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

Internet structure: network of networks

- roughly hierarchical
- at center: “tier-1” ISPs (e.g., UUNet, BBN/Genuity/level3, Sprint, AT&T, QWest), national/international coverage
  - treat each other as equals

Tier-1 providers also interconnect at public network access points (NAPs)

Tier-1 providers interconnect (peer) privately
Tier-1 ISP: e.g., Sprint

Sprint US backbone network

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
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
- packet arrival rate to link exceeds output link capacity
- packets queue, wait for turn

packet being transmitted (delay)
packets queueing (delay)
free (available) buffers: arriving packets dropped (loss) if no free buffers
Four sources of packet delay

1. Nodal processing:
   - Check bit errors
   - Determine output link

2. Queueing:
   - Time waiting at output link for transmission
   - Depends on congestion level of router

Delay in packet-switched networks

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

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

Note: \( s \) and \( R \) are very different quantities!
**Nodal delay**

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

- \( d_{\text{proc}} = \) processing delay
  - Typically a few microsecs or less
- \( d_{\text{queue}} = \) queuing delay
  - Depends on congestion
- \( d_{\text{trans}} = \) transmission delay
  - \( = L/R \), significant for low-speed links
- \( d_{\text{prop}} = \) propagation delay
  - A few microsecs to hundreds of msecs

**Queueing delay (revisited)**

- \( R = \) link bandwidth (bps)
- \( L = \) packet length (bits)
- \( a = \) average packet arrival rate

Traffic intensity = \( L a / R \)

- \( L a / R \approx 0 \): average queueing delay small
- \( L a / R \rightarrow 1 \): delays become large
- \( L a / R > 1 \): more "work" arriving than can be serviced, average delay infinite!
“Real” Internet delays and routes

- What do “real” Internet delay & loss look like?
- **Traceroute program**: provides delay measurement from source to router along end-end Internet path towards destination. For all i:
  - sends three packets that will reach router i on path towards destination
  - router i will return packets to sender
  - sender times interval between transmission and reply.

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

1  cs-gw (128.119.240.254)  1 ms 1 ms 2 ms
2  border1-rt-fa5-1-0.gw.umass.edu (128.119.3.145)  1 ms 1 ms 2 ms
3  chl-vbns.gw.umass.edu (128.119.3.130)  6 ms 5 ms 5 ms
4  jn1-at1-0-0-19.wor.vbns.net (204.147.132.129)  16 ms 11 ms 13 ms
5  jn1-so7-0-0-0.wae.vbns.net (204.147.136.136)  21 ms 18 ms 18 ms
6  abilene-vbns.abilene.ucaid.edu (198.32.11.9)  22 ms 18 ms 22 ms
7  nycm-wash.abilene.ucaid.edu (198.32.8.46)  22 ms 22 ms 22 ms
8  62.40.103.253 (62.40.103.253)  104 ms 109 ms 106 ms
9  de2-1.de1.de.geant.net (62.40.96.129)  109 ms 102 ms 104 ms
10 de.fr1.fr.geant.net (62.40.96.50)  113 ms 121 ms 114 ms
11 renater-gw.fr1.fr.geant.net (62.40.103.54)  112 ms 114 ms 112 ms
12 nio-n2.cssi.renater.fr (193.51.206.13)  111 ms 114 ms 116 ms
13 nice.cssi.renater.fr (195.220.98.102)  123 ms 125 ms 124 ms
14 r3t2-nice.cssi.renater.fr (195.220.98.110)  126 ms 126 ms 124 ms
15 eurecom-valbonne.r3t2.ft.net (193.48.50.54)  135 ms 128 ms 133 ms
16 194.214.211.25 (194.214.211.25)  126 ms 128 ms 126 ms
17 * * *
18 * * *
19 fantasia.eurecom.fr (193.55.113.142)  132 ms 128 ms 136 ms

* means no response (probe lost, router not replying)
**Packet loss**

- queue (aka buffer) preceding link in buffer has finite capacity
- when packet arrives to full queue, packet is dropped (aka lost)
- lost packet may be retransmitted by previous node, by source end system, or not retransmitted at all

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**Protocol “Layers”**

**Networks are complex!**
- many “pieces”:
  - hosts
  - routers
  - links of various media
  - applications
  - protocols
  - hardware, software

**Question:**
- Is there any hope of organizing structure of network?
- Or at least our discussion of networks?

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**Why layering?**

**Dealing with complex systems:**
- explicit structure allows identification, relationship of complex system’s pieces
  - layered reference model for discussion
- modularization eases maintenance, updating of system
  - change of implementation of layer’s service transparent to rest of system
  - e.g., change in one procedure doesn’t affect rest of system
- layering considered harmful?
Internet protocol stack

- **application**: supporting network applications
  - FTP, SMTP, STTP
- **transport**: host-host 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**

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

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

Switch

Router
OSI Reference Model

The International Standards Organization (ISO) proposal for the standardization of the various protocols used in computer networks (specifically those networks used to connect open systems) is called the Open Systems Interconnection Reference Model (1984), or simply the OSI model.

Why a Layered Model?

- Reduces complexity
- Standardizes interfaces
- Facilitates modular engineering
- Ensures interoperable technology
- Accelerates evolution
- Simplifies teaching and learning
Introduction: Summary

Covered a “ton” of material!
- Internet overview
- what’s a protocol?
- network edge, core, access network
  - packet-switching versus circuit-switching
- Internet/ISP structure
- performance: loss, delay
- layering and service models

You now have:
- context, overview, “feel” of networking
- more depth, detail to follow!