Introduction II

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Chapter 1: Roadmap

1.1 What is the Internet?
1.2 Network edge
1.3 Network core
1.4 Network access and physical media
1.5 Internet structure and ISPs
1.6 Delay & loss in packet-switched networks
1.7 Protocol layers, service models
1.8 History
Internet: Network of Networks

- Roughly hierarchical
  - *In the center:* “tier-1” ISPs (e.g., Sprint, AT&T, Verizon), national/international coverage
  - Treat each other as equals, do not pay for upstream bandwidth
  - Form the **backbone** of the Internet

Tier-1 providers interconnect (peer) privately

Tier-1 providers also interconnect at public *network access points* (NAPs)
Internet: 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 pays tier-1 ISP for connectivity to rest of Internet

Tier-2 ISP is customer of tier-1 provider

Tier-2 ISPs also peer privately with each other, or interconnect at NAPs
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!
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**How Do Loss and Delay Occur?**

Packets *queue* in router buffers (typically FIFO queues)

- If packet arrival rate exceeds output link capacity:
  - Packets queue, wait for their turn
  - Analogy: 5 lanes of traffic merge into 1

- packet being transmitted (delay)

- packets queued (delay)

- arriving packets dropped if no free buffers (packet loss)
Four Sources of Packet Delay

1. Router processing delay:
   - Check bit errors
   - Determine output link
   - Place packet in buffer

2. Queueing delay
   - Time waiting at output link for transmission
   - Depends on congestion level of router
Delay in Packet-Switched Networks

3. Transmission delay:
   - $R = \text{link rate (bps)}$
   - $L = \text{packet length (bits)}$
   - Time to send bits into link $= \frac{L}{R}$

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

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

• Car ~ bit; caravan ~ packet
• Cars “propagate” at 100 mph
• Toll booth takes 12 sec to service a car (transmission time of a bit)
• Q: How long until caravan is lined up before the 2nd toll booth?
• Time to “push” entire caravan through toll booth onto highway = 12*10 = 120 sec
• Time for last car to propagate from 1st to 2nd toll both: 100 miles / (100 mph) = 1 hr
• A: 62 minutes
Caravan Analogy (more)

- Toll booth now takes 1 min to service a car
- Q: Will cars arrive to 2nd booth before all cars are serviced at 1st booth?
  - Yes! After 7 min, 1st car at 2nd booth and 3 cars still at 1st booth
  - 1st bit of packet can arrive at 2nd router before packet is fully transmitted from 1st router!
  - Can a packet be at 3 routers simultaneously?
**Nodal (Per-Router) Delay**

\[ d_{\text{nodal}} = d_{\text{proc}} + d_{\text{queue}} + d_{\text{trans}} + d_{\text{prop}} \]

- \( d_{\text{proc}} = \) processing delay
  - A few microsecs or less, usually fixed for all packets
- \( d_{\text{queue}} = \) queuing delay
  - Depends on congestion, randomly varies between packets
- \( d_{\text{trans}} = \) transmission delay
  - Equals \( L/R \), high for low-speed links, depends on packet size
- \( d_{\text{prop}} = \) propagation delay
  - A few microsecs to hundreds of msecs, depends on physical length of the link
Queueing Delay (Revisited)

- $R = \text{link bandwidth (bps)}$
- $L = \text{packet length (bits)}$
- $a = \text{average packet arrival rate (pkts/sec)}$
- Infinite buffer space

Traffic intensity $\rho = \frac{La}{R}$

- $\rho \approx 0$: average queueing delay is small
- $\rho \geq 1$: more “work” arriving than can be serviced, average delay is infinite
- $\rho \rightarrow 1$: delay quickly shoots up
“Real” Internet Delays and Routes

• What do “real” Internet delay & loss look like?
• **Traceroute (tracert in Windows):** provides delay measurement from source to all routers along end-end Internet path towards destination. For all $i$:
  - Sends three packets that reach router $i$ on path towards destination
  - Router $i$ returns a response to sender
  - Sender times interval between transmission and reply
### “Real” Internet Delays and Routes

**traceroute**: gaia.cs.umass.edu to www.eurecom.fr

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<thead>
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<th>Host</th>
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<th>Delay 2</th>
<th>Delay 3</th>
<th>Delay 4</th>
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<td>133 ms</td>
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<td>128 ms</td>
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<td>19</td>
<td>fantasia.eurecom.fr (193.55.113.142)</td>
<td>132 ms</td>
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Packet Loss

- Queues have finite capacity
- When packets arrive to a full buffer, they are dropped (aka lost) – drop-tail queuing
- Lost packet may be retransmitted by previous router, by the source (end system), or not at all
- **Loss rate**: average fraction of data lost over a long period of time
- **Example**: link capacity \( R = 10 \text{ Mbps} \) and total arrival rate of traffic is 11 Mbps
  - Q: What’s the average loss rate on the link?
  - A: About 9%
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Protocol “Layers”

Networks are complex!
- Many “pieces”
  - Hosts
  - Routers
  - Links of various media
  - Applications
  - Protocols
- Some type of modular organization is desirable

Solution: Layered structure
- Same host: each layer interacts only with adjacent (upper/lower) layers
- Remote host: each layer talks to identical layer on the other end-host
Layering

- Information travels **down** the protocol stack on the sender side and **up** on the receiver side
### Layering

<table>
<thead>
<tr>
<th>Manager (idea)</th>
<th>Manager (decision)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Assistant (type)</td>
<td>Assistant (read)</td>
</tr>
<tr>
<td>Mailroom (package)</td>
<td>Mailroom (receive)</td>
</tr>
<tr>
<td>FedEx</td>
<td>FedEx</td>
</tr>
<tr>
<td>Truck driver</td>
<td>Truck driver</td>
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</tbody>
</table>

**Layers:** each layer implements a service
- Via its own internal-layer actions
- Relying on services provided by the layer below
- Talks to same layer on the other host
Why Layering?

Benefits of layered organization:

* Sufficient to specify only the relationship between the system’s pieces
  - Instead of defining one big protocol that does everything
  - Complexity reduced by separately standardizing individual components

* Modularization eases maintenance and upgrade
  - Change of implementation of layer’s service transparent to the rest of system
  - For example, change in FedEx truck routing doesn’t affect other layers
Internet Protocol Stack

- **Application**: interacts with user and supports network applications
  - FTP, SMTP, HTTP (ch 2)
- **Transport**: inter-process data transfer
  - TCP, UDP (ch 3)
- **Network**: routing of datagrams from source to destination host
  - IP, routing protocols (ch 4)
- **Link**: data transfer between neighboring network elements
  - 802.11b, Ethernet (ch 5)
- **Physical**: bits “on the wire”
  - Not covered in this class