CS 457 – Lecture 20
Transport Layer: UDP and TCP

Fall 2011

Topics

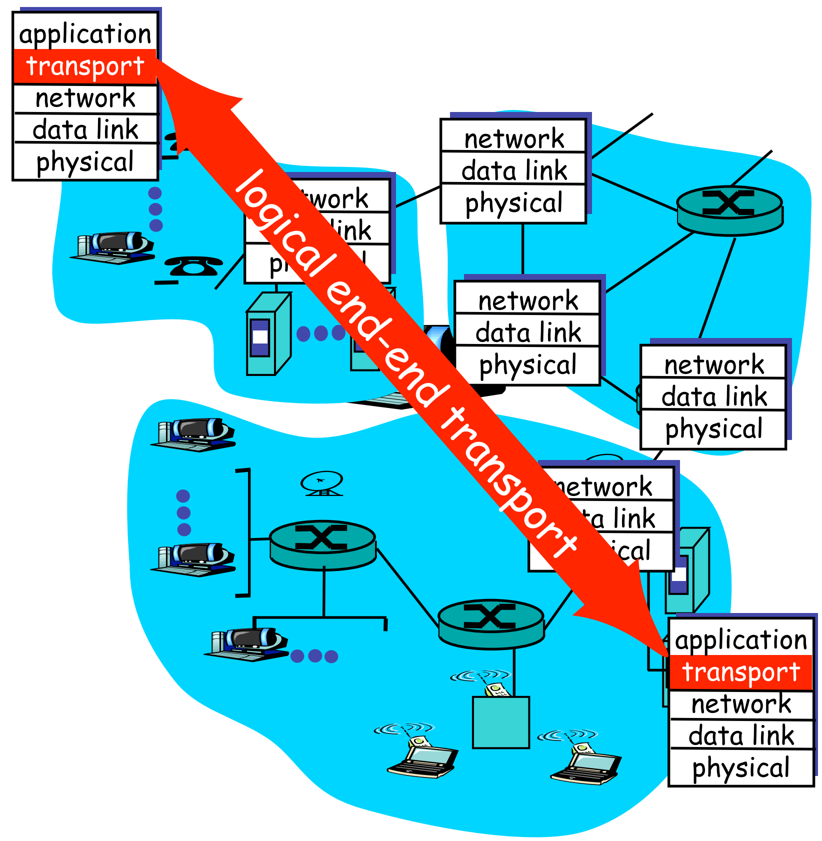
- Principles underlying transport-layer services
  - Demultiplexing
  - Detecting corruption
  - Reliable delivery
  - Flow control
- Transport-layer protocols
  - User Datagram Protocol (UDP)
  - Transmission Control Protocol (TCP)

Role of Transport Layer

- Application layer
  - Communication between networked applications
  - Protocols: HTTP, FTP, NNTP, and many others
- **Transport layer**
  - **Communication between processes (e.g., socket)**
  - **Relies on network layer and serves the application layer**
  - **Protocols: TCP and UDP**
- Network layer
  - Communication between nodes
  - Protocols: IP

Transport Protocols

- Provide *logical communication* between application processes running on different hosts
- Run on end hosts
  - Sender: breaks application messages into segments, and passes to network layer
  - Receiver: reassembles segments into messages, passes to application layer
- Multiple transport protocol available to applications
  - Internet: TCP and UDP

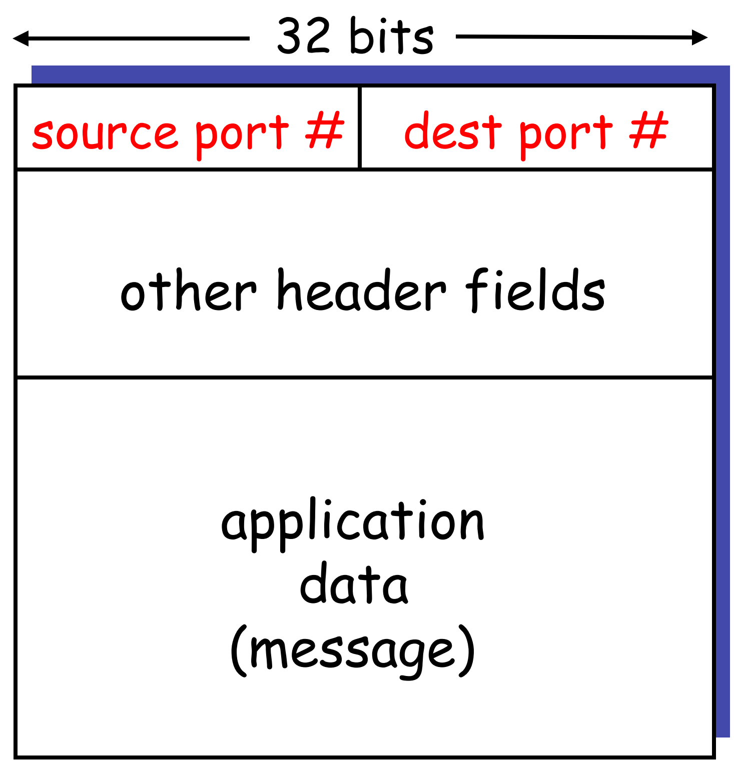


Internet Transport Protocols

- Datagram *messaging* service (UDP)
  - No-frills extension of “best-effort” IP
  - Just send the data – **each send is a message**
- Reliable, *streaming*, in-order delivery (TCP)
  - Connection set-up
  - Discarding of corrupted packets
  - Retransmission of lost packets
  - Flow control
  - Congestion control (next lecture)
- Services **not** available
  - Delay guarantees
  - Bandwidth guarantees

Multiplexing and Demultiplexing

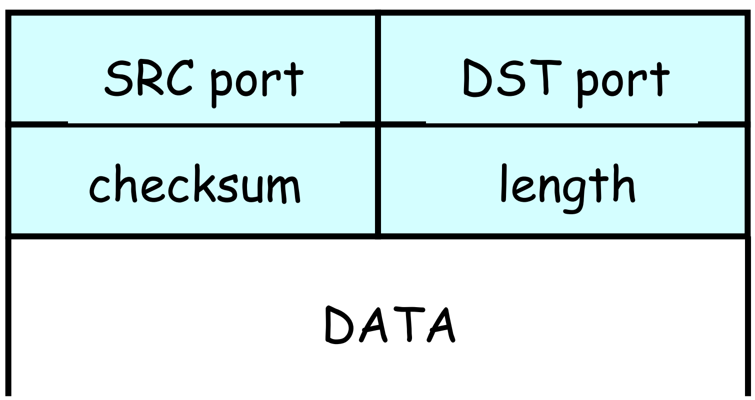
- Host receives IP datagrams
  - Each datagram has source and destination IP address,
  - Each datagram carries one transport-layer segment
  - Each segment has source and destination port number
- Host uses IP addresses and port numbers to direct the segment to appropriate socket



TCP/UDP segment format

User Datagram Protocol (UDP)

- Lightweight communication between processes
  - Avoid overhead and delays of ordered, reliable delivery
  - Send messages to and receive them from a socket
- Lightweight delivery service
  - IP plus port numbers to support (de)multiplexing
  - Optional error checking on the packet contents

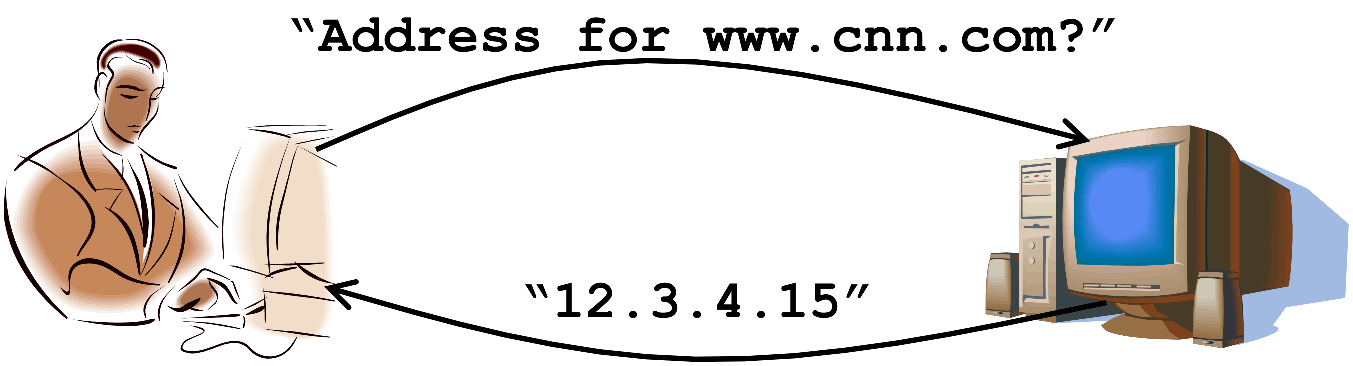


Why Would Anyone Use UDP?

- Finer control over what data is sent and when
  - As soon as an application process writes into the socket
  - … UDP will package the data and send the packet
- Low delay
  - UDP just blasts away without any formal preliminaries
  - … which avoids introducing delays such as setup
- No connection state
  - No allocation of buffers, parameters, sequence #s, etc.
  - … making it easier to handle many active clients
- Small packet header overhead
  - UDP header is only eight-bytes long

Popular Applications That Use UDP

- Multimedia streaming
  - Retransmitting lost/corrupted packets is not worthwhile
  - By the time the packet is retransmitted, it's too late
  - E.g., telephone calls, video conferencing, gaming
- Simple query protocols like Domain Name System
  - Overhead of connection establishment is overkill
  - Easier to have application retransmit if needed



Transmission Control Protocol (TCP)

- Connection oriented
  - Explicit set-up and tear-down of TCP session
- Stream-of-bytes service
  - Sends and receives a stream of bytes, not messages
  - Similar to file I/O
- Reliable, in-order delivery
  - Checksums to detect corrupted data
  - Acknowledgments & retransmissions for reliable delivery
  - Sequence numbers to detect losses and reorder data
- Flow control
  - Prevent overflow of the receiver’s buffer space
- Congestion control
  - Adapt to network congestion for the greater good

Human Analogy: Talking on a Cell Phone

- Alice and Bob talk on their cell phones
- What if Bob couldn't understand Alice?
  - ..or there was a brief dropout?
  - Bob asks Alice to repeat what she said
- What if Bob hasn't heard Alice for a while?
  - Is Alice just being quiet?
  - Or, have Bob and Alice lost connection?
  - Maybe Alice should periodically say "uh huh"
  - … or Bob should ask "Can you hear me now?" ☺
  - How long should Bob just keep on talking?

Highlights from Previous Example

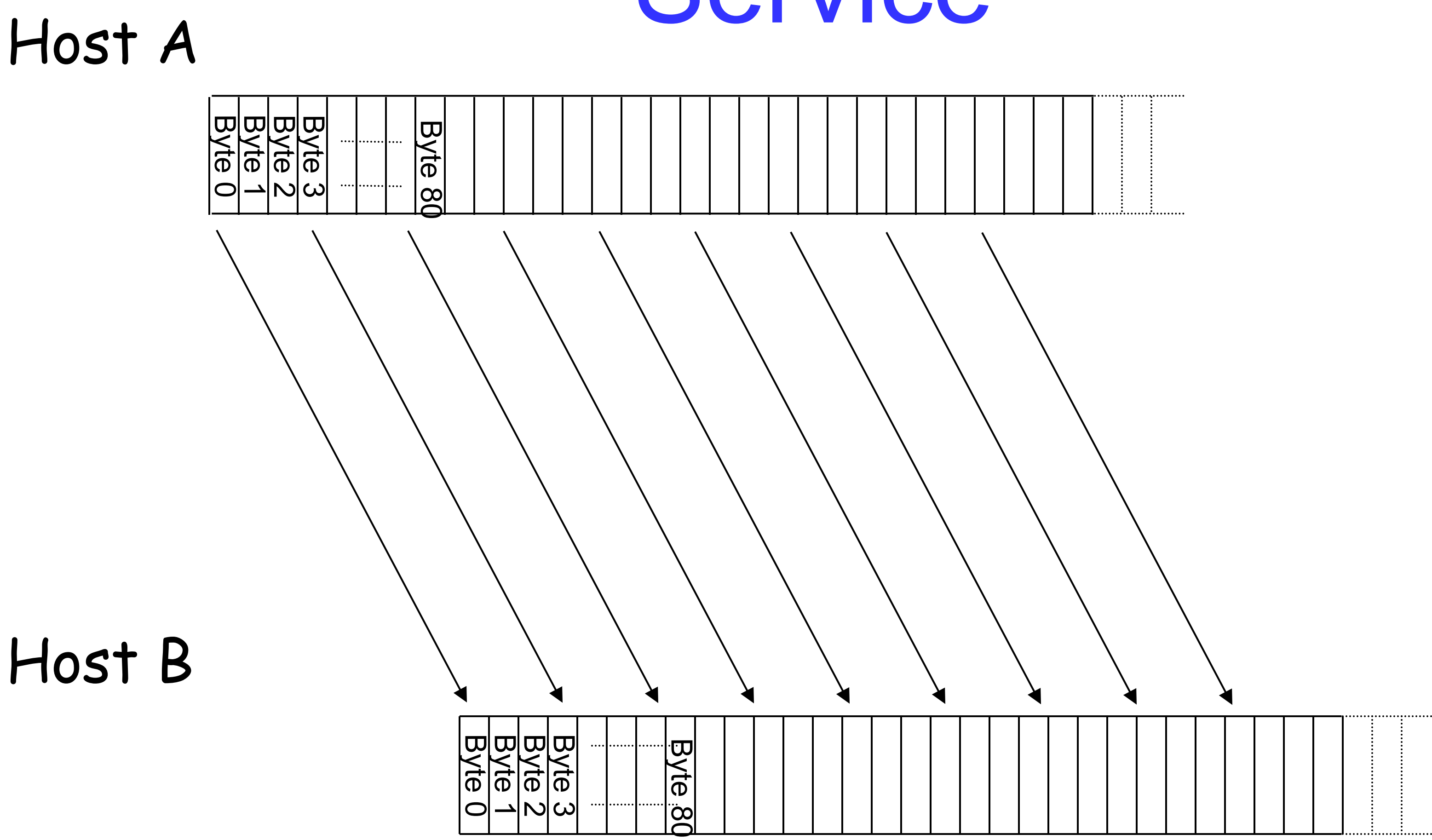
- Acknowledgments from receiver
  - Positive: “okay” or “ACK”
  - Negative: “please repeat that” or “NACK”
- Timeout by the sender (“stop and wait”)
  - Don’t wait indefinitely without receiving some response
  - … whether a positive or a negative acknowledgment
- Retransmission by the sender
  - After receiving a “NACK” from the receiver
  - After receiving no feedback from the receiver

TCP Support for Reliable Delivery

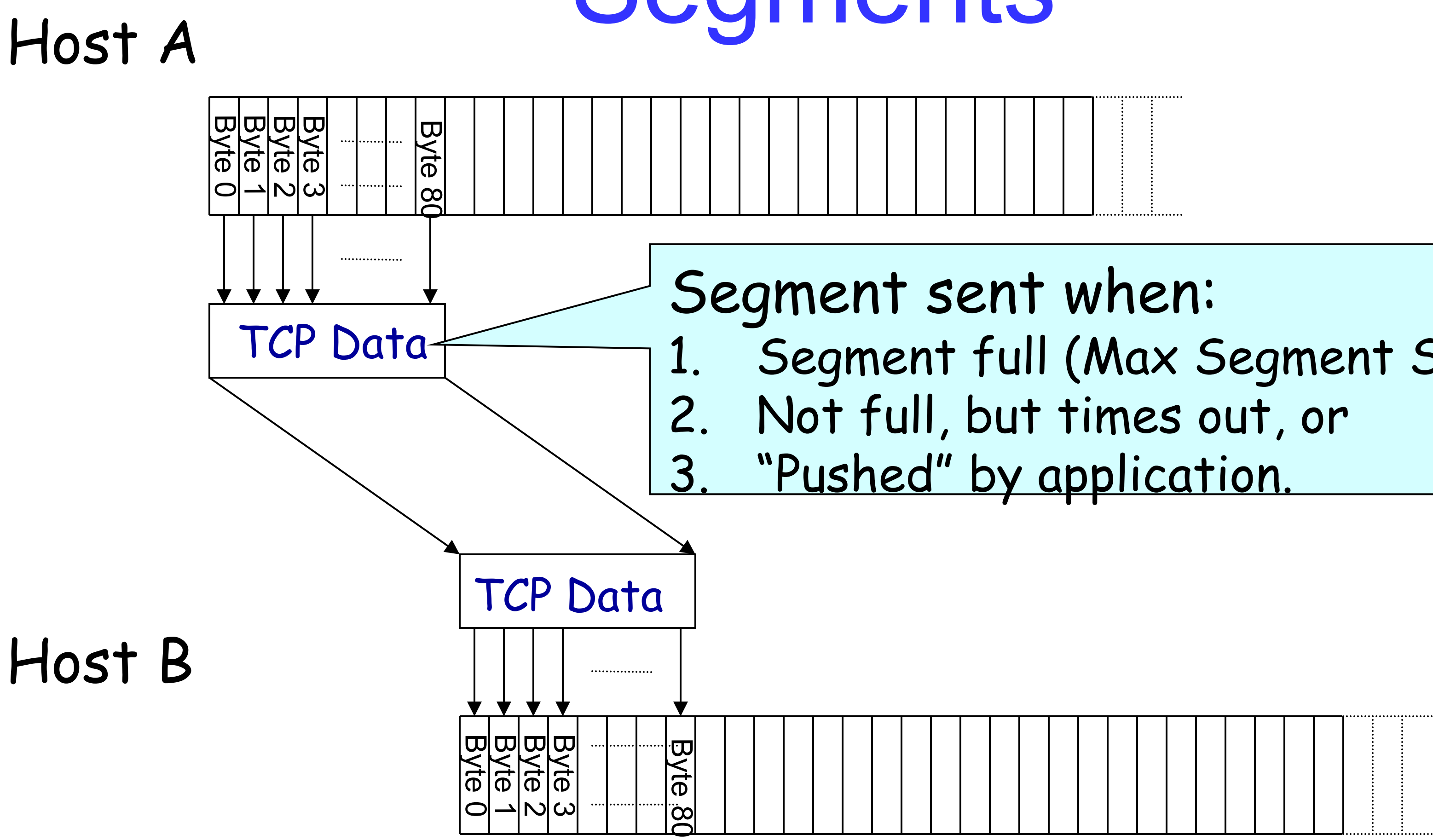
- Checksum
  - Used to detect corrupted data at the receiver
  - …leading the receiver to drop the packet
- Sequence numbers
  - Used to detect missing data
  - ... and for putting the data back in order
- Retransmission
  - Sender retransmits lost or corrupted data
  - Timeout based on estimates of round-trip time
  - Fast retransmit algorithm for rapid retransmission

TCP Segments

TCP "Stream of Bytes" Service



…Emulated Using TCP "Segments"



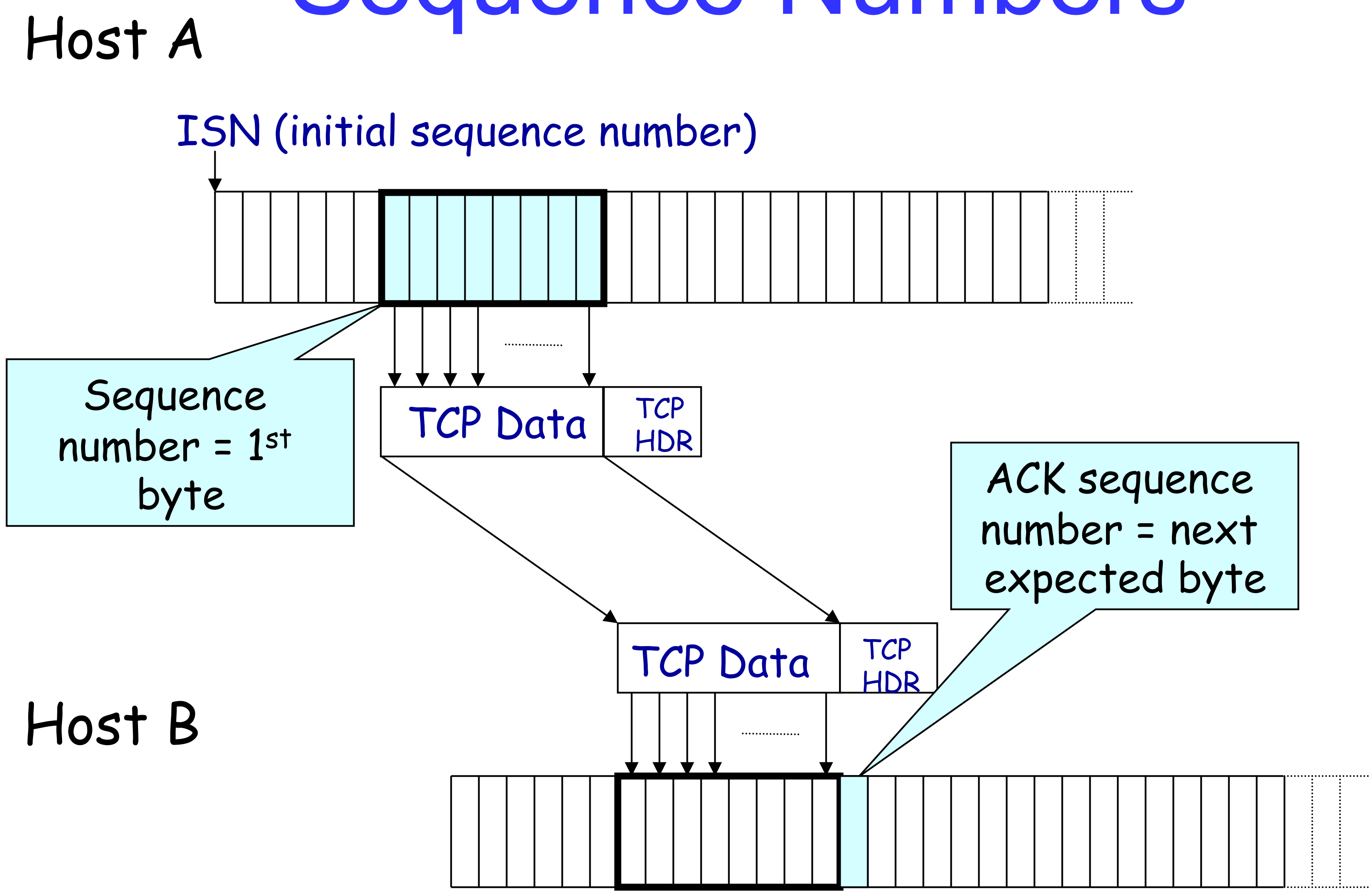
Segment sent when:

1. Segment full (Max Segment Size),
2. Not full, but times out, or
3. "Pushed" by application.

TCP Segment

- IP packet
  - No bigger than **Maximum Transmission Unit (MTU)**
  - E.g., up to 1500 bytes on an Ethernet
- TCP packet
  - IP packet with a TCP header and data inside
  - TCP header is typically 20 bytes long
- TCP segment
  - No more than **Maximum Segment Size (MSS)** bytes
  - E.g., up to 1460 consecutive bytes from the stream

Sequence Numbers

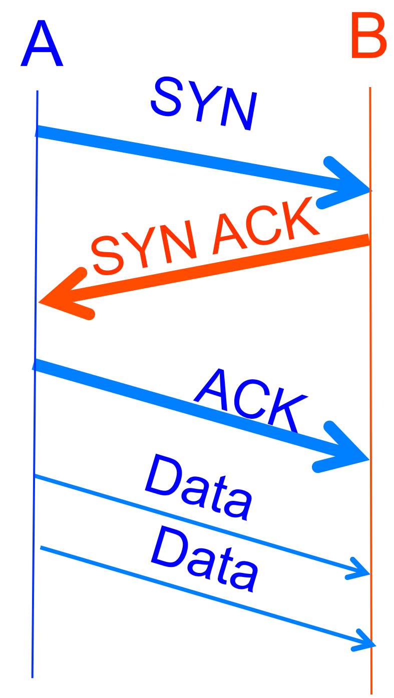


Initial Sequence Number (ISN)

- Sequence number for the very first byte
  - Why not a de facto ISN of 0?
- Practical issue
  - IP addresses and port #s uniquely identify a connection
  - Eventually, though, these port #s do get used again
  - … and there is a chance an old packet is still in flight
  - … and might be associated with the new connection
- Security issue
  - An adversary can guess ISNs and hijack a connection
- So, TCP requires changing the ISN over time
  - Set from a 32-bit clock that ticks every 4 microseconds
  - … which only wraps around once every 4.55 hours!
- But, this means the hosts need to exchange ISNs

TCP Three-Way Handshake

Establishing a TCP Connection

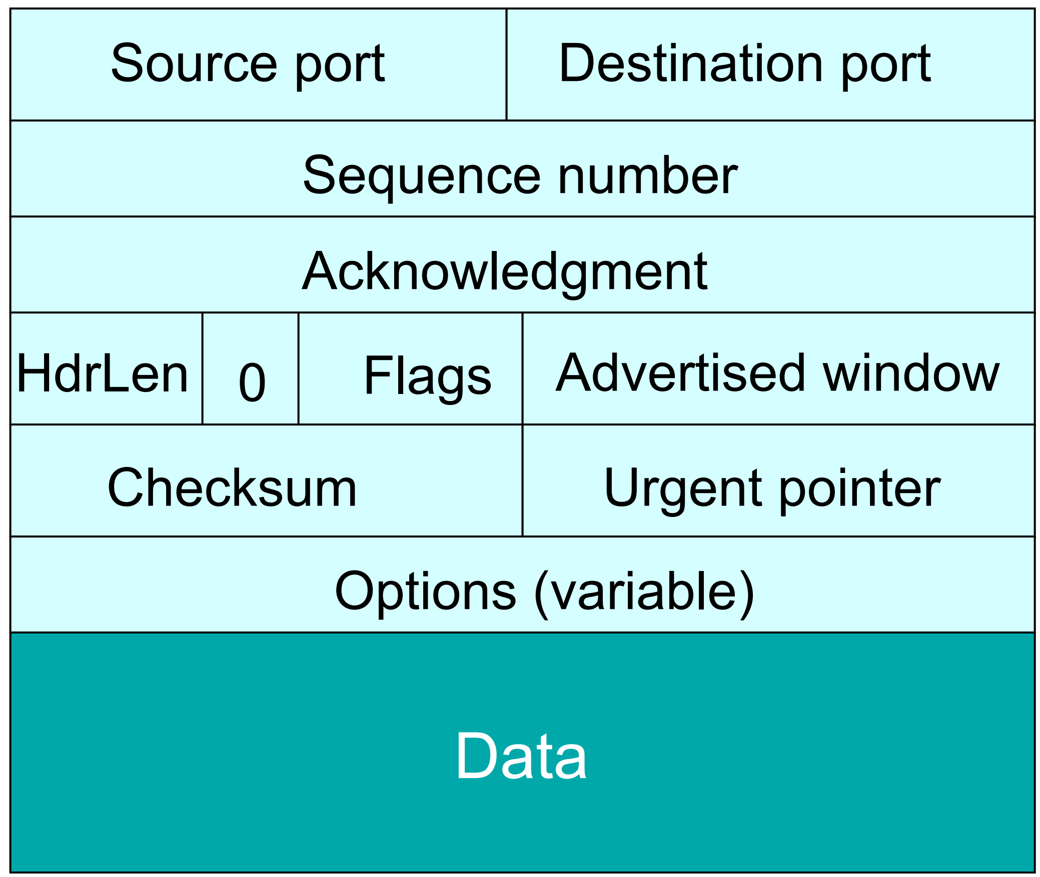


Each host tells its ISN to the other host.

- Three-way handshake to establish connection
  - Host A sends a **SYN** (open) to the host B
  - Host B returns a SYN acknowledgment (**SYN ACK**)
  - Host A sends an **ACK** to acknowledge the SYN ACK

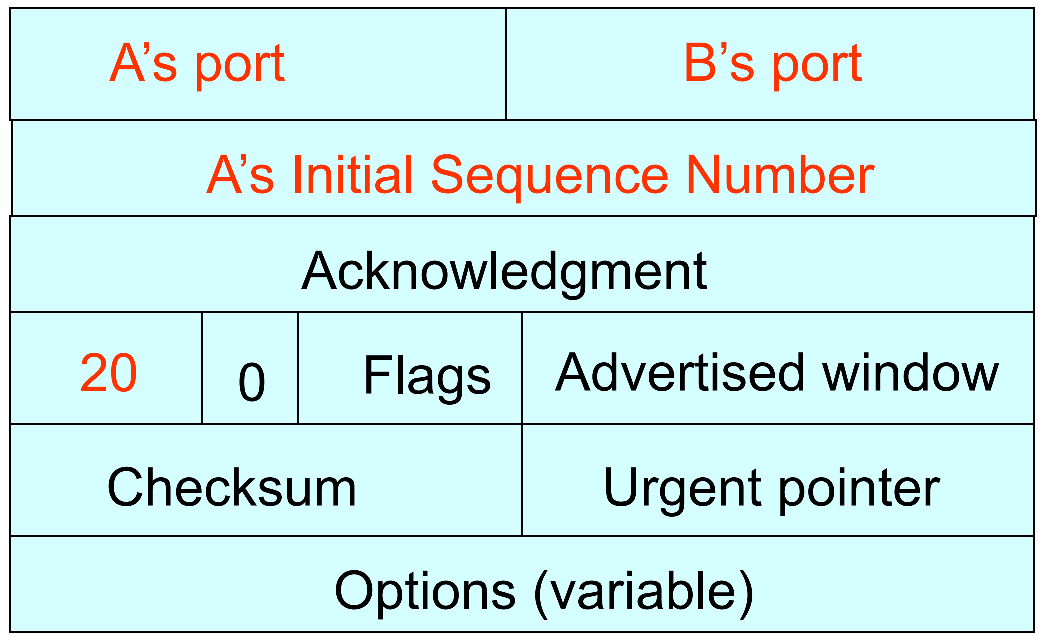
TCP Header

Flags: SYN
FIN
RST
PSH
URG
ACK



Step 1: A's Initial SYN Packet

Flags: SYN
FIN
RST
PSH
URG
ACK



A tells B it wants to open a connection…

Step 2: B's SYN-ACK Packet

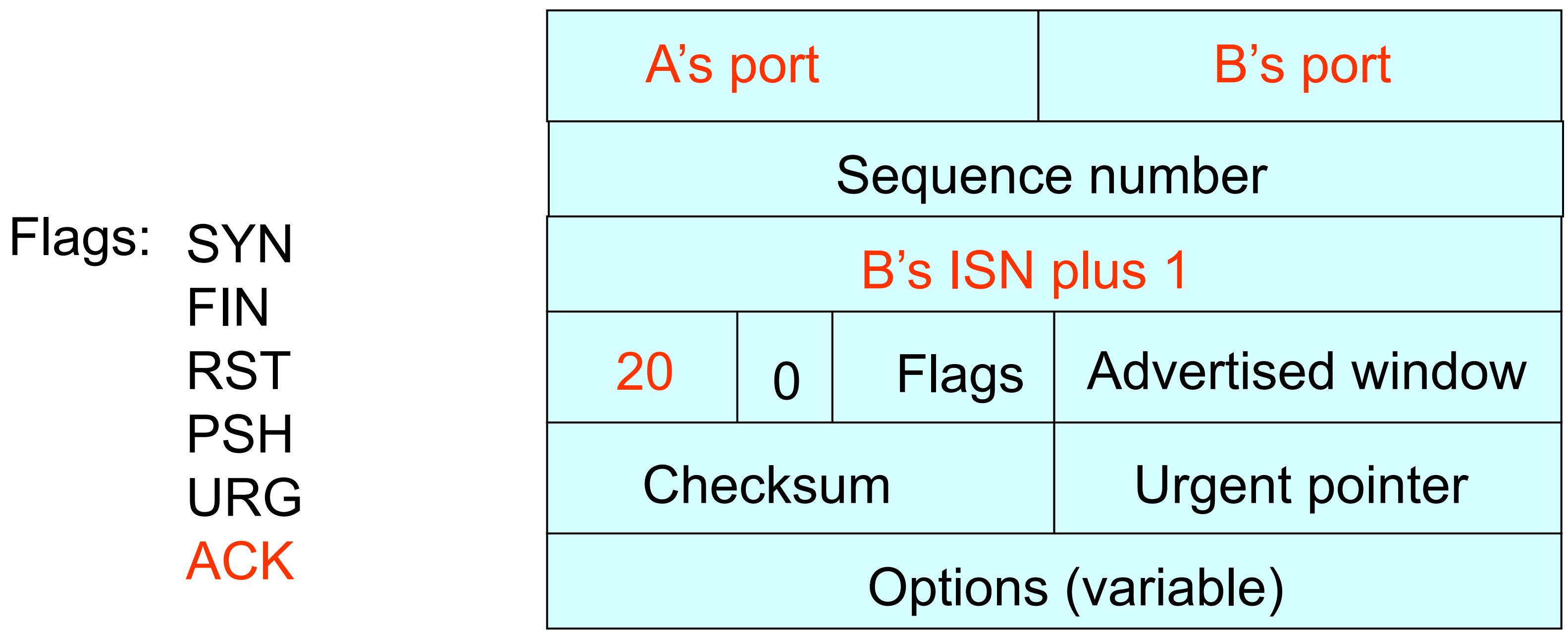
Flags:
- SYN
- FIN
- RST
- PSH
- URG
- ACK

B's port		A's port	
B's Initial Sequence Number			
A's ISN plus 1			
20	0	Flags	Advertised window
Checksum		Urgent pointer	
Options (variable)			

B tells A it accepts, and is ready to hear the next byte…

… upon receiving this packet, A can start sending data

Step 3: A’s ACK of the SYN-ACK



A tells B it wants is okay to start sending

… upon receiving this packet, B can start sending data

What if the SYN Packet Gets Lost?

- Suppose the SYN packet gets lost
  - Packet is lost inside the network, or
  - Server rejects the packet (e.g., listen queue is full)
- Eventually, no SYN-ACK arrives
  - Sender sets a timer and wait for the SYN-ACK
  - … and retransmits the SYN-ACK if needed
- How should the TCP sender set the timer?
  - Sender has no idea how far away the receiver is
  - Hard to guess a reasonable length of time to wait
  - Some TCPs use a default of 3 or 6 seconds

SYN Loss and Web Downloads

- User clicks on a hypertext link
  - Browser creates a socket and does a "connect"
  - The "connect" triggers the OS to transmit a SYN
- If the SYN is lost…
  - The 3-6 seconds of delay may be very long
  - The user may get impatient
  - … and click the hyperlink again, or click "reload"
- User triggers an "abort" of the "connect"
  - Browser creates a new socket and does a "connect"
  - Essentially, forces a faster send of a new SYN packet!
  - Sometimes very effective, and the page comes fast

What's Next

- Read Chapter 1, 2, 3, 4.1-4.3, and 5.1-5.2
- Next Lecture Topics from Chapter 5.3 and 5.4
  - UDP and TCP
- Homework
  - Due ***Thursday*** in lecture
- Project 3
  - Posted on the course webiste