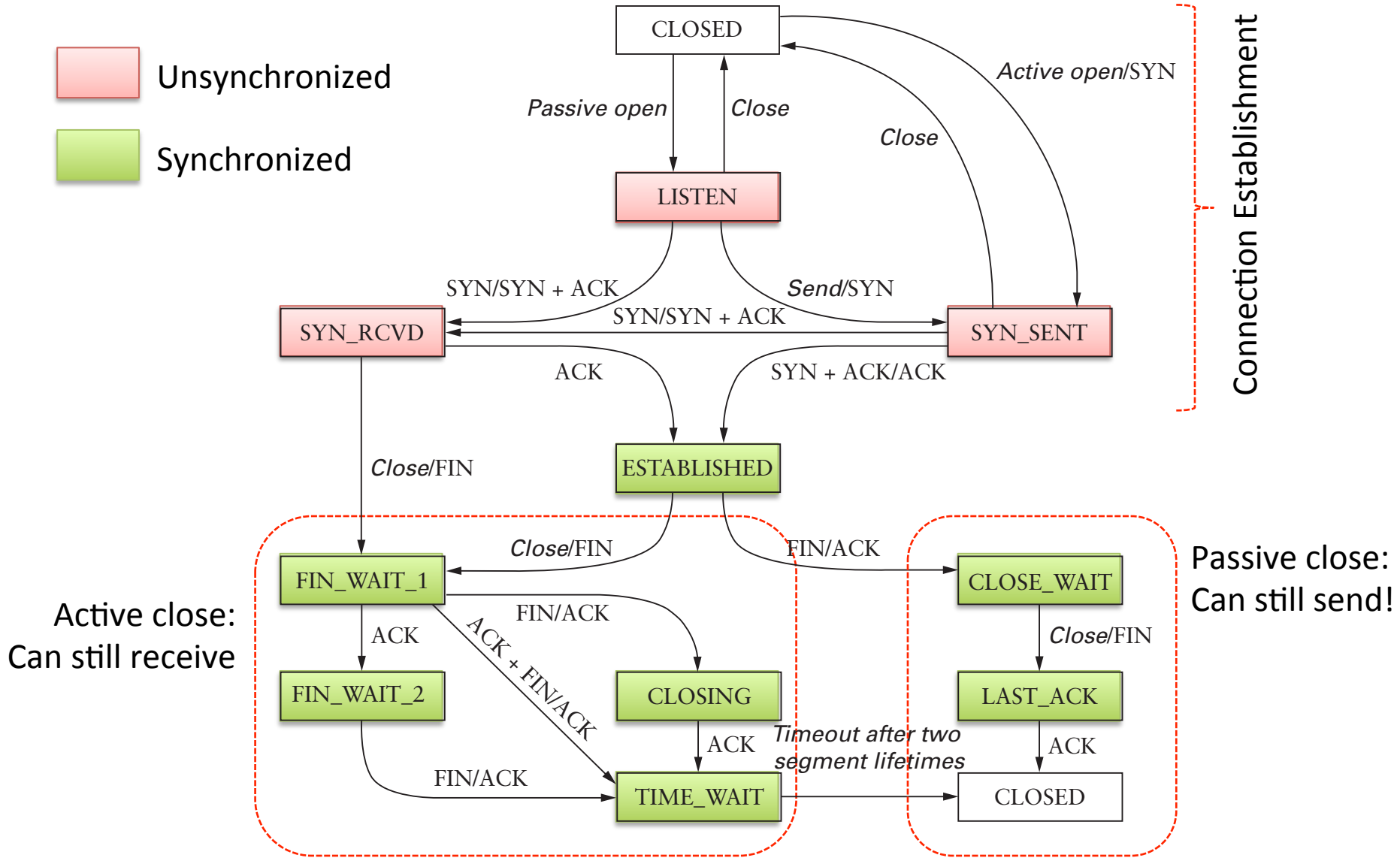
- Three-way handshake
  - Two sides agree on respective initial sequence nums
- If no one is listening on port: server sends RST
- If server is overloaded: ignore SYN
- If no SYN-ACK: retry, timeout

Connection Termination

- FIN bit says no more data to send
  - Caused by close or shutdown
  - Both sides must send FIN to close a connection
- Typical close



Summary of TCP States



TIME_WAIT

- Why do you have to wait for 2MSL in TIME_WAIT?
  - What if last ack is severely delayed, AND
  - Same port pair is immediately reused for a new connection?
- Solution: active closer goes into TIME_WAIT
  - Waits for 2MSL (Maximum Segment Lifetime)
- Can be problematic for active servers
  - OS has too many sockets in TIME_WAIT, can accept less connections
    - Hack: send RST and delete socket, SO_LINGER = 0
  - OS won't let you re-start server because port in use
    - SO_REUSEADDR lets you rebind

Reliable Delivery

- TCP retransmits if data corrupted or dropped
  - Also retransmit if ACK lost
- When should TCP retransmit?
- Challenges in estimating RTT
  - Dynamic
  - No additional traffic

Smoothing RTT

- RTT measurement can have large variation
- Need to smooth the samples
  - One RTT measurement = one sample
- Some ways to smooth the sample
  - Average of the whole sequence
  - Windowed Mean
- Problems?

EWMA

- EWMA: Exponentially Weighted Moving Average
- Give greater weight to recent samples
  - Why?

http://en.wikipedia.org/wiki/Moving_average

EWMA

- Estimate RTT
- RTT(t) = α × RTT(t-1) + (1-α) × newEst

α = 0.8

Time	RTT	newEst
0	-	10