Demultiplexing & Error Detection

Lecture 10
http://www.cs.rutgers.edu/~sn624/352-S22
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Quick recap of concepts

DASH
Video streaming over HTTP
Varying quality, varying sources, over the duration of the video
Can use CDNs!
Demultiplexing Packets
Demultiplexing

socket()  Ports

Machine

IP addr 1
Port 1
Port 2
...
...
...
...
Port 65535

IP addr 2

Denotes an attachment point with the network.

Each IP address comes with a full copy of its own ports.

Applications
Transport
Network
Link layer
Demultiplexing

Each IP address comes with a full copy of its own ports.

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Demultiplexing

Each IP address comes with a full copy of its own ports.

Denotes an attachment point with the network.
Demultiplexing

Connection lookup: The operating system does a lookup using these data to determine the right socket and app.

Denotes an attachment point with the network.

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socket() Ports

Machine

Src IP, Dst IP, Tp Protocol

Src port, Dst port

Port 1
Port 2
...
...
...
...
...
Port 65535

IP addr 1

IP addr 2
Demultiplexing

Connection lookup: The operating system does a lookup using these data to determine the right socket and app.

TCP sockets: (src IP, dst IP, src port, dst port)

→ Socket ID

Each IP address comes with a full copy of its own ports.

Denotes an attachment point with the network.

Machine

socket() Ports

Port 1
Port 2
...
...
...
...
...
Port 65535

IP addr 1

IP addr 2
Demultiplexing

Connection lookup: The operating system does a lookup using these data to determine the right socket and app.

TCP sockets: (src IP, dst IP, src port, dst port)

Socket ID

Machine

socket()  Ports

IP addr 1

Denotes an attachment point with the network.

Port 1
Port 2
...
Port 44262
...
Port 65535

Each IP address comes with a full copy of its own ports.

IP addr 2

Denotes an attachment point with the network.

IP addr 1

Denotes an attachment point with the network.

IP addr 2
Demultiplexing

Connection lookup: The operating system does a lookup using these data to determine the right socket and app.

TCP sockets: (src IP, dst IP, src port, dst port)
  ➔
  Socket ID

UDP sockets: (dst IP, dst port)
  ➔
  Socket ID

Connectionless: the socket is shared across all sources!
Demultiplexing

Connection lookup: The operating system does a lookup using these data to determine the right socket and app.

TCP sockets** Some caveats!
(src IP, dst IP, src port, dst port)

Socket ID

UDP sockets:
(dst IP, dst port)

Socket ID

Connectionless: the socket is shared across all sources!

Machine

Port 1
Port 2
...
...
...
...
...
...
Port 65535

socket() Ports

IP addr 1

Denotes an attachment point with the network.

IP addr 2

Each IP address comes with a full copy of its own ports.

Each IP address comes with a full copy of its own ports.
TCP sockets of different types

**Listening** (bound but unconnected)

# On server side
ss = socket(AF_INET, SOCK_STREAM)
ss.bind(serv_ip, serv_port)
ss.listen() # no accept() yet

**Connected** *(Established)*

# On server side
c.sockid, addr = ss.accept()

# On client side
cs.connect(serv_ip, serv_port)

(src IP, dst IP, src port, dst port)

→

Socket *(c.sockid NOT ss)*
TCP sockets of different types

**Listening** (bound but unconnected)

# On server side
ss = socket(AF_INET, SOCK_STREAM)
ss.bind(serv_ip, serv_port)
ss.listen() # no accept() yet

(dst IP, dst port) ➔

**Socket** (ss)
Enables new connections to be demultiplexed correctly

**Connected** (Established)

# On server side
csockid, addr = ss.accept()

# On client side
cs.connect(serv_ip, serv_port)

(src IP, dst IP, src port, dst port) ➔

**Socket** (csockid NOT ss)
Enables existing connections to be demultiplexed correctly

accept() creates a new socket with the 4-tuple (established) mapping
TCP demultiplexing

• When a TCP packet comes in, the operating system:
  • Looks up table of existing connections using 4-tuple
    • If success, send to corresponding (established) socket
  • If fail (no table entry), look up table of listening connections using just (dst IP, dst port)
    • If success, send to corresponding (listening) socket
  • If fail again (no table entry), send error to client
    • Connection refused
UDP demultiplexing

• When a UDP packet comes in, the operating system:

  • Looks up table of listening UDP sockets using (dst IP, dst port)
    • If success, send packet to corresponding socket
    • There are no established UDP sockets; they’re all “unconnected”

  • If fail (no table entry), send error to client
    • Port unreachable
Listing sockets and connections

- List all sockets with `ss`

- Create and observe UDP sockets with `iperf`

- Observe a TCP listening socket with `iperf` (or your own server!)
User Datagram Protocol
UDP: User Datagram Protocol [RFC 768]

- Best effort service. UDP segments may be:
  - Lost
  - Delivered out of order to app
- UDP is connectionless
  - Each UDP segment handled independently of others (i.e. no “memory” across packets)
- Suitable for one-off req/resp
  - E.g., DNS uses UDP
- Also for loss-tolerant delay-sensitive apps, e.g., video calling

Why are UDP’s guarantees even okay?
Simple & low overhead compared to TCP:
- No delays due to connection establishment
  - UDP can send data immediately
- No memory for connection state at sender & receiver
- Small segment header
- UDP can blast away data as fast as desired
  - UDP has no “congestion control”
UDP segment structure

Length of segment (UDP header + data)

Error detection info (more to come)

Applications

Transport

Network

Link layer

source port #
dest port #

length
checksum

application data (message)
Review: UDP demultiplexing

- Source IP address
- Destination IP address
- Source port #
- Dest port #
- Length
- Checksum
- Application data (message)
Seeing UDP packets in action

• How to craft and send (UDP) packets?
  • It’s simpler than you think!

/sudo tcpdump -i lo udp –XAvvv # observe packets
/sudo scapy # tool used to send crafted packets
/Example: send(IP(dst="127.0.0.1")/UDP(sport=1024, dport=2048)/"hello world", iface="lo")
/Super other fields of UDP using UDP().fields_desc
/Super can send and receive crafted packets!
  • However, it requires sudo (superuser privileges)
Error Detection
Why error detection?

• Network provides best effort service
• UDP is a simple and low overhead transport
  • Data may be lost
  • Data may be corrupted along the way (e.g., 1 \rightarrow 0)
  • Data may be reordered

• However, simple error detection is possible!
  • Was the data I received the same data the remote machine sent?

• Error detection is a useful feature for all transport protocols including TCP
Error Detection in UDP and TCP

• Key idea: have sender compute a function over the data
  • Store the result in the packet
  • Receiver can check the function’s value in received packet

• An analogy: you’re sending a package of goodies and want your recipient to know if goodies were leaked along the way

• Your idea: weigh the package; stamp the weight on the package
  • Have the recipient weigh the package and cross-check the weight with the stamped value
Requirements on error detection function

• Function must be easy to compute
• Function must capture the likely changes to the packet
  • If the packet was corrupted through these likely changes, the function value must change
• Function must be easy to verify

• UDP and TCP use a class of function called a checksum
  • Very common idea: used in multiple parts of networks and computer systems
UDP & TCP’s Checksum function

Sender:
• treat segment contents as sequence of 16-bit integers
• checksum: addition (1’s complement sum) of segment contents
• sender puts checksum value into UDP checksum field

Receiver:
• compute a checksum of the received segment, including the checksum in packet itself
• check if the resulting (computed) checksum is 0
• NO – an error is detected
• YES – assume no error
Computing 1’s complement sum

• Very similar to regular (unsigned) binary addition.
• However, when adding numbers, a carryout from the most significant bit needs to be added to the result

• Example: add two 16-bit integers

\[
\begin{align*}
\text{1110011001100110} & \quad 1101010101010101 \\
\text{1101010101010101} & \quad \text{wraparound sum} \\
\text{110111011101110111} & \quad \text{sum} \\
\text{01000100010001000011} & \quad \text{checksum}
\end{align*}
\]
From the UDP specification (RFC 768)

• Checksum is the 16-bit one's complement of the one's complement sum of a pseudo header of information from the IP header, the UDP header, and the data, padded with zero octets at the end (if necessary) to make a multiple of two octets.

• The pseudo header conceptually prefixed to the UDP header contains the source address, the destination address, the protocol, and the UDP length.
Some observations on checksums

• Checksums don’t detect all bit errors
  • Consider \((x, y)\) vs. \((x - 1, y + 1)\) as adjacent 16-bit values in packet
  • Analogy: you can’t assume the package hasn’t been meddled with if its weight matches the one on the stamp. More smarts needed for that.
  • But it’s a lightweight method that works well in many cases

• Checksums are part of the packet; they can get corrupted too
  • The receiver will just declare an error if it finds an error
  • However, checksums don’t enable the receiver to detect where the error lies or correct the error(s)
  • Checksum is an error detection mechanism; not a correction mechanism.
Some observations on checksums

• Checksums are insufficient for reliable data delivery
  • If a packet is lost, so is its checksum

• UDP and TCP use the same checksum function
  • TCP also uses the lightweight error detection capability
  • However, TCP has more mature mechanisms for reliable data delivery (more to come on this)
Playing with checksums
Summary of UDP

- UDP is a thin shim around network layer’s best-effort delivery
  - One-off request/response messages
  - Lightweight transport for loss-tolerant delay-sensitive applications

- Provides basic multiplexing/demultiplexing for application
- No reliability, performance, or ordering guarantees
- Can do basic error detection (bit flips) using checksums
  - Error detection is necessary to deliver data reliably, but it is insufficient