Announcements:

- Assign 1 will be posted today and due in a week from now.
Chapter 1: roadmap

1 What is the Internet?
2 Network edge
3 Network core
4 Internet structure and ISPs
5 Protocol layers, service models
6 Delay & loss in packet-switched networks
Internet structure: network of networks

- roughly hierarchical: tier 1, tier 2, and tier 3
- at center: “tier-1” ISPs
  - e.g., MCI, Sprint, AT&T, Cable and Wireless,
  - national/international coverage
Tier-1 ISP: e.g., Sprint

Sprint US backbone network

- Seattle
- Tacoma
- Stockton
- San Jose
- Anaheim
- Kansas City
- Fort Worth
- Cheyenne
- Chicago
- Roachdale
- Atlanta
- New York
- Pennsauken
- Relay
- Wash. DC
- Orlando
- DS3 (45 Mbps)
- OC3 (155 Mbps)
- OC12 (622 Mbps)
- OC48 (2.4 Gbps)
Internet structure: network of networks

- “Tier-2” ISPs: smaller (often regional) ISPs
  - Connect to one or more tier-1 ISPs, possibly other tier-2 ISPs

Tier-2 ISP is customer of tier-1 provider

Tier-2 ISPs also peer privately with each other, interconnect at IXP
Internet structure: network of networks

- “Tier-3” ISPs and local ISPs
  - last hop (“access”) network (closest to end systems)

Local and tier-3 ISPs are customers of higher tier ISPs connecting them to rest of Internet
Internet structure: network of networks

- a packet passes through many networks!
Chapter 1: roadmap

1 What is the Internet?
2 Network edge
3 Network core
4 Internet structure and ISPs
5 Protocol layers, service models
6 Delay & loss in packet-switched networks
Protocol “Layers”

Networks are complex!

- many “pieces”:
  - hosts
  - routers
  - links of various media
  - applications
  - protocols
  - hardware, software

**Question:**
Is there any hope of an organizing structure of network?
Organization of air travel

- ticket (purchase)
- baggage (check)
- gates (load)
- runway takeoff
- airplane routing

- ticket (repurpose)
- baggage (claim)
- gates (unload)
- runway landing
- airplane routing

- a series of steps
Layering of airline functionality

<table>
<thead>
<tr>
<th>Layer</th>
<th>Action</th>
<th>Location</th>
</tr>
</thead>
<tbody>
<tr>
<td>ticket</td>
<td>purchase</td>
<td>departure airport</td>
</tr>
<tr>
<td>baggage</td>
<td>check</td>
<td>intermediate air-traffic</td>
</tr>
<tr>
<td></td>
<td></td>
<td>control centers</td>
</tr>
<tr>
<td>gate</td>
<td>load</td>
<td></td>
</tr>
<tr>
<td>runway</td>
<td>takeoff</td>
<td></td>
</tr>
<tr>
<td>airplane</td>
<td>routing</td>
<td></td>
</tr>
<tr>
<td>airplane</td>
<td>routing</td>
<td></td>
</tr>
<tr>
<td>airplane</td>
<td>routing</td>
<td></td>
</tr>
<tr>
<td>airplane</td>
<td>routing</td>
<td></td>
</tr>
</tbody>
</table>

Layers: each layer implements a service

- via its own internal-layer actions
- relying on services provided by layer below
Why layering?

Dealing with complex systems:

- Easing assignment of tasks
  - identify relationship among pieces of complex systems

- Easing maintenance, updating of system
  - change of implementation of layer’s service transparent to rest of system
  - e.g., change in gate procedure doesn’t affect rest of system
Internet protocol stack

- **application**: supporting network applications
  - FTP, SMTP, HTTP
- **transport**: process-process data transfer
  - TCP, UDP
- **network**: routing of datagrams from source to destination
  - IP, routing protocols
- **link**: data transfer between neighboring network elements
  - PPP, Ethernet
- **physical**: bits “on the wire”
Encapsulation

- Message
- Segment
- Datagram
- Frame

Source:
- Application
- Transport
- Network
- Link
- Physical

Destination:
- Application
- Transport
- Network
- Link
- Physical

Switch

Router

Chapter 1, slide: 47
ISO/OSI Model: late 70's

<table>
<thead>
<tr>
<th>7-layer ISO/OSI model</th>
<th>5-layer Internet Protocol Stack</th>
</tr>
</thead>
<tbody>
<tr>
<td>application</td>
<td>application</td>
</tr>
<tr>
<td>presentation</td>
<td>transport</td>
</tr>
<tr>
<td>session</td>
<td>network</td>
</tr>
<tr>
<td>transport</td>
<td>link</td>
</tr>
<tr>
<td>network</td>
<td>physical</td>
</tr>
<tr>
<td>data link</td>
<td></td>
</tr>
<tr>
<td>physical</td>
<td></td>
</tr>
</tbody>
</table>

7-layer ISO/OSI model (OSI: open system interconnections)
Chapter 1: roadmap

1 What is the Internet?
2 Network edge
3 Network core
4 Internet structure and ISPs
5 Protocol layers, service models
6 Delay & loss in packet-switched networks
Sources of packet delay

1. processing:
   - check bit errors
   - determine output link

2. queueing
   - time waiting at output link for transmission
   - depends on congestion level of router
Sources of packet delay

3. Transmission delay:
- $R =$ link bandwidth (bps)
- $L =$ packet length (bits)
- transmission delay $= \frac{L}{R}$

4. Propagation delay:
- $d =$ length of physical link
- $s =$ propagation speed in medium ($\sim 2 \times 10^8$ m/sec)
- propagation delay $= \frac{d}{s}$

Note: $s$ and $R$ are very different quantities!
Caravan analogy

- Cars run at 100 km/hr (speed of propagation)
- Booth takes 12 sec to service a car (transmission time)
- Car ~ bit; caravan ~ packet

Q: How long until caravan is lined up before 2nd toll booth?

- Time to “push” entire caravan through toll booth = 12*10 = 120 sec = 2 mns
- Time for last car to propagate from 1st to 2nd toll both: =100km/(100km/hr)= 1 hr

A: 1 hr 2 minutes
Caravan analogy (more)

- Cars now “propagate” at 1000 km/hr
- Toll booth now takes 1 min to service a car
- Q: Will cars arrive to 2nd booth before all cars serviced at 1st booth?

- Yes! After 7 min, 1st car at 2nd booth and 8th car still at 1st booth.
- 1st bit of packet can arrive at 2nd router before packet is fully transmitted at 1st router!
Exercise 1

Packet length = L bits

trans. rate \( R \) = 1 Mbps

Host A \rightarrow Host B

distance = 1 \text{ km}, \text{ speed} = 2 \times 10^8 \text{ m/s}

Question:

Which bit is being transmitted at the time the first bit arrives at Host B for

Answer:

First bit arrives after

\[
\frac{1}{R} + \frac{d}{s} = \frac{1}{10^6} + \frac{10^3}{(2 \times 10^8)} = 10^{-6} + 5 \times 10^{-6} = 6 \times 10^{-6} = 6 \mu\text{sec}
\]

After 6 \( \mu\text{sec} \)

6 bits are already transmitted; so 7\text{th} bit is being transmitted
Exercise 2

Transmission vs. propagation

L=100Bytes  trans. rate $R = ?$

Host A  $ightarrow$ Host B

distance = 2 km, speed = $2 \times 10^8$ m/s

Question:
☐ At what rate (bandwidth) $R$ would the propagation delay equal the transmission delay of packet?

Answer:
☐ Propagation delay = $2 \times 10^3$ (m)/$2 \times 10^8$ (m/s) = $10^{-5}$ sec
☐ Transmission delay = $100 \times 8$ (bits)/$R$
☐ Prop. delay = trans. delay $\Rightarrow$ $R = 10^5 \times 100 \times 8 = 80$ Mbps
Exercise 3

Voice over IP

\[ \text{trans. rate } R = 1\text{Mbps} \]
\[ \text{delay} \_\text{prop} = 2\text{msec} \]

- **Host A**
  - converts analog to digital at \( a=64\text{Kbps} \)
  - groups bits into \( L=48\text{Byte} \) packets
  - sends packet to Host B as soon it gathers a packet

- **Host B**
  - As soon as it receives the whole packet, it converts it to analog

- **Question**:
  - How much time elapses from the 1\text{st} bit of 1\text{st} packet is created until the last bit of the 1\text{st} packet arrives at Host B?
Exercise 3

Voice over IP

Answer:

- Time to gather 1st pkt: $\frac{48 \times 8 \text{ (bits)}}{64 \times 1000 \text{ (b/s)}} = 6 \text{ msec}$

- Time to push 1st pkt to link: $\frac{48 \times 8 \text{ (bits)}}{1 \times 10^6 \text{ (b/s)}} = 0.384 \text{ msec}$

- Time to propagate: 2 msec

- Total delay = 6 + 0.384 + 2 = 8.384 msec