Chapter 1: Introduction

Our goal:
- get context, overview, "feel" of networking
- more depth, detail later in course
- approach:
  - descriptive
  - use Internet as example

Overview:
- what's the Internet
- what's a protocol?
- network edge
- network core
- access net, physical media
- Internet/ISP structure
- performance: loss, delay
- protocol layers, service models
- history

Internet structure: network of networks
- roughly hierarchical
- at center: "tier-1" ISPs (e.g., UUNet, BBN/Genuity, Sprint, AT&T), national/international coverage
  - treat each other as equals

[Diagram showing the Internet structure with Tier 1 ISPs and NAPs]
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

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, interconnect at NAP
Tier-2 ISP: e.g., Abilene (Internet2)

- Tier-1 ISP
- Tier-2 ISP
- NAP
- Tier-3 ISP
- local ISP
- 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!

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:
   - \( d=\text{length of physical link} \)
   - \( s=\text{propagation speed in medium (} \approx 2\times10^8 \text{ m/sec)} \)
   - Propagation delay = \( d/s \)

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

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

- \( d_{\text{proc}} = \) 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 = \( La/R \)

- \( La/R \approx 0: \) average queueing delay small
- \( La/R \rightarrow 1: \) delays become large
- \( La/R > 1: \) 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
```

Three delay measurements from gaia.cs.umass.edu to cs-gw.cs.umass.edu

3 probes

1  cs-gw (128.119.240.254)  1 ms  1 ms  2 ms
2  border1-t-fab5-1-0.gw.umass.edu (128.119.3.145)  1 ms  1 ms  2 ms
3  cht-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  nie-n2.cisti.renater.fr (193.51.206.13)  111 ms 114 ms 116 ms
13  nice.cisti.renater.fr (195.220.98.102)  123 ms 125 ms 124 ms
14  r3t2-nice.cisti.renater.fr (195.220.98.110)  126 ms 126 ms 124 ms
15  eurecom-valbonne.r3t2.fr.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

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?
Organization of air travel

- ticket (purchase) → ticket (complain)
- baggage (check) → baggage (claim)
- gates (load) → gates (unload)
- runway takeoff → runway landing
- airplane routing

* a series of steps

Organization of air travel: a different view

- ticket (purchase) → ticket (complain)
- baggage (check) → baggage (claim)
- gates (load) → gates (unload)
- runway takeoff → runway landing
- airplane routing

Layers: each layer implements a service via its own internal-layer actions relying on services provided by layer below
Layered air travel: services

- Counter-to-counter delivery of person+bags
- Baggage-claim-to-baggage-claim delivery
- People transfer: loading gate to arrival gate
- Runway-to-runway delivery of plane
- Airplane routing from source to destination

Distributed implementation of layer functionality

<table>
<thead>
<tr>
<th>Departing airport</th>
<th>Arriving airport</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>ticket (purchase)</strong></td>
<td><strong>ticket (complain)</strong></td>
</tr>
<tr>
<td><strong>baggage (check)</strong></td>
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<td><strong>gates (unload)</strong></td>
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<td><strong>runway takeoff</strong></td>
<td><strong>runway landing</strong></td>
</tr>
<tr>
<td><strong>airplane routing</strong></td>
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</tr>
</tbody>
</table>

Intermediate air traffic sites

- Airplane routing
- Airplane routing
- Airplane routing
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 gate 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”
Layering: logical communication

Each layer:
- distributed
- "entities" implement layer functions at each node
- entities perform actions, exchange messages with peers

E.g.: transport
- take data from app
- add addressing, reliability check info to form "datagram"
- send datagram to peer
- wait for peer to ack receipt
- analogy: post office
Layering: physical communication

Protocol layering and data

Each layer takes data from above
- adds header information to create new data unit
- passes new data unit to layer below

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**Internet History**

1961-1972: Early packet-switching principles

- **1961**: Kleinrock - queueing theory shows effectiveness of packet-switching
- **1964**: Baran - packet-switching in military nets
- **1967**: ARPAnet conceived by Advanced Research Projects Agency
- **1969**: first ARPAnet node operational
- **1972**: ARPAnet demonstrated publicly
  - NCP (Network Control Protocol) first host-host protocol
  - first e-mail program
  - ARPAnet has 15 nodes

1970-1980: Internetworking, new and proprietary nets

- **1970**: ALOHAnet satellite network in Hawaii
- **1973**: Metcalfe's PhD thesis proposes Ethernet
- **1974**: Cerf and Kahn - architecture for interconnecting networks
- **late 70’s**: proprietary architectures: DECnet, SNA, XNA
- **late 70’s**: switching fixed length packets (ATM precursor)
- **1979**: ARPAnet has 200 nodes

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Cerf and Kahn’s internetworking principles:

- minimalism, autonomy - no internal changes required to interconnect networks
- best effort service model
- stateless routers
- decentralized control define today’s Internet architecture
Internet History

1980-1990: new protocols, a proliferation of networks

- 1983: deployment of TCP/IP
- 1982: SMTP e-mail protocol defined
- 1983: DNS defined for name-to-IP-address translation
- 1985: FTP protocol defined
- 1988: TCP congestion control
- new national networks: Csnet, BITnet, NSFnet, Minitel
- 100,000 hosts connected to confederation of networks

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Internet History

1990, 2000's: commercialization, the Web, new apps

- Early 1990's: ARPAnet decommissioned
- early 1990s: Web
  - hypertext [Bush 1945, Nelson 1960's]
  - HTML, HTTP: Berners-Lee
- 1994: Mosaic, later Netscape
- late 1990's: commercialization of the Web
- Late 1990’s - 2000’s:
  - more killer apps: instant messaging, peer2peer file sharing (e.g., Napster)
  - network security to forefront
  - est. 50 million host, 100 million+ users
  - backbone links running at Gbps
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
- History

You now have:

- Context, overview, “feel” of networking
- More depth, detail to follow!