Networks review; Day 2 of 2
And start of RPC
Jan 9, 2017
Last Time

- Modularity, Layering, and Decomposition
  - Example: UDP layered on top of IP to provide application demux ("ports")
- Resource sharing and isolation
  - Statistical multiplexing - packet switching
- Dealing with heterogeneity
  - IP “narrow waist” -- allows many apps, many network technologies
  - IP standard -- allows many impls, same proto
IP Packets/Service Model

- Low-level communication model provided by Internet
- Datagram
  - Each packet self-contained
    - All information needed to get to destination
    - No advance setup or connection maintenance
  - Analogous to letter or telegram

![IPv4 Packet Format Diagram]

<table>
<thead>
<tr>
<th>0</th>
<th>4</th>
<th>8</th>
<th>12</th>
<th>16</th>
<th>19</th>
<th>24</th>
<th>28</th>
<th>31</th>
</tr>
</thead>
<tbody>
<tr>
<td>version</td>
<td>HLen</td>
<td>TOS</td>
<td>Length</td>
<td>Identifier</td>
<td>Flag</td>
<td>Offset</td>
<td>TTL</td>
<td>Protocol</td>
</tr>
<tr>
<td>Source Address</td>
<td>Destination Address</td>
<td>Options (if any)</td>
<td>Data</td>
<td>Header</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>
Goals [Clark88]

0. **Connect existing networks**
   initially ARPANET and ARPA packet radio network

1. **Survivability**
   ensure communication service even in the presence of network and router failures

2. **Support multiple types of services**

3. **Must accommodate a variety of networks**

4. **Allow distributed management**

5. **Allow host attachment with a low level of effort**

6. **Be cost effective**

7. **Allow resource accountability**
Goal 1: Survivability

- If network is disrupted and reconfigured…
  - Communicating entities should not care!
  - No higher-level state reconfiguration

- How to achieve such reliability?
  - Where can communication state be stored?

<table>
<thead>
<tr>
<th></th>
<th>Network</th>
<th>Host</th>
</tr>
</thead>
<tbody>
<tr>
<td>Failure handing</td>
<td>Replication</td>
<td>“Fate sharing”</td>
</tr>
<tr>
<td>Net Engineering</td>
<td>Tough</td>
<td>Simple</td>
</tr>
<tr>
<td>Routing state</td>
<td>Maintain state</td>
<td>Stateless</td>
</tr>
<tr>
<td>Host trust</td>
<td>Less</td>
<td>More</td>
</tr>
</tbody>
</table>
Fate Sharing

• Lose state information for an entity if and only if the entity itself is lost.

• Examples:
  • OK to lose TCP state if one endpoint crashes
    • NOT okay to lose if an intermediate router reboots
  • Is this still true in today’s network?
    • NATs and firewalls

• Tradeoffs
  • Less information available to the network
  • Must trust endpoints more
Networks [including end points] Implement Many Functions

- Link
- Multiplexing
- Routing
- Addressing/naming (locating peers)
- **Reliability**
- Flow control
- Fragmentation
- Etc....
Design Question

- If you want reliability, where should you implement it?

Option 1: Hop-by-hop (at switches)

Option 2: end-to-end (at end-hosts)
Options

• Hop-by-hop: Have each switch/router along the path ensure that the packet gets to the next hop

• End-to-end: Have just the end-hosts ensure that the packet made it through

• What do we have to think about to make this decision??
A question

• Is hop-by-hop enough?
• [hint: What happens if a switch crashes? What if it’s buggy and goofs up a packet?]
End-to-End Argument

• Deals with **where** to place functionality
  • Inside the network (in switching elements)
  • At the edges

• Guideline not a law

• Argument
  • If you have to implement a function end-to-end anyway (e.g., because it requires the knowledge and help of the end-point host or application), **don’t implement it inside the communication system**
  • Unless there’s a compelling performance enhancement

*Further Reading: “End-to-End Arguments in System Design.” Saltzer, Reed, and Clark.*
Questions to ponder

• If you have a whole file to transmit, how do you send it over the Internet?
  • You break it into packets (packet-switched medium)
  • TCP, roughly speaking, has the sender tell the receiver “got it!” every time it gets a packet. The sender uses this to make sure that the data’s getting through.
  • But by e2e, if you have to acknowledge the correct receipt of the entire file... why bother acknowledging the receipt of the individual packets???
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• This is a bit of a trick question -- it’s not asking e2e vs in-network. :)
The answer: Imagine the waste if you had to retransmit the entire file because one packet was lost. Ow.
Internet Design: Types of Service

- **Principle**: network layer provides one simple service: best effort datagram (packet) delivery
  - All packets are treated the same

  - Relatively simple core network elements
  - Building block from which other services (such as reliable data stream) can be built
  - Contributes to scalability of network

- No QoS support assumed from below
  - In fact, some underlying nets only supported reliable delivery (not best effort)
    - This made Internet datagram service less useful!
  - Hard to implement QoS without network support
  - QoS is an ongoing debate…
User Datagram Protocol (UDP): An Analogy

<table>
<thead>
<tr>
<th>UDP</th>
<th>Postal Mail</th>
</tr>
</thead>
<tbody>
<tr>
<td>• Single socket to receive messages</td>
<td>• Single mailbox to receive letters</td>
</tr>
<tr>
<td>• No guarantee of delivery</td>
<td>• Unreliable 😛</td>
</tr>
<tr>
<td>• Not necessarily in-order delivery</td>
<td>• Not necessarily in-order delivery</td>
</tr>
<tr>
<td>• Datagram – independent packets</td>
<td>• Letters sent independently</td>
</tr>
<tr>
<td>• Must address each packet</td>
<td>• Must address each letter</td>
</tr>
</tbody>
</table>

Example UDP applications
Multimedia, voice over IP
Transmission Control Protocol (TCP): An Analogy

<table>
<thead>
<tr>
<th>TCP</th>
<th>Telephone Call</th>
</tr>
</thead>
<tbody>
<tr>
<td>Reliable – guarantee delivery</td>
<td>Guaranteed delivery</td>
</tr>
<tr>
<td>Byte stream – in-order delivery</td>
<td>In-order delivery</td>
</tr>
<tr>
<td>Connection-oriented – single socket per connection</td>
<td>Connection-oriented</td>
</tr>
<tr>
<td>Setup connection followed by data transfer</td>
<td>Setup connection followed by conversation</td>
</tr>
</tbody>
</table>

Example TCP applications
Web, Email, Telnet
Why not always use TCP?

- TCP provides “more” than UDP
- Why not use it for everything??
Why not always use TCP?

- TCP provides “more” than UDP
- Why not use it for everything??

A: Nothing comes for free...
- Connection setup (take on faith) -- TCP requires one round-trip time to setup the connection state before it can chat...
- How long does it take, using TCP, to fix a lost packet?
  - At minimum, one “round-trip time” (2x the latency of the network)
  - That could be 100+ milliseconds!
- If I guarantee in-order delivery, what happens if I lose one packet in a stream of packets?
- Has semantics that may be too strong for the app (e.g., Netflix streaming)
Design trade-off

• If you’re building an app...

• Do you need everything TCP provides?
• If not:
  • Can you deal with its drawbacks to take advantage of the subset of its features you need?
    OR
  • You’re going to have to implement the ones you need on top of UDP
    • Caveat: There are some libraries, protocols, etc., that can help provide a middle ground.
    • Takes some looking around
Socket API Operation Overview

Client
- socket
- connect
- write
- read
- close

Server
- socket
- bind
- listen
- accept
- read
- write
- close

open_clientfd
open_listenfd

Client / Server Session
Connection request
read
write

EOF
Blocking sockets

• What happens if an application write()s to a socket waaaaay faster than the network can send the data?
  • TCP figures out how fast to send the data...
  • And it builds up in the kernel socket buffers at the sender... and builds...
  • until they fill. The next write() call *blocks* (by default).
  • What’s blocking? It suspends execution of the blocked thread until enough space frees up...
In contrast to UDP

- UDP doesn’t figure out how fast to send data, or make it reliable, etc.
- So if you write() like mad to a UDP socket...
- It often silently disappears. *Maybe* if you’re lucky the write() call will return an error. But no promises.
Summary: Internet Architecture

- Packet-switched datagram network
- IP is the “compatibility layer”
  - Hourglass architecture
  - All hosts and routers run IP
- Stateless architecture
  - no per flow state inside network
Summary: Minimalist Approach

- Dumb network
  - IP provide minimal functionalities to support connectivity
    - Addressing, forwarding, routing
- Smart end system
  - Transport layer or application performs more sophisticated functionalities
    - Flow control, error control, congestion control
- Advantages
  - Accommodate heterogeneous technologies (Ethernet, modem, satellite, wireless)
  - Support diverse applications (telnet, ftp, Web, X windows)
  - Decentralized network administration
RPC: Remote Procedure Calls
Common communication pattern

Client

⇒ Hey, do something

⇒ working {

⇒ Done/Result

Server
struct foomsg {
    u_int32_t len;
}

send_foo(char *contents) {
    int msglen = sizeof(struct foomsg) + strlen(contents);
    char buf = malloc(msglen);
    struct foomsg *fm = (struct foomsg *)buf;
    fm->len = htonl(strlen(contents));
    memcpy(buf + sizeof(struct foomsg), contents, strlen(contents));
    write(outsock, buf, msglen);
}

Then wait for response, etc.
RPC land

- RPC overview
- RPC challenges
- RPC other stuff
RPC

- A type of client/server communication
- Attempts to make remote procedure calls look like local ones

```c
{ ... foo() }
void foo() {
    invoke_remote_foo()
}
```

figure from Microsoft MSDN
Go Example

• Need some setup in advance of this but...

```go
// Synchronous call
args := &server.Args{7, 8}
var reply int
err = client.Call("Arith.Multiply", args, &reply)
if err != nil {
    log.Fatal("arith error:", err)
}
```
RPC Goals

- Ease of programming
- Hide complexity
- Automates task of implementing distributed computation
- Familiar model for programmers (just make a function call)

Historical note: Seems obvious in retrospect, but RPC was only invented in the ‘80s. See Birrell & Nelson, “Implementing Remote Procedure Call” ... or Bruce Nelson, Ph.D. Thesis
Remote procedure call

- A remote procedure call makes a call to a remote service look like a local call
  - RPC makes transparent whether server is local or remote
  - RPC allows applications to become distributed transparently
  - RPC makes architecture of remote machine transparent

Emphasis on transparency
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Emphasis on transparency

What are some problems with this transparency?