COS 140: Foundations of Computer Science

Transport-Layer Protocols*

Fall 2018

*This lecture draws heavily from Kurose & Ross (2008): *Computer Networks: A Top-Down Approach*

Homework

- ☐ Reading: None
- ☐ Slides online
- ☐ Homework:
  - – On Blackboard
  - – Due 12/10

Transport Layer

Protocols

- ☐ Recall: Protocol is a description of a pattern of interaction between agents
- ☐ Most common: TCP/IP

Review: Layered protocols

- Recall: Layered *network stack*
  - Application: network applications (e.g., Web clients/servers), application protocols (e.g., HTTP)
  - Transport: Delivery of application messages between applications: error correction, reliable transport (some protocols), etc.
  - Network: Delivery of transport-layer messages: routing, etc.
  - Data link: Delivery of network-layer messages – e.g., forwarding to next router/host (e.g., Ethernet, WiFi, link layers on routers)
  - Physical: Moving the bits (Ethernet has variants for different media)

Layered protocols

- As message goes from top⟶ bottom:
  - Broken into pieces
  - Each piece has its own header added at each level

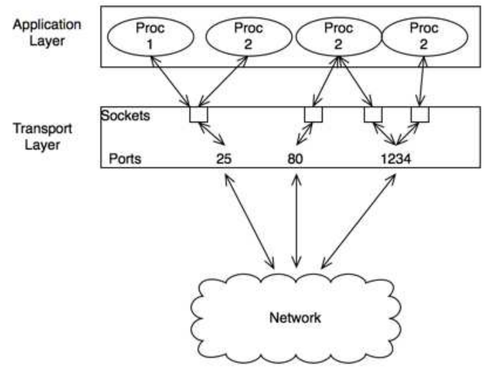
Transport layer

- ☐ Responsible for delivery of application-layer messages between processes
- ☐ Interacts with: application and network layers
- ☐ Divides/encapsulates application messages as *segments*
- ☐ Possibly:
  - Error correction
  - Reliable delivery
  - Congestion control
- ☐ Connectionless (e.g., UDP) versus connection-oriented (e.g., TCP)

Ports and sockets

- ☐ Network stack manages set of *ports* on host:
  - Interface of host to outside world
  - Numbered (virtual) connection points
  - Some: well-known ports (e.g., email (25), Web (80))
  - Some: usable on fly by processes
- ☐ *Sockets*: virtual connections between application process and transport layer (and thus, a port)
- ☐ Each application process talks to (e.g.) TCP via a socket
- ☐ Can have multiple sockets attached to a port
- ☐ E.g.: Web server
- ☐ Transport layer: multiplexing/demultiplexing of sockets $\leftrightarrow$ ports

Ports and sockets



Connection-oriented and connectionless protocols

- Connectionless protocols:
  - E.g., User Datagram Protocol (UDP)
  - Send segments ("datagrams") between application layers
  - No notion of a continuous connection – think US Mail
  - Maybe some error checking embedded
  - No error correcting
  - Not reliable
- Connection-oriented protocols:
  - E.g., Transmission Control Protocol (TCP)
  - Connection: a virtual pipeline between applications
  - Think "phone", but no real connection
  - Reliable transport protocols

Unreliable Transport Protocols

Unreliable Transport Protocols

- Very simple
- Possibly segment application data
- Possibly add error-checking code (e.g., CRC)
- Just pass along to network layer

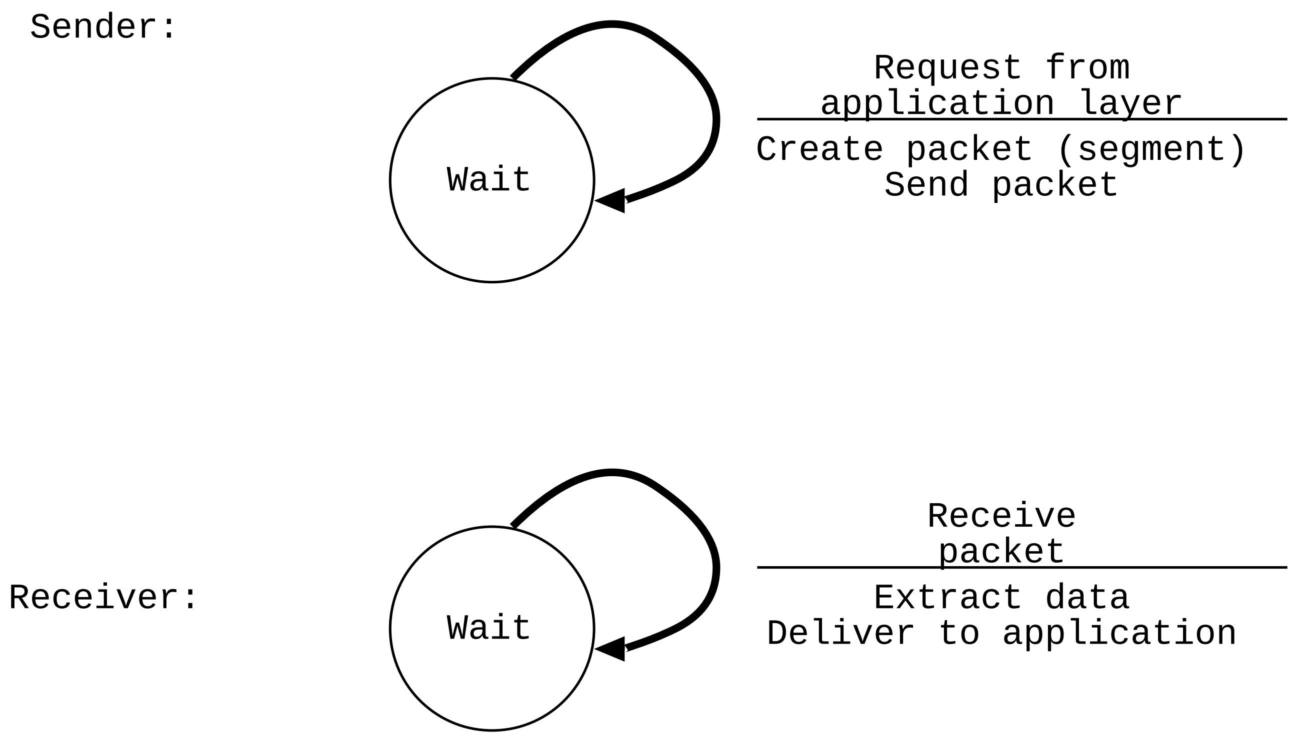
Reliable Transport Protocols

Reliable transport protocols

- More complex
- Have to deal with:
  - bitwise errors
  - lost segments
  - out-of-order segments
- Can conceptualize as *state machines*
- We'll look at increasingly-complex variants

Using a reliable channel

- Simplest



Using a channel with bit errors

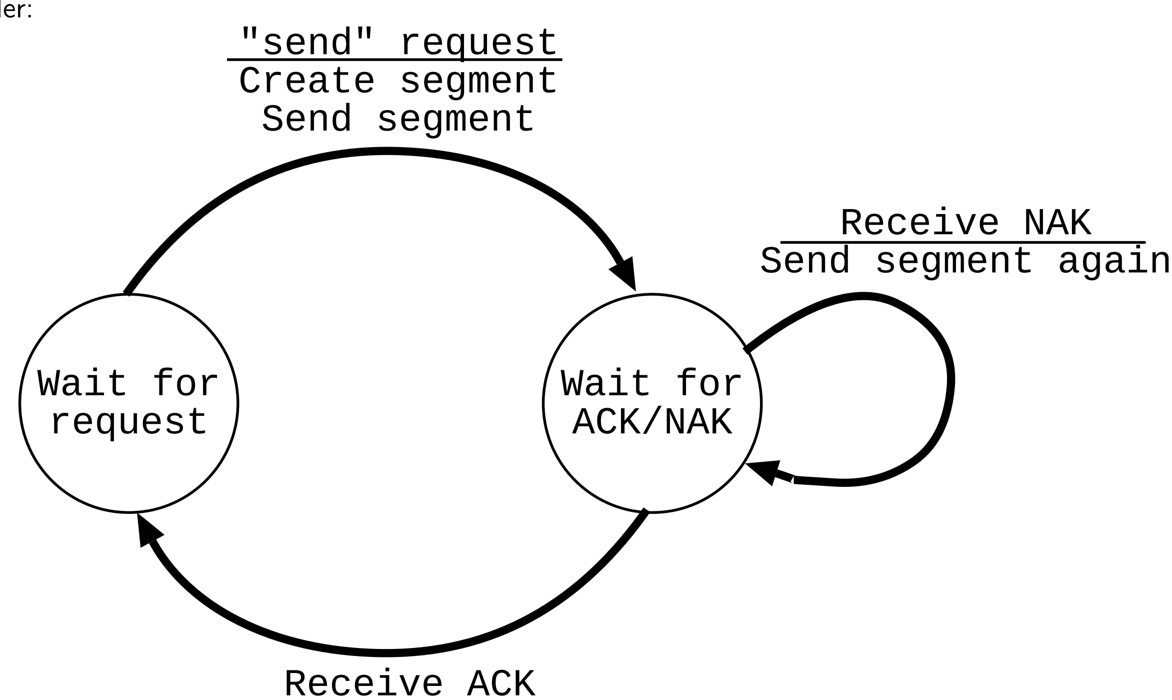
- Problem: Few channels are reliable
- Simple problem: errors in some bits
- Detect this with: parity, cyclic redundancy checks (CRC)
- The question is: what to do when detected?

Using a channel with bit errors

- For this, need additional messages:
  - ACK: to acknowledge correct receipt
  - NAK: negative acknowledgment
- Recipient checks the packet, sends the appropriate message in reply
- Problem: ACKs and NAKs can be garbled, too!

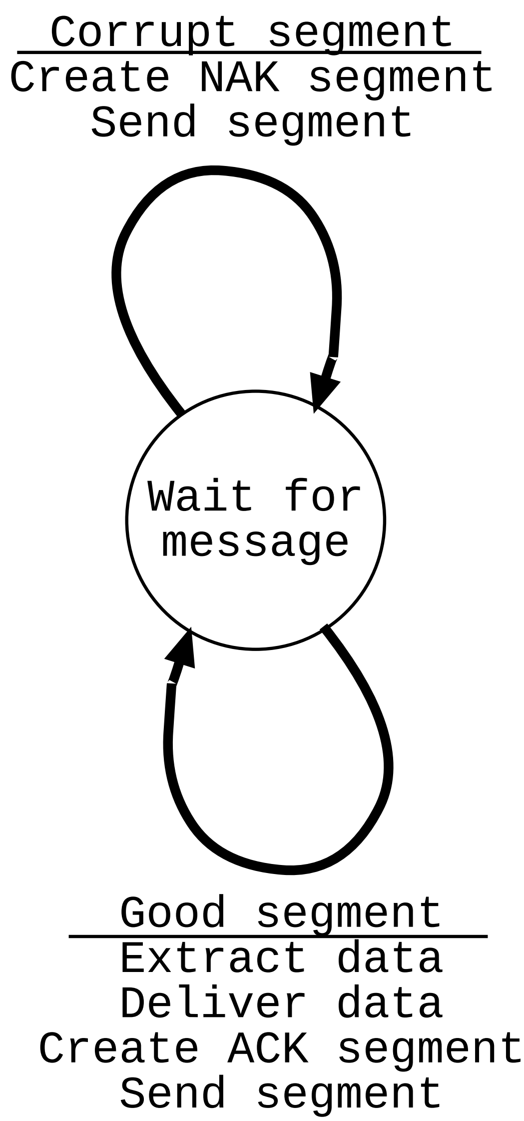
A protocol for handling bit errors

- Sender:



A protocol for handling bit errors

- Recipient:



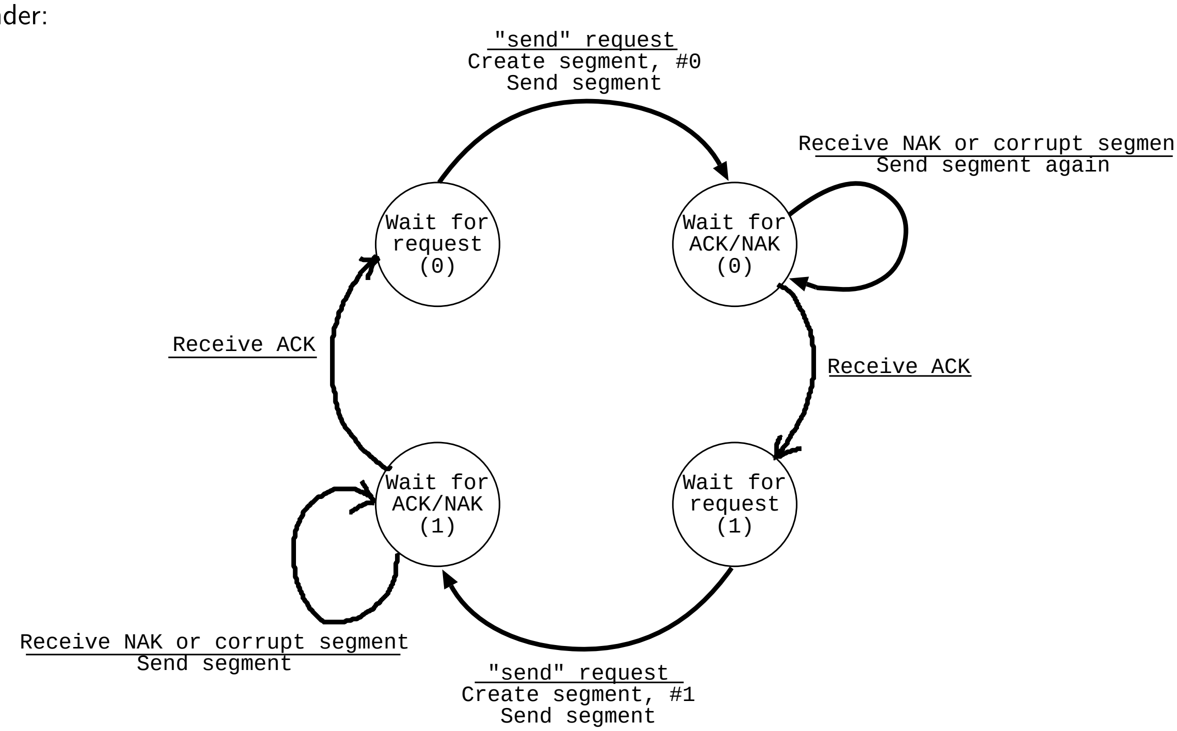
- Any problems with this? Yes! What about errors in ACK/NAK?

A better protocol for handling bit errors

- Have the sender number its segments
- Receiver can then determine if the packet received is a retransmission
- ACK/NAK don't need to say what they're ACK'ing (or not) – since no messages are lost, garbled or okay, the last ACK/NAK was for its last message
- For this simple protocol, we only need two sequence numbers, 0 and 1 (a bit) – only one packet being dealt with at a time.

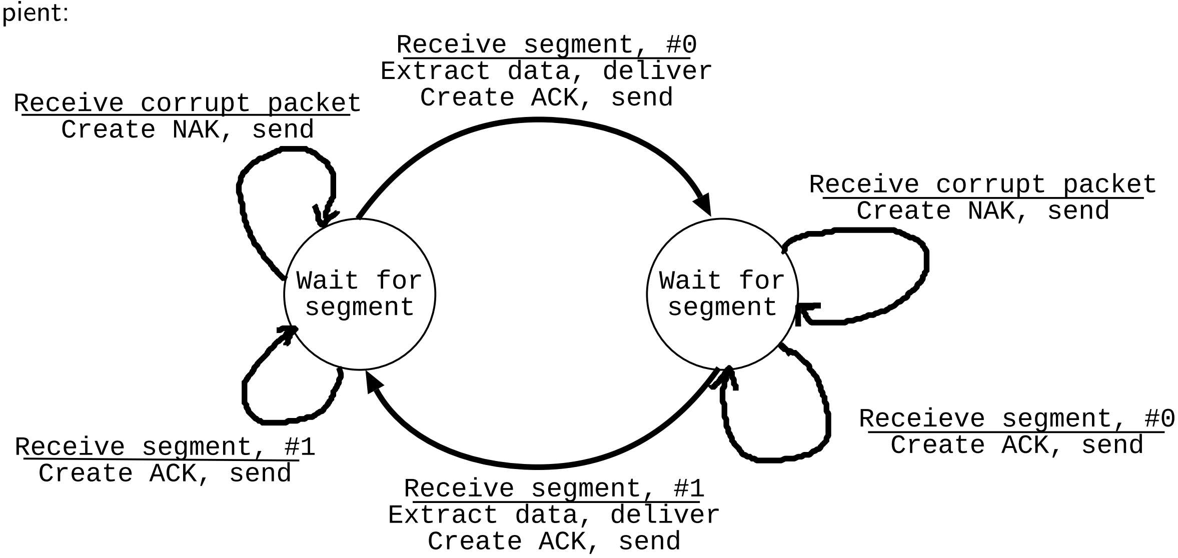
A better protocol for handling bit errors

- Sender:



A better protocol for handling bit errors

- Recipient:

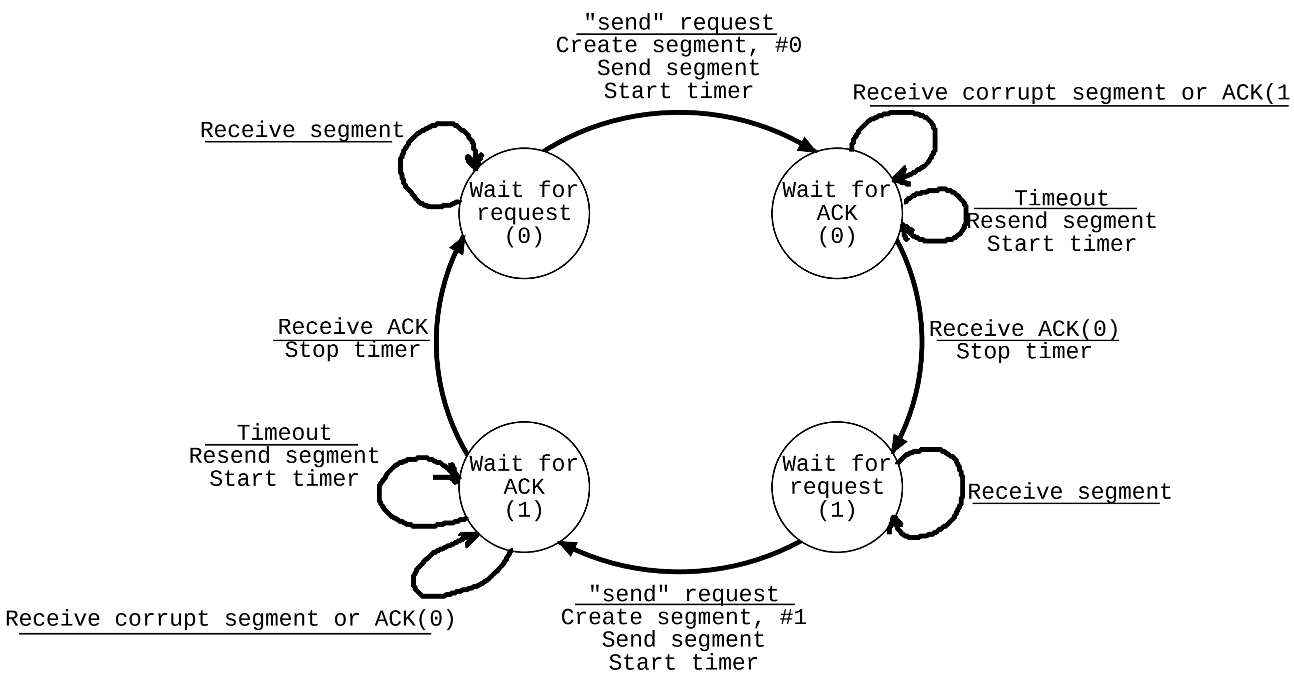


Using a "lossy" channel

- Even harder: What if the channel can lose some messages?
- ACKs and NAKs could also be lost or garbled.
- Need timers, now – if haven't received an ACK after some time, retransmit
- How to choose the time? At least round trip delay + some

Protocol for lossy channels

- Sender:



Pipelining

- ☐ Problem: reliable, but inefficient
- ☐ Suppose it takes 5 ms for message to propagate from sender to receiver, or vice versa – a 1 Gbps channel, and time to actually put the message on the channel is negligible
- ☐ Time to send, say, a 1 KB message:
  - Send message: 5 ms
  - Send ACK: 5 ms
  - Total 10 ms/message
  - Transfer rate = 1 KB/10 ms = only 100 KB/s!

Pipelining

- ☐ Better idea: don't wait for ACK before sending other messages
- ☐ Now can have n messages "in the pipe" at once.
- ☐ How many, potentially?
  - If 1 Gbps channel, 1 KB messages, then a message takes

$$\frac{8Kb}{1Gb/s} = \frac{2^{13}}{2^{30}}s = 2^{-17}s \approx 7.6\mu s$$

  - So there can be $\frac{5ms}{7.6\mu s} \approx 658$ messages in the pipe at once
  - In practice, have (far) fewer:
    - ▹ *Window*: what can be sent before an ACK received
    - ▹ Receive an ACK: slide window, can transmit more

Recovery in pipelining

- ☐ In send-and-wait protocols, pretty clear what you're ACKing
- ☐ What about pipelined protocols?
- ☐ Have to mark ACK with what is being acknowledged
- ☐ What to do when one is missing/corrupt?
  - Go-Back-N: When missing one (corrupt or timeout), repeat it and all others after it
  - Selective repeat: Just repeat the one missing
- ☐ GBN simpler, not as efficient

Example: TCP

Example: TCP

- ☐ Connection-oriented, reliable data transport protocol
- ☐ Can handle bit errors, lossy channels
- ☐ Full-duplex

TCP segment structure

- Header + data
- Source port number, destination port number
- Sequence number
- ACK number
- Checksum
- Header length field, flags, options, some other stuff

Sequence numbers

- Each half of the conversation is considered an ordered sequence of bytes
- Sequence number of a segment is the byte number of the first byte in the segment – not the segment number!
- ACK number: The next byte expected from the sender
- These are *cumulative acknowledgments*

Connection initiation: "three-way handshake"

- First: Client sends a special segment ("SYN segment") to request connection
  - No application data contained
  - SYN bit in header = 1
  - Random sequence number
- Second: Server sets up its side of the connection and sends message 2 ("SYNACK segment")
  - Allocates buffers, variables
  - Response segment: no application data
  - SYN = 1, ACK = client sequence number + 1, random sequence number

Connection initiation: "three-way handshake"

- Third: Client sets up its side, sends another message
  - Allocates client-side buffers, variables
  - Segment has SYN = 0, server's sequence number +1 as ACK
  - Can carry application data (*payload*)

Handling problems

- Corrupt segment received (bitwise error) – don't ACK
- Receive duplicate segment –
  - Why? Lost ACK
  - Just discard data, re-ACK
- Timeout –
  - Why? Lost segment
  - Single timer for all messages to reduce overhead
  - Retransmit segment

Handling problems

- ACK received for segment *after* one it's expecting an ACK for –
  - Not really a problem
  - Cumulative acknowledgment, so previous segments received, too

Handling problems

- Segment received out of order –
  - One reason: a segment was lost
  - For this, send ACK, but with next byte expected being the missing segment
  - Another reason: segment tied up in network
  - For this, ACK with next real byte expected, necessarily one right after this one

Other Transport Layer Topics

Other transport layer topics

- How to choose timeouts
- Flow control
- Congestion control
- When to use UDP vs TCP