This Time

- More on the Transport Layer
  - Focus: How do we connect processes?
  - Topics:
    - Naming processes
    - Connection setup / teardown
    - Flow control

Last Time

- We began on the Transport layer
- Focus: How do we send information reliably?
- Topics: ARQ and sliding windows

Naming Processes/Services

- Process here is an abstract term for your Web browser (HTTP), Email servers (SMTP), hostname translation (DNS), RealAudio player (RTSP), 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 reserved for "well-known" services
- Clients use OS-assigned temporary (ephemeral) ports
  - Above 1024, recycled by OS when client finished

User Datagram Protocol (UDP)

- Provides message delivery between processes
  - Source port filled in by OS as message is sent
  - Destination port identifies UDP delivery queue at endpoint

- Includes checksum for data transmission

<table>
<thead>
<tr>
<th>SrcPort</th>
<th>DstPort</th>
<th>Checksum</th>
<th>Length</th>
<th>Data</th>
</tr>
</thead>
<tbody>
<tr>
<td>0</td>
<td>16-31</td>
<td>0</td>
<td>32</td>
<td></td>
</tr>
</tbody>
</table>
UDP Delivery

- Application process
- Application process
- Application process
- Kernel boundary
- Packets arrive
- DaMux
- Ports
- Message Queues

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

Transmission Control Protocol (TCP)

- Reliable bi-directional bytestream between processes
  - Message boundaries are not preserved
- Connections
  - Conversation between two endpoints with beginning and end
- Flow control
  - Prevents sender from over-running receiver buffers
- Congestion control
  - Prevents sender from over-running network buffers

TCP Delivery

- Application process
  - Write bytes
  - Send segments
- Application process
  - Read bytes
  - Receive segments

TCP Header Format

- Ports plus IP addresses identify a connection

TCP Header Format

- Sequence and Ack numbers used for the sliding window
  - Congestion control works by controlling the window size
TCP Header Format

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

Options (variable)
Data
Checksum
SrcPort  DstPort
HdrLen  0  Flags  AdvertisedWindow
CheckSum  UrgPtr
Options (variable)
Data

Advertised window is used for flow control

Options (variable)
Data
Checksum
SrcPort  DstPort
HdrLen  0  Flags  AdvertisedWindow
CheckSum  UrgPtr
Options (variable)
Data

Other TCP Header Fields

- Header length allows for variable length TCP header with options for extensions such as timestamps, selective acknowledgements, etc.
- Checksum is analogous to that of UDP
- Urgent pointer/data not used in practice
- Very few bits not assigned ...

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, e.g., the Maximum Segment Size (MSS)
  - This is signaling
    - It sets up state at the endpoints
    - Compare to “dialing” in the telephone network
- In TCP a Three-Way Handshake is used

Three-Way Handshake

- Opens both directions for transfer

Active participant (client)
Passive participant (server)

SYN, SequenceNum = x
SYN + ACK, SequenceNum = y
ACK, Acknowledgment = y + 1
Acknowledgment = x + 1 + data

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
- But with random ISN it actually proves that two hosts can communicate
  - Weak form of authentication
TCP State Transitions

Again, with States

Connection Teardown

The Two-Army Problem

TCP Connection Teardown

The TIME_WAIT State
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

Sender and Receiver Buffering

Example – Exchange of Packets

Example – Buffer at Sender

Key Concepts

- We use ports to name processes in TCP/UDP
  - "Well-known" ports are used for popular services
- Connection setup and teardown complicated by the effects of the network on messages
  - TCP uses a three-way handshake to set up a connection
  - TCP uses a symmetric disconnect
- Flow control prevents sender over-running receiver
  - Implemented using an advertised window