CSE 123b
Communications Software

Spring 2003

Lecture 4: Connections and Flow Control

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Some slides courtesy David Wetherall

Administrativa

- Computer accounts have been setup
- You can use the following facilities
  - CSE uAPE lab (basement of CSE)
  - Engineering Building 2, room 313
  - EBU1-3327 (served by ieng9)
  - EBU1-3329 (served by ieng9)
  - Or login from home (ieng9.ucsd.edu)
- If you don't have an active OCE account you will need to get one (see me after class)
- We will give the first programming assignment next week, so go make sure you account works **now!**

Last Class

- We talked about how to implement a reliable channel in the transport layer
- Approaches
  - ARQ (Automatic Repeat reQuest), Sliding window
    - » Good RTT estimates
    - » Packet sequencing as an indicator of loss (Fast Retransmit)
  - FEC (Forward Error Correction)
    - » Redundant data encoding
    - » Appropriate for asymmetric channels, multicast, or high delay high loss channels

Today

- Finish basic transport protocol issues in context of
  - User Datagram Protocol (UDP)
  - Transmission Control Protocol (TCP)
- Connection-oriented vs connection-less transport
  - Naming
  - Connection setup
  - Connection teardown
- Flow control
  - How do we manage buffering at the endpoints?

Naming Processes/Services

- Process here is an abstract term for your Web browser (HTTP), Email servers (SMTP), hostname translation (DNS), RealAudio player (RTSP/RDT), etc.
- How do we identify for remote communication?
  - Process id or memory address are OS-specific and transient
- So TCP and UDP use Ports
  - 16-bit integers representing mailboxes that processes "rent"
  - Identify process uniquely as (IP address, protocol, port)

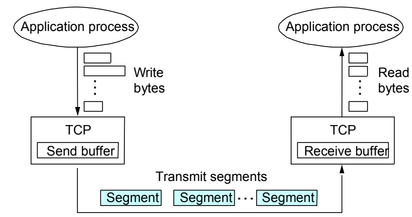
Picking Port Numbers

- We still have the problem of allocating port numbers
  - What port should a Web server use on host X?
  - To what port should you send to contact that Web server?
- Servers typically bind to "well-known" port numbers
  - e.g., HTTP 80, SMTP 25, DNS 53, … look in /etc/services
  - Ports below 1024 traditionally reserved for "well-known" services
- Clients use OS-assigned temporary (ephemeral) ports
  - Above 1024, recycled by OS when client finished

Transmission Control Protocol (TCP)

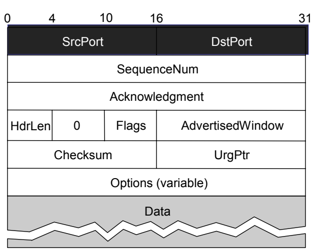
- Reliable **bi-directional** bytestream between processes
  - Message boundaries are not preserved
- Connection-oriented
  - Conversation between two endpoints with beginning and end
- Flow control (later)
  - Prevents sender from over-running receiver buffers
- Congestion control (next class)
  - Prevents sender from over-running network buffers

TCP Delivery



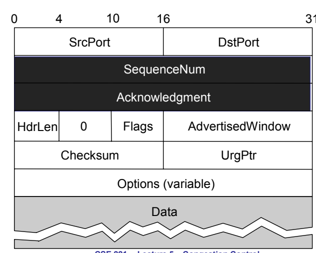
TCP Header Format

- Ports plus IP addresses identify a connection



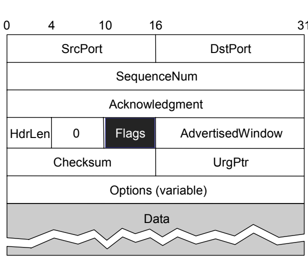
TCP Header Format

- Sequence, Ack numbers used for the sliding window
  - How big a window? Flow control/congestion control determine



TCP Header Format

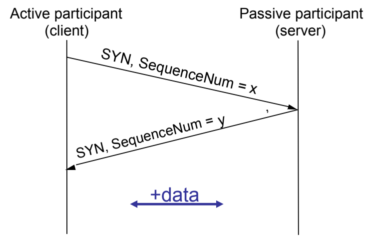
- Flags may be URG, ACK, PSH, RST, SYN, FIN



Connection Establishment

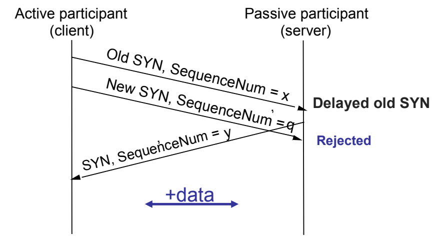
- Both sender and receiver must be ready before we start to transfer the data
  - Sender and receiver need to agree on a set of parameters
  - Most important: sequence number space in each direction
  - Lots of other parameters: e.g., the Maximum Segment Size
- This is signaling
  - It sets up state at the endpoints
  - Similar to “dialing” in the telephone network
- Handshake protocols: setup state between two oblivious endpoints

Two-way handshake?



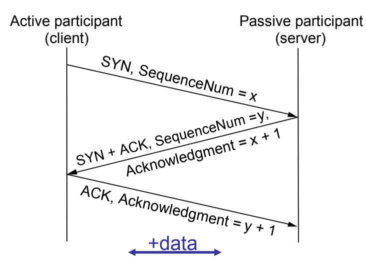
What's wrong here?

Two-way handshake?



Three-Way Handshake

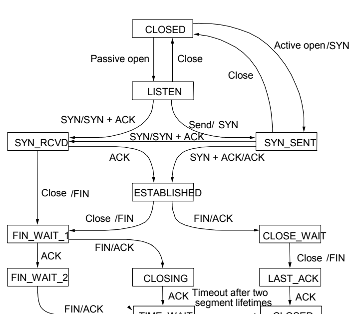
- Opens both directions for transfer



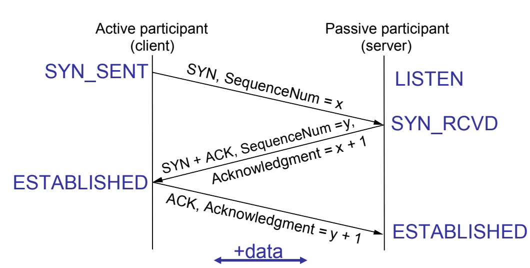
Some Comments

- We could abbreviate this setup, but it was chosen to be robust, especially against delayed duplicates
  - Three-way handshake from Tomlinson 1975
- Choice of changing initial sequence numbers (ISNs) minimizes the chance of hosts that crash getting confused by a previous incarnation of a connection
- How to choose ISNs?
  - Maximize period between reuse
  - Minimize ability to guess (why?)

TCP State Transitions



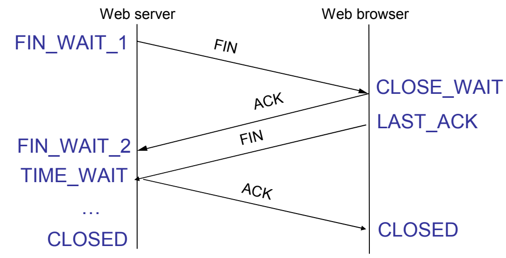
Again, with States



Connection Teardown

- Orderly release by sender and receiver when done
  - Delivers all pending data and "hangs up"
- Cleans up state in sender and receiver
- TCP provides a "symmetric" close
  - both sides shutdown independently

TCP Connection Teardown



The TIME_WAIT State

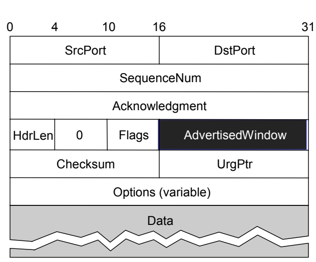
- We wait 2MSL (two times the maximum segment lifetime of 60 seconds) before completing the close
- Why?
- ACK might have been lost and so FIN will be resent
- Could interfere with a subsequent connection
- Real life: Abortive close
  - Some systems don't wait for 2*MSL, simply send Reset packet (RST)
  - Why? Frees up resources immediately

Flow Control

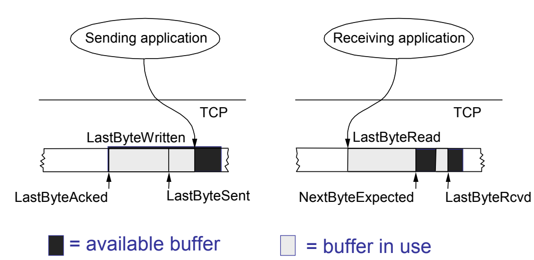
- Sender must transmit data no faster than it can be consumed by the receiver
  - Receiver might be a slow machine
  - App might consume data slowly
- Implement by adjusting the size of the sliding window used at the sender based on receiver feedback about available buffer space
  - This is the purpose of the Advertised Window field

TCP Header Format

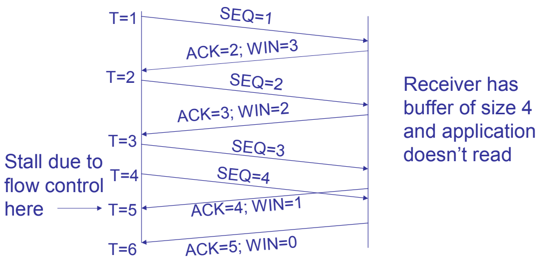
- Advertised window is used for flow control



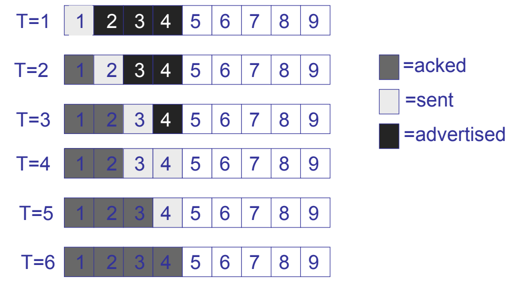
Sender and Receiver Buffering



Example – Exchange of Packets



Example – Buffer at Sender



Lots of icky details

- Window probes
- Silly Window Syndrome
- Nagel's algorithm
- PAWS
- Etc…

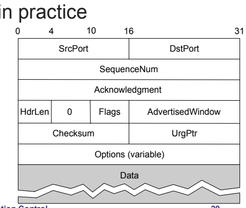
- Steven's books "TCP/IP Illustrated (vol 1,2)" is a great source of information on this

Example Icky Detail: Advertised Window Deadlock

- If the receiving process does not empty the buffer (e.g., not scheduled), then the sender fills up the receiver's buffer
  - Advertised Window is 0
  - Effective Window goes to 0 when all data is ACKed
- Problem: When can the sender start sending again?
  - No timeouts because all data is ACKed
  - No packets from receiver with a new Advertised Window because receiver isn't running
- Solution: Ping with a segment of 1 byte of data
  - Eventually receiver responds with a new Advert. Window

Misc TCP Header fields

- Header length allows for variable length TCP header with options for extensions such as timestamps, selective acknowledgements, etc.
- Checksum protects TCP header and data
- Urgent pointer/data not used in practice



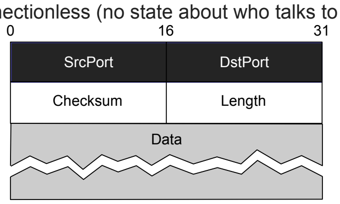
TCP applications

- HTTP/WWW
- FTP
- SMTP, POP, IMAP (E-mail)

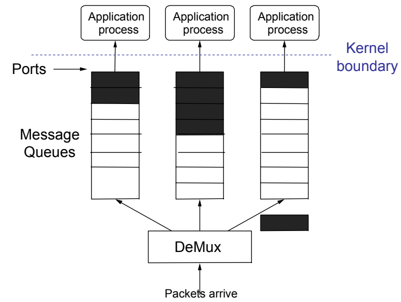
- Why is TCP well suited to these applications?

User Datagram Protocol (UDP)

- Provides **unreliable** *message delivery* between processes
  - Source port filled in by OS as message is sent
  - Destination port identifies UDP delivery queue at endpoint
- Connectionless (no state about who talks to whom)

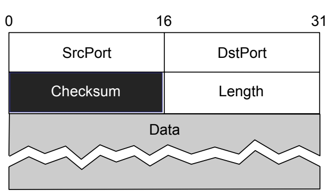


UDP Delivery



UDP Checksum

- UDP includes optional protection against errors
  - Checksum intended as an end-to-end check on delivery
  - So it covers data, UDP header, and IP pseudoheader



Applications for UDP

- Streaming media
- DNS (Domain Name Service)
- NTP (Network Time Protocol)
- Why is UDP appropriate for these?

Homework

- Problems from Peterson & Davies:
  - **1.5, 1.8, 2.20, 2.22, 2.26, 4.4(a,b)**
- Next class: Congestion Control
- No new reading, make sure you're caught up