A Whirlwind Introduction to the Internet

*Overview*

- What’s the Internet
- Network Edge
- Network Core
- Performance: Loss and Delay
- Protocol Layering
- History
**Performance: Loss and Delay**

How do delay and loss occur?

- Packets *queue* in router buffers
  - packet arrival rate to link exceeds output link capacity
  - packets queue, wait for turn

- If queue is full, packets are not admitted (dropped)

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**Performance: Loss and Delay**

Delay in packet-switched networks

- Packets experience variable delays along the path from source to destination
- Four sources of delay at each hop
  - **Processing**:
    - Check for bit errors
    - Determine the output interface to forward packet on
  - **Transmission**
  - **Queuing**:
    - Time spent waiting at outbound interface for transmission
    - Duration depends on the level of congestion at the interface
  - **Propagation**
**Performance: Loss and Delay**

**Delay in packet-switched networks**

Transmission delay = time to “put bits onto the link”
= \( \frac{L}{R} \)

- \( R \) = link bandwidth (bps)
- \( L \) = packet length (bits)

Propagation delay = \( \frac{d}{s} \)

- \( d \) = length of physical link
- \( s \) = signal propagation speed in medium (~2\( \times \)10^8 m/sec)

**Beware:** \( s \) and \( R \) are very different quantities!

**Delay in Packet-Switched Networks**

**Transmission & Propagation Delay**

- **propagation delay**
  - time it takes a *bit* to travel (propagate) the length of a wire
  - depends upon the length of the wire and the *propagation speed* of the physical medium (coaxial cable, fiber optics, air, etc.)
  - tells you when the first bit will reach the other end of the wire

- **transmission delay**
  - time it takes to put (transmit) a *packet* on the wire
  - depends on the length (size) of the packet and the *transmission speed* (or link speed or bandwidth)
  - tells you when the last bit of the packet is transmitted (leave the sender)
Delay in Packet-Switched Networks
Calculating Transmission & Propagation Delay

- **propagation delay** \( d_{prop} = \frac{m}{s} \)
  - divide the length of the wire \( m \) by the propagation speed \( s \)
    - (typically \( 2.5 \times 10^8 \) meters/second)
  - end result is a time, so units should be seconds or milliseconds

- **transmission delay** \( d_{trans} = \frac{L}{R} \)
  - divide the size of the packet \( L \) by the transmission speed \( R \)
  - end result is a time, so units should be seconds or milliseconds

\[ \text{transmission speed (or link speed or bandwidth)} \]

\[ \begin{array}{c}
\text{10 Mbps} \\
20 \text{ ms}
\end{array} \]

- **end-to-end delay**
  - time it takes for the entire packet to reach the receiver
    - *i.e.*, when does the last bit of the packet reach the receiver?
  - transmission delay + propagation delay
Questions

- What is the transmission delay for a 2000-byte packet over a 1 Mbps link?

- Where is the last bit of the packet after the transmission delay has passed?

- What is the transmission delay for a 250,000-bit packet over a 1 Mbps link?

Questions

- What are the four types of delay that are (potentially) encountered at every router/hop? Which one may not be encountered?

- What is the difference between transmission delay and propagation delay?

- What two things affect the duration of queuing delay for a particular packet?
Delay in Packet-Switched Networks
Effect of Store and Forward

![Diagram of network with time delays and packet transmission]

- Can't begin transmitting a packet over the next link until the entire packet has first been received

\[
\text{time} = d_{\text{trans}}^1
\]

![Image of sender, router, and receiver]

\[
\text{time} = d_{\text{trans}}^1 + d_{\text{prop}}^1
\]

![Image of sender, router, and receiver with additional propagation delay]

\[
\text{time} = d_{\text{trans}}^1 + d_{\text{prop}}^1 + d_{\text{trans}}^2
\]

![Image of sender, router, and receiver with multiple propagation delays]

\[
\text{time} = d_{\text{trans}}^1 + d_{\text{prop}}^1 + d_{\text{trans}}^2 + d_{\text{prop}}^2
\]

Question

How long would it take a 5000-bit packet to travel from source to destination over the following network?

![Image of network with different link speeds and delays]
Performance: Loss and Delay
Example: What was the delay from my house?

- I live in Larchmont (less than 1 mile from campus)

```bash
% ping fast.cs.odu.edu
Pinging fast.cs.odu.edu [128.82.4.4] with 32 bytes of data:

Reply from 128.82.4.4: bytes=32 time=30ms TTL=238
Reply from 128.82.4.4: bytes=32 time=40ms TTL=238
Reply from 128.82.4.4: bytes=32 time=28ms TTL=238
Reply from 128.82.4.4: bytes=32 time=32ms TTL=238

Ping statistics for 128.82.4.4:
   Packets: Sent = 4, Received = 4, Lost = 0 (0% loss),
Approximate round trip times in milli-seconds:
   Minimum = 28ms, Maximum = 40ms, Average = 32ms
```

*Round trip time:* time between sending data and the response returning, roughly equal to 2 * propagation delay

Performance: Loss and Delay
Example: What was the path from my house?

1. wrt54g.weigle.home  my cable modem router
2. 10.11.184.1     Cox Cable default router
3. 68.10.14.137
4. nrfkdsrj01-ge0705.rd.hr.cox.net Cox network - Hampton Roads
5. 12.118.122.77  What’s this?
6. tbr1-p010401.wsmdc.ip.att.net AT&T network - Rockville, MD
7. ar5-p3110.wsmdc.ip.att.net
8. att-gw.dc.sprint.net AT&T Gateway - Sprint network - DC
9. sl-st22-ash-15-0.sprintlink.net Sprint network - Ashburn, VA
10. sl-bb24-rly-8-0.sprintlink.net Sprint network - Relay, MD
11. sl-gw21-rly-9-0.sprintlink.net
12. sl-vwan-9-0.sprintlink.net ODU’s Sprint default router
13. 128.82.254.198 ODU’s campus router
Performance: Loss and Delay

**Traceroute**

- 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

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**Example: What was the route from my house?**

```
% traceroute fast.cs.odu.edu

Tracing route to fast.cs.odu.edu [128.82.4.4] over a maximum of 30 hops:

1     1 ms  <1 ms  <1 ms  wrt54g.weigle.home [192.168.2.127]
2     29 ms  8 ms  8 ms  10.11.184.1
3     13 ms  13 ms  7 ms  68.10.14.137
4      9 ms  9 ms  23 ms  nrfkdsrj01-ge0705.rd.hr.cox.net [68.10.14.25]
5     17 ms  15 ms  14 ms  12.118.122.77
6     34 ms  16 ms  14 ms  tbrl-p010401.wswdc.ip.att.net [12.123.8.26]
7     13 ms  15 ms  13 ms  ar5-p3110.wswdc.ip.att.net [12.123.8.129]
8     18 ms  15 ms  19 ms  att-gw.dc.sprint.net [192.205.32.166]
9     15 ms  27 ms  22 ms  sl-st22-ash-15-0.sprintlink.net [144.232.29.207]
10     *      27 ms  37 ms  sl-bb24-rly-8-0.sprintlink.net [144.232.20.154]
11     18 ms  18 ms  18 ms  sl-gw21-rly-9-0.sprintlink.net [144.232.14.54]
12     21 ms  22 ms  19 ms  sl-vwan-9-0.sprintlink.net [160.81.98.58]
13     33 ms  50 ms  24 ms  128.82.254.198
```
Performance: Loss and Delay

Packet Loss

- Queue (buffer) preceding the link has finite capacity
- Packet arriving to full queue dropped (lost)
- Lost packet may be retransmitted by previous node, by source end system, or not at all

![Diagram of packet loss](image)

Performance: Loss and Delay

Throughput

- *throughput*: rate (bits/time unit) at which bits transferred between sender/receiver
  - *instantaneous*: rate at given point in time
  - *average*: rate over long(er) period of time

![Diagram of throughput](image)
Performance: Loss and Delay
Throughput

- $R_s < R_c$ What is average end-end throughput?

- $R_s > R_c$ What is average end-end throughput?

**bottleneck link**
link on end-end path that constrains end-end throughput

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- Protocol Layering
- History
Protocol Layering in the Internet

Internet protocol layers (“stack”)

- **Application layer**
  - Supporting network applications
    - FTP, SMTP, HTTP

- **Transport layer**
  - Host-host data transfer
    - TCP, UDP

- **Network layer**
  - Routing of packets from source to destination
    - IP, routing protocols

- **Link layer**
  - Data transfer between directly connected network elements
    - Ethernet, 802.11, SONET, …

- **Physical layer**
  - The insertion of individual bits “on the wire”
    - Manchester encoding

![Diagram showing the protocol layers](image)

Protocol Layering in the Internet

Internet protocol layers (“stack”)

- Each layer implements a protocol with its peer layer in a distributed system

![Diagram showing the protocol interactions](image)
Protocol Layering in the Internet

Logical communication

- The implementation of each layer is distributed throughout the network
  - Some layers just distributed on the end-systems

- The distributed components perform actions, exchange messages with peers

Logical Communication Example

The transport layer

- Receive data from application
- Add transport-layer protocol information
- Send to peer transport layer
- Wait for peer transport layer to respond
- Peer transport delivers data to its application layer
Protocol Layering in the Internet

Data flow through protocol layers

- Protocol Layering in the Internet

Protocol layering and data formats

- At sender, each layer takes data from above
  - Adds header information to create new data unit
  - Passes new data unit to layer below
- Process reversed at receiver

Source

Destination

Send Message

Receive Message

M

H_app

H_trans

H_net

H_link

M

M

Message

Segment

Datagram

Frame
Questions

- What are the five network protocol layers?
- Which layers do end systems use?
- Which layers do routers use?

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Internet History Lesson

1961-1972: Early packet-switching principles

1972-1980: Internetworking, new and proprietary nets

1980-1990: New protocols, a proliferation of networks

1990-2007: commercialization, the Web, new apps

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 public demonstration

» NCP (Network Control Protocol) first host-host protocol

» first e-mail program

» ARPAnet has 15 nodes
Internet History Lesson

1972-1980: Internetworking, new and proprietary nets

- 1970: ALOHAnet satellite network in Hawaii
- 1974: Cerf and Kahn - architecture for interconnecting networks
- 1976: Ethernet at Xerox PARC
- late 70's: proprietary architectures: DECnet, SNA, XNA
- late 70's: switching fixed length packets (ATM precursor)
- 1979: ARPAnet has 200 nodes

- Cerf and Kahn’s internetworking principles:
  - minimalism, autonomy - no internal changes required to interconnect networks
  - best effort service model
  - stateless routers
  - decentralized control

Internet History Lesson

1980-1990: new protocols, a proliferation of networks

- 1982: SMTP e-mail protocol defined
- 1983: deployment of TCP/IP
- 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
Internet History Lesson

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

- **Early 1990’s**: ARPAnet decommissioned
- **1991**: NSF lifts restrictions on commercial use of NSFnet (decommissioned, 1995)

- **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, P2P file sharing
  - network security to forefront
  - est. 50 million host, 100 million+ users
  - backbone links running at Gbps

Internet History Lesson

Today

- ~900 million hosts

- Voice, Video over IP

- P2P applications: BitTorrent (file sharing) Skype (VoIP), PPLive (video)

- more applications: social networking (Facebook, etc.), YouTube, gaming

- wireless, mobility
A Whirlwind Introduction to the Internet

Summary

◆ Covered a “ton” of material
  » Internet overview
  » What’s a protocol?
  » Network edge, core, access network
  » Performance: loss, delay
  » Layering and service models
  » Backbones, NAPs, ISPs
  » History

◆ You now hopefully have:
  » Context, overview, “feel” of networking

◆ Something dangerous to mumble at parties!