CSCD 330
Network Programming
Winter 2020

Lecture 3
Introduction to Networks

Reading: Chapter 1 - Continued
Topics in Chapter 1

• What’s the Internet?
• What’s a protocol?
• Network edge; hosts, access net, physical media
• Network core: packet/circuit switching, Internet structure
• Performance: loss, delay, throughput
• Protocol layers, service models
• History
Last time …

• Presented an overview of the Internet
  • Network of networks …
  • Backbone routers owned mostly by Telephone and cable companies
    • Not the government, not universities
  • Complex set of policies dictate routes and passage through the backbone
  • Not obvious to most users
  • Today discuss alternative network models
Broadcast vs. Switched Communication Networks

- **Broadcast networks**
  - Nodes share a common channel
  - Information transmitted by a node is received by all other nodes in the network
  - Examples: TV, radio, cell phone networks

- **Switched networks**
  - Information is transmitted to a small sub-set (usually only one) of the nodes
A Taxonomy of Switched Networks

- **Circuit switching**: Dedicated circuit per call/session: e.g., telephone network
- **Packet switching**: Data sent thru network in discrete “chunks” e.g., Internet
Circuit vs. Packet Switched

• **Circuit Switching**

• Two network nodes establish a dedicated communications channel (circuit)

  • Circuit guarantees full bandwidth of channel
  • Remains connected for duration of session

  • Circuit functions as if nodes were physically connected as with an **electrical circuit**

• **Example:** **Analog telephone network**
  • Switches within telephone exchanges create continuous wire circuit between two telephones
Circuit vs. Packet Switched

• **Packet Switching**
  • Model based on dividing data into packets
    – Sent through network independently

• Packet switching, network links are shared by packets from competing users
  • Results in loss of service guarantees that are provided by circuit switching
  • More uncertainty that packet will actually arrive at destination .. they can get lost
How do you Share a Network?

Answer: Switching

Three different switching technologies

• Circuit switching
• Message switching
• Packet switching
Circuit Switching

- Circuit switching designed in 1878 to send telephone calls down a dedicated channel
- **Key Idea:** Channel remains open and in use throughout whole call and cannot be used by any other data or phone calls
Plain Old Telephone Network (POTS)

- Early days, phone calls traveled as analog signals across copper wire
- Every phone call needed its own dedicated copper wire connecting two phones.
- Operators sat at a switchboard, literally connecting one piece of copper wire to another
- Long-distance calls were comparatively expensive, because you were renting use of a very long piece of copper wire every time you made a call
Circuit Switching

• **Three phases in circuit switching**
  1. Establish circuit
  2. Transfer message
  3. Disconnect call

• Telephone message is sent all together
  – It is not broken up

• Message arrives in same order that it was originally sent
Circuit Switch
Setup, Call, Disconnect
Circuit Switching

- During a call no other network traffic can use those switches!!!
- Resources remain dedicated to circuit during entire data transfer and entire message follows the same path
- Circuit switching can be analog or digital
Advantages Circuit Switching

1. Connection guaranteed fraction of bandwidth for duration of connection
2. Dedicated resources for each call
3. Constant transmission rate for duration of connection
4. Message arrives in order by its nature
   – First bits or signals transmitted first, next bits...
Disadvantages Circuit Switching

1. Inefficient
   Equipment may be unused for a lot of the call if no data is being sent, dedicated line remains open

2. It takes time to set up, tear down the circuit

3. Completely blocked during congestion
   Call cannot be made
Circuit Switching

Network resources (e.g., bandwidth) Must be divided into “pieces”

• Pieces allocated to calls
• Resource *idle* if not used by call
  • *No Sharing of that resource!!!*
• Two common ways to divide link bandwidth into “pieces”
  1. Time division Multiplexing
  2. Frequency division Multiplexing
Circuit Switching

Time Division Multiplexing

- **Time** divided into frames of fixed duration
- Network dedicates one **time slot** in every frame to this connection
- Slots **dedicated** for sole use of that connection

Example:

```
+-----------+-----------+-----------+-----------+
|          |          |          |          |
|  TDM      |  Frame   |  Example:|  4 users |
|          |          |          |          |
```

```
+-----------+-----------+-----------+-----------|
| TDM       |            | Example:  | 4 users   |
|           |            |           |           |
```
Time Division Multiplexing

- **Real Example of TDM**
  - GSM (Global System for Mobile Communications)
    - European Standard for Mobile phones
    - TDM has 8 full-rate or 16 half-rate speech channels per radio frequency channel
    - 8 radio time slots grouped into a frame
  - Also used extensively in satellite systems
Circuit Switching

2. Frequency Division Multiplexing (FDM)

- **FDM** – Link dedicates a frequency band to each connection for duration of connection

- Like FM radio where multiple stations share frequency spectrum between 88 and 108 MHz
Numerical example
Circuit Switching

• How long does it take to send a file of 640,000 bits from host A to host B over a circuit-switched network?

• Link speed is 1.536 Mbps
• Each link uses TDM with 24 slots/sec
• 500 msec to establish End-to-End Circuit

$$\frac{1.536 \text{ Mbps}}{24} = 64 \text{ kbps}$$
$$\frac{640,000 \text{ bits}}{64 \text{ Kbps}} = 10 \text{ sec}$$

Total time = 10 sec + 500 msec
Network Core – Message and Packet Switching

Message Switching

Not too popular, precursor to packet switching
Message sent in one long packet
Example maximum IP packet length is > 65,000 bits
Message switching

Why not message switching?

Advantages?
Disadvantages?

Store-and-Forward
Message switching

Store complete message and than forward

EXAMPLE

L = Message Length
R = Link Rate
Takes \( \frac{L}{R} \) seconds to transmit a message

3 Hops Transmission Delay

\[
\begin{align*}
L &= 7.5 \text{ Mbits} \\
R &= 1.5 \text{ Mbps} \\
\frac{L}{R} &= \frac{7.5}{1.5} = 5 \text{ Secs} \\
3 \times \frac{L}{R} &= 3 \times 5 = 15 \text{ Secs}
\end{align*}
\]
Packet Switching Example

Assume now that we break up the message into 5000 packets

- Each packet 1,500 bits
- 1 msec to transmit packet on one link
- *pipelining*: each link works in parallel
- Delay reduced from 15 sec to 5.002 sec
Packet Switching

• What do we need if we send “packets” of information from A to B, and route is not determined ahead of time?
  • So ... packets can take different routes
Packet Switching

• Packets now need
  1. Headers – needed for addressing
    - Need to identify the Source and
    - Need to identify the Destination
  2. Need to number the packets
  3. Need to possibly resend them if lost
Packet Switching

Advantages

• Bandwidth used to full potential
• Devices of different speeds can communicate
• Not so affected by line failure
• Availability – do not have to wait for a direct connection to become available
Packet Switching

Disadvantages

• Under heavy use, there can be a delay
• Data packets can get lost or become corrupted
• Protocols are needed for reliable transfer
• Not so good for some data types
  • Real-time video or audio
Packet Switching - Statistical Multiplexing

Sequence of A & B packets does not have fixed pattern, bandwidth shared on demand. **Statistical multiplexing**

Unlike **TDM** where each host gets same slot in revolving TDM frame
Packet switching vs. Circuit switching

Is packet switching then always better?

- Great for **bursty** data,
  - Bursty traffic is an uneven distribution of traffic
  - Simpler, no call setup

- But .... Sometimes, excessive congestion
  - Packet delay and loss
  - Real-time time sensitive applications use Real-time protocols to overcome delays
Performance Ideal

- Any network, Internet included
  - Move all data no matter how large
  - Instantaneously
  - Little to no delay
  - With no data loss
- Is this achievable today?
Congestion and Delay in Networks
If network Ideal not Possible

• What causes delays in networks?
  • Congestion
    • Too much data or too bursty data
  • Links
    • Slow since Internet is uncontrolled network
  • Failure of links
    • Deliberate, accidental nature or man
  • Mis-configured devices
    • Many routers, switches, servers don’t operate correctly, contribute to delay

Result ... Interesting problems, jobs, research
Network Performance Definitions
Round Trip Time, RTT

- Packet is sent from sender to receiver
- Receiver sends ACK back to sender
- Total time delay incurred between instant packet sent to time ACK received
- Note if forward delay = backward delay, RTT = 2 * Latency or total delay

Terms
- \textbf{RTT} = Time it takes for packet to travel from one end of the pipe to the other and get an ACK back again is round trip time
Network Bandwidth

- **Bandwidth**
  - Number of bits that can be transmitted over a time period -- typically per unit time
  - Bandwidth stated in terms of bits per sec (bps)
  - Bandwidth is capacity of the connection → Greater the capacity, likely that greater performance will follow
    - Also depends on other factors, such as latency
Network Bandwidth

• If we make an analogy between plumbing and network connections
• Bandwidth is like diameter of a water pipe
• A larger pipe carries a larger volume of water, and hence you can deliver more water between two points
• Talk about “data flows”
Network Bandwidth

- Bandwidth can be compared to lanes on a highway
- More lanes, more capacity for cars to get from one place to another
- Cars are the bits or simply packets that need to get through a network

More Traffic? Vs
Network Delay

• Network Designers/Engineers worry about Delay

• Key Question:

• **How** does delay occur in networks?

• **Where** does delay occurs?

Want to determine places in network that packets can slow down or get lost

Goal is to optimize flow through the network
Four sources of packet delay

1. Processing Delay
   - Check bit errors
   - Read header, Figure out route

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

3. Transmission Delay
- Time to push packet bits onto the link
- \( R \) = link bandwidth (bps)
  - 10 Mbps,
- \( L \) = packet length (bits)
- Time to send bits into link = \( \frac{L}{R} \)

4. Propagation Delay
- Physical delay of medium
- \( d \) = length of physical link
- \( s \) = propagation speed in medium (~2x10^8 meters/sec)
- Propagation delay = \( \frac{d}{s} \)

Note: \( s \) and \( R \) are very different quantities!
Transmission vs. Propagation Delay

- Transmission Delay
  - Time for the router to push out packet
  - Function (packetlength, Speed)
    \( L, \) and \( R, \) speed of link
  - Measured in \( L/R \)

- Propagation Delay
  - Time for bit to travel from one router to another
  - Function (distance, speed)
    Length of physical link, \( d \) and speed of physical media, \( s \)
  - Measured in \( d/s \)
Network Delay Example Problems
What is the propagation time if distance between the two points is **12,000 km**?

Assume propagation speed to be $2.4 \times 10^8 \text{ m/s}$ in cable

Solution

How do we set up the Propagation Delay?
What is the propagation time if distance between the two points is 12,000 km?

Assume propagation speed to be $2.4 \times 10^8 \text{ m/s}$ in cable.

Solution

We can calculate the propagation time as

\[
\text{Propagation time} = \frac{12,000 \times 1000}{2.4 \times 10^8} = 50 \text{ ms}
\]

Example shows that a bit can go over the Atlantic Ocean in 50 ms if there is a direct cable between the source and destination.
What are propagation and transmission time for a 2.5-kbyte message (an e-mail) if bandwidth of the network is 1 Gbps?

Assume that distance between sender and receiver is 12,000 km and that light travels at $2.4 \times 10^8$ m/s

Solution
We can calculate propagation and transmission time (delay) as shown on the next slide:
Note because message is short and bandwidth is high, **dominant factor** is propagation time, not the transmission time

Transmission time can pretty much be ignored
What are propagation time and transmission time for a 5-Mbyte message (an image) if bandwidth of the network is 1 Mbps?
Assume that distance between sender and receiver is 12,000 km and that light travels at 2.4 \times 10^8 \text{ m/s}

Solution
We can calculate the propagation and transmission times as shown on the next slide.
Note that in this case, message is very long and bandwidth is not very high, dominant factor is transmission time, not propagation time.

Propagation time can be ignored.
Nodal delay or Latency

Total of Other Delays

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

- \( d_{\text{proc}} \) = 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 microsecs

Another word for Nodal delay = Latency
Queuing Delay Revisited

- **Something called Traffic Intensity**
  - Captures the relationship between packet arrival and queuing delay
    - $a =$ Ave arrival rate of packet
    - $L =$ assume all packets have uniform length
    - $R =$ transmission Rate b/sec

- Can then examine the effects of different queuing behaviors as you vary above parameters!
Queueing Delay (revisited)

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

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

- $\frac{La}{R} \sim 0$: average queueing delay small
- $\frac{La}{R} \rightarrow 1$: delays become large
- $\frac{La}{R} > 1$: more “work” arriving than can be serviced, average delay infinite!

- Rule of traffic engineering, queue delay never $> 1$
“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 each router 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

![Diagram of traceroute](image)
Traceroute Details

• How does traceroute work in detail?
  • Traceroute works by increasing "time-to-live" value of each successive batch of packets sent
    • 1st three packets sent have a time-to-live (TTL) value of one (implying that they are not forwarded by the next router and make only a single hop)
    • Next three packets have a TTL value of 2, and so on
    • Three timestamp values returned for each host along path are the delay (latency) values, milliseconds (ms) for each packet in batch
    • Final message sent back, when it reaches its destination is an ICMP “port unreachable” message
“Real” Internet delays and routes

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 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 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 *** * means no response (probe lost, router not replying)
18 ***
19 fantasia.eurecom.fr (193.55.113.142)  132 ms  128 ms  136 ms

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

trans-oceanic link
C:\WINDOWS\system32>tracert www.yahoo.com

Tracing route to www.yahoo-ht3.akadns.net [209.131.36.158] (Fall 2007) over a maximum of 30 hops:

1  2 ms  <1 ms  <1 ms  192.168.1.1
2  *  *  *  Request timed out.
3  8 ms  *  10 ms  ge-3-24-ur01.spokane.wa.spokane.comcast.net [68.87.160.169]
4  11 ms  9 ms  *  te-9-3-ar01.spokane.wa.spokane.comcast.net [68.87.160.9]
5  15 ms  16 ms  18 ms  12.117.243.5
6  39 ms  41 ms  38 ms  12.127.6.54
7  41 ms  40 ms  47 ms  cr2.st6wa.ip.att.net [12.122.23.205]
8  39 ms  39 ms  38 ms  cr1.sffca.ip.att.net [12.122.28.33]
9  38 ms  45 ms  39 ms  tbr2.sffca.ip.att.net [12.122.19.66]
10  40 ms  39 ms  38 ms  12.122.114.73
11  41 ms  38 ms  38 ms  12.86.154.18
12  44 ms  40 ms  41 ms  g-1-0-0-p150.msr2.sp1.yahoo.com [216.115.107.77]
13  41 ms  43 ms  40 ms  te-9-1.bas-a1.sp1.yahoo.com [209.131.32.21]
14  43 ms  41 ms  41 ms  f1.www.vip.sp1.yahoo.com [209.131.36.158]

Trace complete.
C:\WINDOWS\system32>tracert www.yahoo.com

Tracing route to www.yahoo-ht3.akadns.net [209.191.93.52] (Fall 2008) over a maximum of 30 hops:

1   *   *   * Request timed out.
2   8 ms  6 ms  7 ms ge-3-24-ur01.spokane.wa.seattle.comcast.net [68.87.160.169]
3  16 ms 15 ms 14 ms te-9-1-ar02.seattle.wa.seattle.comcast.net [68.86.90.210]
4  18 ms 17 ms 15 ms COMCAST-IP.car1.Seattle1.Level3.net [4.79.104.110]
5  15 ms 13 ms 14 ms te-3-3.car1.Seattle1.Level3.net [4.79.104.109]
6  24 ms 17 ms 17 ms ae-31-53.ebr1.Seattle1.Level3.net [4.68.105.94]
7  25 ms 17 ms 27 ms ae-1-100.ebr2.Seattle1.Level3.net [4.69.132.18]
8  58 ms 52 ms 53 ms ae-2.ebr2.Denver1.Level3.net [4.69.132.54]
9  50 ms 54 ms 53 ms ae-1-100.ebr1.Denver1.Level3.net [4.69.132.37]
10 88 ms 74 ms 73 ms ae-2.ebr2.Dallas1.Level3.net [4.69.132.106]
12 77 ms 75 ms 73 ms ae-41-99.car1.Dallas1.Level3.net [4.68.19.195]
13 75 ms 74 ms 74 ms YAHOO-INC.car1.Dallas1.Level3.net [4.79.180.2]
14 79 ms 75 ms 76 ms ae1-p130.msr2.mud.yahoo.com [216.115.104.85]
15 77 ms 75 ms 77 ms te-9-1.bas-c1.mud.yahoo.com [68.142.193.9]
16 76 ms 75 ms 75 ms f1.www.vip.mud.yahoo.com [209.191.93.52]

Trace complete.
traceroute to www.yahoo.com (209.131.36.158), 30 hops max, 40 byte packets

1  * * *
2  68.85.145.13 (68.85.145.13)  11.842 ms  12.634 ms  12.666 ms
3  te-0-8-0-4-ar01.burien.wa.seattle.comcast.net (68.85.24...)  34.765 ms  34.938 ms  35.343 ms
4  pos-0-6-0-0-cr01.portland.or.ibone.comcast.net (68.86.90...)  38.050 ms  38.163 ms  38.793 ms
5  pos-1-14-0-0-cr01.sacramento.ca.ibone.comcast.net (68.86....  50.750 ms  50.863 ms  50.935 ms
6  pos-0-8-0-0-cr01.sanjose.ca.ibone.comcast.net (68.86.85.78)  52.737 ms  49.117 ms  52.219 ms
7  pos-0-0-0-0-pe01.11greatoaks.ca.ibone.comcast.net (68.86... )  55.980 ms  52.281 ms  55.486 ms
8  75.149.228.254 (75.149.228.254)  57.192 ms  56.133 ms  56.401 ms
9  if-13-0-0-55.core3.sqn-sanjose.as6453.net (66.198.97.9)  56.171 ms  50.551 57.147 ms
10 ix-6-0-2.core3.sqn-sanjose.as6453.net (216.6.33.42)  61.014 ms  56.230 ms  52.237 ms
11 ae1-p161.msr1.sp1.yahoo.com (216.115.107.63)  60.115 ms ae1-p171.msr2.sp1.yahoo.com (216.115.107.87)  52.836 ms ae0-p171.msr2.sp1.yahoo.com (216.115.107.83)  60.015 ms
12 te-8-1.bas-a1.sp1.yahoo.com (209.131.32.17)  53.211 ms te-9-1.bas-a2.sp1.yahoo.com (209.131.32.23)  61.969 ms te-8-1.bas-a2.sp1.yahoo.com (209.131.32.19)  53.569 ms
ctaylor@ctaylor-lt:~$ traceroute www.yahoo.com (Fall 2009)

traceroute to www.yahoo.com (209.131.36.158), 30 hops max, 40 byte packets
1 73.100.100.1 (73.100.100.1)  11.730 ms  17.799 ms  18.175 ms
2 68.85.145.1 (68.85.145.1)  18.283 ms  18.480 ms  18.504 ms
3  te-0-8-0-4-ar01.seattle.wa.seattle.comcast.net (68.85.240.73)  25.892 ms  26.104 ms  26.170 ms
4  pos-0-5-0-0-cr01.seattle.wa.ibone.comcast.net (68.86.90.213)  26.294 ms  26.474 ms  26.643 ms
5  pos-0-8-0-0-cr01.portland.or.ibone.comcast.net (68.86.85.206)  42.713 ms  42.854 ms  42.944 ms
6  pos-1-13-0-0-cr01.sacramento.ca.ibone.comcast.net (68.86.85.162)  55.125 ms  49.924 ms  45.476 ms
7  pos-0-9-0-0-cr01.sanjose.ca.ibone.comcast.net (68.86.85.181)  57.524 ms  58.383 ms  59.094 ms
8  pos-0-0-0-0-pe01.11greatoaks.ca.ibone.comcast.net (68.86.86.50)  60.772 ms  62.891 ms  63.077 ms
9  75.149.228.254 (75.149.228.254)  60.515 ms  63.961 ms  64.123 ms
10 if-13-0-0-1280.core4.SQN-SanJose.as6453.net (216.6.30.25)  66.295 ms  66.587 ms if-10-0-0-
96.core3.SQN-SanJose.as6453.net (209.58.116.50)  65.600 ms
11 ix-2-0-2.core4.SQN-SanJose.as6453.net (216.6.30.10)  65.100 ms  65.343 ms ix-6-0-2.core3.SQN-
SanJose.as6453.net (216.6.33.42)  263.378 ms
12 ae1-p160.msr1.sp1.yahoo.com (216.115.107.61)  243.328 ms ae0-p160.msr1.sp1.yahoo.com
(216.115.107.57)  248.216 ms  251.833 ms
13 te-8-1.bas-a1.sp1.yahoo.com (209.131.32.17)  **65.709 ms** te-9-1.bas-a1.sp1.yahoo.com (209.131.32.21)
259.847 ms te-8-1.bas-a1.sp1.yahoo.com (209.131.32.17)  **65.817 ms**
ctaylor@ctaylor-lt:~$ traceroute www.yahoo.com   [Fall 2010]

traceroute to www.yahoo.com (72.30.2.43), 30 hops max, 40 byte packets
1  * * *
2  68.85.145.1 (68.85.145.1)  17.591 ms  18.268 ms  18.343 ms
3  te-0-8-0-4-ar01.seattle.wa.seattle.comcast.net (68.85.240.73)  24.735 ms  24.912 ms  28.315 ms
4  pos-0-11-0-0-cr01.seattle.wa.ibone.comcast.net (68.86.90.213)  28.977 ms  29.162 ms  29.600 ms
5  pos-0-9-0-0-cr01.portland.or.ibone.comcast.net (68.86.85.102)  40.606 ms  40.757 ms  41.172 ms
6  pos-1-14-0-0-cr01.sacramento.ca.ibone.comcast.net (68.86.85.201)  53.138 ms  41.099 ms  43.996 ms
7  pos-0-8-0-0-cr01.sanjose.ca.ibone.comcast.net (68.86.85.78)  47.064 ms  45.384 ms  45.340 ms
8  pos-0-1-0-0-pe01.11greatoaks.ca.ibone.comcast.net (68.86.86.50)  48.475 ms  47.987 ms  48.098 ms
9  75.149.228.254 (75.149.228.254)  58.810 ms  65.746 ms  66.026 ms
10 if-13-0-0-55.core3.sqn-sanjose.as6453.net (66.198.97.9)  52.528 ms  44.453 ms if-12-0-0-45.core4.sqn-sanjose.as6453.net (216.6.30.29)  53.783 ms
11 ix-2-0-8.core4.sqn-sanjose.as6453.net (209.58.3.6)  131.170 ms  127.531 ms  123.926 ms
12 ae0-p231.msr2.sk1.yahoo.com (216.115.106.143)  45.894 ms ae1-p430.msr2.sk1.yahoo.com (216.115.106.165)  66.569 ms ae0-p231.msr2.sk1.yahoo.com (216.115.106.143)  65.846 ms
13 te-9-1.bas-k1.sk1.yahoo.com (68.180.160.13)  66.262 ms te-8-1.bas-k1.sk1.yahoo.com (68.180.160.9)  59.732 ms te-8-1.bas-k2.sk1.yahoo.com (68.180.160.11)  55.234 ms
traceroute to www.yahoo.com (72.30.2.43), 30 hops max, 40 byte packets

1  * * *
2  ge-5-13-ur01.spokane.wa.seattle.comcast.net  16.064 ms  16.693 ms  18.130 ms
3  te-0-8-0-4-ar01.seattle.wa.seattle.comcast.net  25.609 ms  25.749 ms  26.135 ms
4  68.86.177.134 (68.86.177.134)                22.396 ms  23.182 ms  23.376 ms
5  pos-1-13-0-0-cr01.seattle.wa.ibone.comcast.net 24.062 ms  24.755 ms  23.433 ms
6  te-3-2.car1.Seattle1.Level3.net (4.79.104.105) 225.796 ms  210.451 ms  210.382 ms
7  ae-31-51.ebr1.Seattle1.Level3.net (4.68.105.30) 45.704 ms  60.774 ms  59.488 ms
8  4.69.132.49 (4.69.132.49)                      49.887 ms  49.971 ms  48.569 ms
11 YAHOO-INC.car3.SanJose1.Level3.net (4.71.112.14) 49.409 ms  54.356 ms  53.398 ms
12 ae-1-d431.msr2.sk1.yahoo.com (216.115.106.167) 55.457 ms  54.775 ms ae-0-d231.msr2.sk1.yahoo.com (216.115.106.143) 50.885 ms
13 te-8-1.bas-k2.sk1.yahoo.com (68.180.160.11)  51.909 ms  51.212 ms  46.532 ms
<table>
<thead>
<tr>
<th>Hop</th>
<th>IP Address</th>
<th>Time 1</th>
<th>Time 2</th>
<th>Time 3</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>73.100.96.1</td>
<td>9.120 ms</td>
<td>9.356 ms</td>
<td>9.852 ms</td>
</tr>
<tr>
<td>2</td>
<td>ge-5-9-ur02.spokane.wa.seattle.comcast.net</td>
<td>9.400 ms</td>
<td>13.650 ms</td>
<td>13.680 ms</td>
</tr>
<tr>
<td>3</td>
<td>te-0-10-0-5-ar01.burien.wa.seattle.comcast.net</td>
<td>36.013 ms</td>
<td>36.150 ms</td>
<td>36.328 ms</td>
</tr>
<tr>
<td>4</td>
<td>ae-0-0-ar03.burien.wa.seattle.comcast.net</td>
<td>35.120 ms</td>
<td>35.277 ms</td>
<td>35.447 ms</td>
</tr>
<tr>
<td>5</td>
<td>pos-0-1-0-0-cr01.portland.or.ibone.comcast.net</td>
<td>41.195 ms</td>
<td>39.541 ms</td>
<td>pos-0-4-0-0-cr01.portland.or.ibone.comcast.net (68.86.90.81)</td>
</tr>
<tr>
<td>6</td>
<td>pos-1-7-0-0-cr01.seattle.wa.ibone.comcast.net</td>
<td>32.351 ms</td>
<td>28.766 ms</td>
<td>27.306 ms</td>
</tr>
<tr>
<td>7</td>
<td>4.79.104.109</td>
<td>31.391 ms</td>
<td>31.133 ms</td>
<td>32.145 ms</td>
</tr>
<tr>
<td>8</td>
<td>ae-31-51.ebr1.Seattle1.Level3.net (4.69.147.150)</td>
<td>32.867 ms</td>
<td>32.364 ms</td>
<td>32.513 ms</td>
</tr>
<tr>
<td>9</td>
<td>ae-7-7.ebr2.SanJose1.Level3.net (4.69.132.49)</td>
<td>56.119 ms</td>
<td>56.317 ms</td>
<td>59.846 ms</td>
</tr>
<tr>
<td>10</td>
<td>ae-72-72.csw2.SanJose1.Level3.net</td>
<td>60.014 ms</td>
<td>59.565 ms</td>
<td>59.348 ms</td>
</tr>
<tr>
<td>11</td>
<td>ae-23-70.car3.SanJose1.Level3.net (4.69.152.69)</td>
<td>61.053 ms</td>
<td>ae-43-90.car3.SanJose1.Level3.net (4.69.152.197)</td>
<td>60.819 ms ae-23-70.car3.sanjose1.level3.net (4.69.152.69)</td>
</tr>
<tr>
<td>12</td>
<td>YAHOO-INC.car3.SanJose1.Level3.net</td>
<td>59.105 ms</td>
<td>58.457 ms</td>
<td>53.722 ms</td>
</tr>
<tr>
<td>13</td>
<td>ae-1-d431.msr2.sk1.yahoo.com</td>
<td>56.795 ms</td>
<td>ae-1-d421.msr1.sk1.yahoo.com (216.115.106.163)</td>
<td>59.337 ms ae-1-d431.msr2.sk1.yahoo.com (216.115.106.167)</td>
</tr>
<tr>
<td>14</td>
<td>te-9-1.bas-k2.sk1.yahoo.com</td>
<td>58.105 ms</td>
<td>57.509 ms</td>
<td>56.802 ms</td>
</tr>
</tbody>
</table>
traceroute to www.yahoo.com (206.190.36.45), 30 hops max, 60 byte packets

1  **  **
2  te-3-4-ur01.spokane.wa.seattle.comcast.net (68.87.160.209) 17.543 ms 23.148 ms 23.235 ms
3  ae-19-0-ar03.seattle.wa.seattle.comcast.net (69.139.164.109) 30.495 ms 30.663 ms 30.705 ms
4  he-1-4-0-0-10-cr01.seattle.wa.ibone.comcast.net (68.86.94.237) 40.085 ms he-1-5-0-0-10-
   cr01.seattle.wa.ibone.comcast.net (68.86.94.57) 38.489 ms te-1-3-0-4-
   cr01.sanjose.ca.ibone.comcast.net (68.86.93.173) 45.828 ms
5  208.178.58.85 (208.178.58.85) 164.069 ms 164.103 ms 163.849 ms
6  64.211.195.66 (64.211.195.66) 63.797 ms 46.562 ms 40.965 ms
7  ae-7.pat2.gqb.yahoo.com (216.115.101.109) 24.012 ms 27.963 ms 27.426 ms
8  ae-1.msr2.gq1.yahoo.com (66.196.67.3) 27.890 ms ae-0.msr1.gq1.yahoo.com
   (66.196.67.1) 49.560 ms ae-0.msr2.gq1.yahoo.com
   (66.196.67.23) 22.815 ms
9  xe-4-0-0.clr1-a-gdc.gq1.yahoo.com (68.180.253.129) 23.180 ms xe-7-0-0.clr2-a-gdc.gq1.yahoo.com
   (67.195.0.27) 27.139 ms xe-4-0-0.clr2-a-gdc.gq1.yahoo.com (68.180.253.133) 20.875 ms
10 et-17-1.fab1-1-gdc.gq1.yahoo.com (98.137.31.164) 20.552 ms et-18-25.fab6-1-gdc.gq1.yahoo.com
    (98.137.31.186) 24.592 ms et-18-25.fab8-1-gdc.gq1.yahoo.com (98.137.31.194) 26.781 ms
11 po-14.bas1-7-prd.gq1.yahoo.com (206.190.32.23) 21.246 ms po-9.bas1-7-prd.gq1.yahoo.com
    (206.190.32.13) 26.981 ms po-12.bas1-7-prd.gq1.yahoo.com (206.190.32.19) 27.212 ms
carol@debian:~$ traceroute www.yahoo.com
traceroute to www.yahoo.com (206.190.36.45), 30 hops max, 60 byte packets
1  * * *
2  te-0-1-0-15-sur02.spokane.wa.seattle.comcast.net (68.87.205.133) 13.558 ms 17.287 ms 17.498 ms
3  be-37-ar01.seattle.wa.seattle.comcast.net 26.408 ms 26.390 ms 25.771 ms
4  he-1-3-0-0-10-cr01.seattle.wa.ibone.comcast.net 26.371 ms 28.619 ms 26.340 ms
5  * * *
6  ae-14-51.car4.Seattle1.Level3.net (4.69.147.134) 40.703 ms 27.213 ms 23.496 ms
8  ae-7.pat2.gqb.yahoo.com (216.115.101.109) 28.634 28.586 ms 27.980 ms
9  ae-1.msr1.gq1.yahoo.com (66.196.67.5) 30.576 ms ae-0.msr2.gq1.yahoo.com
(66.196.67.23) 26.212 ms ae-1.msr1.gq1.yahoo.com (66.196.67.5) 25.020 ms
(68.180.253.133) 39.093 ms
11  et-18-25.fab5-1-gdc.gq1.yahoo.com (98.137.31.182) 22.604 ms et-17-25.fab4-1-gdc.gq1.yahoo.com (67.195.1.87) 24.671 ms et-17-1.fab5-1-gdc.gq1.yahoo.com
(98.137.31.180) 23.287 ms
12  po-12.bas1-7-prd.gq1.yahoo.com (206.190.32.19) 28.028 ms po-12.bas2-7-prd.gq1.yahoo.com (206.190.32.35) 22.440 ms po-13.bas2-7-prd.gq1.yahoo.com
(206.190.32.37) 23.187 ms
traceroute to yahoo.com (98.138.253.109), 30 hops max, 60 byte packets

1  R7500.local (192.168.1.1)  1.291 ms  1.387 ms  1.541 ms
2  96.120.101.89 (96.120.101.89)  10.271 ms  10.366 ms  10.514 ms
3  te-0-1-0-15-sur02.spokane.wa.seattle.comcast.net (68.87.205.133)  12.526 ms  14.923 ms  15.298 ms
4  be-37-ar01.seattle.wa.seattle.comcast.net (68.86.96.5)  22.290 ms  22.256 ms  22.776 ms
5  4.68.71.73 (4.68.71.73)  22.588 ms  23.105 ms  21.938 ms
6  ***
7  4.34.62.118 (4.34.62.118)  46.197 ms  46.173 ms  46.166 ms
8  ae-6.pat1.nez.yahoo.com (216.115.104.118)  70.833 ms ae-5.pat2.nez.yahoo.com (216.115.96.70)  54.979 ms 54.849 ms
9  et-19-1-0.msr2.ne1.yahoo.com (216.115.105.181)  70.267 ms et-1-0-0.msr2.ne1.yahoo.com (216.115.105.183) 79.822 ms et-19-1-0.msr1.ne1.yahoo.com (216.115.105.27)  60.115 ms
10 et-0-0-0.clr2-a-gdc.ne1.yahoo.com (98.138.97.65)  75.430 ms  76.214 ms et-1-0-0.clr2-a-gdc.ne1.yahoo.com (98.138.97.73)  74.984 ms
11 et-17-1.fab1-1-gdc.ne1.yahoo.com (98.138.0.79)  59.461 ms et-17-1.fab6-1-gdc.ne1.yahoo.com (98.138.93.5)  60.671 ms et-17-1.fab2-1-gdc.ne1.yahoo.com (98.138.0.81)  61.319 ms
12 po-15.bas1-7-prd.ne1.yahoo.com (98.138.240.16)  61.940 ms po-16.bas2-7-prd.ne1.yahoo.com (98.138.240.34)  61.930 ms po-13.bas2-7-prd.ne1.yahoo.com (98.138.240.28)  61.911 ms
carol@debian:~$ traceroute www.yahoo.com
traceroute to www.yahoo.com (206.190.36.45), 30 hops max, 60 byte packets

<table>
<thead>
<tr>
<th>Hop</th>
<th>IP Address</th>
<th>Time</th>
<th>Time</th>
<th>Time</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>R7500.local (192.168.1.1)</td>
<td>5.842 ms</td>
<td>6.393 ms</td>
<td>6.379 ms</td>
</tr>
<tr>
<td>2</td>
<td>* * *</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>3</td>
<td>te-0-1-0-15-sur02.spokane.wa.seattle.comcast.net</td>
<td>12.811 ms</td>
<td>13.087 ms</td>
<td>13.274 ms</td>
</tr>
<tr>
<td>4</td>
<td>be-37-ar01.seattle.wa.seattle.comcast.net</td>
<td>18.063 ms</td>
<td>18.418 ms</td>
<td>18.722 ms</td>
</tr>
<tr>
<td>5</td>
<td>* * *</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>6</td>
<td>YAHOO-INC.ear2.Seattle1.Level3.net</td>
<td>21.482 ms</td>
<td>16.971 ms</td>
<td>17.128 ms</td>
</tr>
<tr>
<td>7</td>
<td>UNKNOWN-216-115-97-X.yahoo.com</td>
<td>24.427 ms</td>
<td>22.861 ms</td>
<td>24.402 ms</td>
</tr>
<tr>
<td>8</td>
<td>et-19-1-0.msr1.gq1.yahoo.com</td>
<td>22.345 ms</td>
<td>23.022 ms</td>
<td>23.662 ms</td>
</tr>
<tr>
<td>10</td>
<td>et-18-1.fab3-1-gdc.gq1.yahoo.com (67.195.1.81)</td>
<td>22.146 ms</td>
<td>et-18-1.fab2-1-gdc.gq1.yahoo.com (67.195.1.77) 21.344 ms 22.491 ms</td>
<td></td>
</tr>
<tr>
<td>11</td>
<td>po-13.bas2-7-prd.gq1.yahoo.com (206.190.32.37)</td>
<td>24.663 ms</td>
<td>23.294 ms</td>
<td>24.682 ms</td>
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</tbody>
</table>
traceroute to www.yahoo.com (98.138.219.231), 30 hops max, 60 byte packets

<table>
<thead>
<tr>
<th>Hop</th>
<th>IP Address</th>
<th>Time (ms) 1</th>
<th>Time (ms) 2</th>
<th>Time (ms) 3</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>192.168.1.1 (192.168.1.1)</td>
<td>1.561</td>
<td>2.807</td>
<td>4.004</td>
</tr>
<tr>
<td>2</td>
<td>96.120.103.17 (96.120.103.17)</td>
<td>24.667</td>
<td>26.145</td>
<td>26.137</td>
</tr>
<tr>
<td>3</td>
<td>po-106-rur02.spokane.wa.seattle.comcast.net (68.86.98.113)</td>
<td>22.968</td>
<td>22.965</td>
<td>22.945</td>
</tr>
<tr>
<td>4</td>
<td>be-37-ar01.seattle.wa.seattle.comcast.net (68.86.96.5)</td>
<td>26.915</td>
<td>26.904</td>
<td>26.886</td>
</tr>
<tr>
<td>5</td>
<td>lag-16.ear2.Seattle1.Level3.net (4.68.71.73)</td>
<td>27.800</td>
<td>28.867</td>
<td>*</td>
</tr>
<tr>
<td>6</td>
<td>* * *</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>7</td>
<td>4.34.62.118 (4.34.62.118)</td>
<td>46.267</td>
<td>45.103</td>
<td>47.366</td>
</tr>
<tr>
<td>8</td>
<td>ae-6.pat1.nez.yahoo.com (216.115.104.118)</td>
<td>69.954</td>
<td>68.936</td>
<td>64.142</td>
</tr>
<tr>
<td>9</td>
<td>et-0-0-0.msr1.ne1.yahoo.com (216.115.105.25)</td>
<td>53.171</td>
<td>52.120</td>
<td></td>
</tr>
<tr>
<td>10</td>
<td>et-19-1-0.clr1-a-gdc.ne1.yahoo.com (98.138.97.71)</td>
<td>56.831</td>
<td>54.737</td>
<td>59.089</td>
</tr>
<tr>
<td>11</td>
<td>po254.bas2-1-flk.ne1.yahoo.com (98.138.0.87)</td>
<td>75.533</td>
<td>72.321</td>
<td>58.103</td>
</tr>
<tr>
<td>12</td>
<td>media-router-fp1.prod1.media.vip.ne1.yahoo.com</td>
<td>74.469</td>
<td>73.270</td>
<td>67.938</td>
</tr>
</tbody>
</table>
traceroute to www.yahoo.com (98.137.246.8), 30 hops max, 60 byte packets

1  192.168.1.1 (192.168.1.1)  0.740 ms  0.864 ms  2.049 ms
2  96.120.101.237 (96.120.101.237)  11.434 ms  11.641 ms  15.519 ms
3  po-304-1270-rur02.spokane.wa.seattle.comcast.net  14.973 ms  15.042 ms  15.284 ms
4  be-37-ar01.seattle.wa.seattle.comcast.net  29.243 ms  29.551 ms  31.773 ms
5  ***
6  YAHOO-INC.ear2.Seattle1.Level3.net (4.16.146.58)  22.047 ms  15.264 ms  17.061 ms
7  ae-7.pat2.gqb.yahoo.com (216.115.101.109)  23.553 ms  30.176 ms  31.198 ms
8  et-19-1-0.msr2.gq1.yahoo.com (66.196.67.111)  32.320 ms et-1-0-
    0.msr2.gq1.yahoo.com (66.196.67.113)  32.292 ms et-19-1-0.msr2.gq1.yahoo.com
    (66.196.67.111)  32.316 ms
9  et-1-1-0.clr2-a-gdc.gq1.yahoo.com (67.195.37.75)  32.302 ms et-1-1-0.clr1-a-
    gdc.gq1.yahoo.com (67.195.37.71)  21.635 ms et-1-0-0.clr1-a-gdc.gq1.yahoo.com
    (67.195.37.93)  20.379 ms
10 et-16-6.bas1-2-flk.gq1.yahoo.com (98.137.120.6)  26.307 ms  26.290 ms  26.600 ms
11 media-router-fp2.prod1.media.vip.gq1.yahoo.com  26.229 ms  25.097 ms  25.300 ms
ctaylor@cscd106733up:~$
Try It from Other Sites

• Pick servers around the world
• Show the route from them to you!!!
• It might surprise you the route taken

• Several Tools, Sites with Traceroute
  http://navigators.com/traceroute.html

• Visualization of Traceroute from CAIDA
  http://www.caida.org/publications/animations/
  active_monitoring/traceroute.mov

• Traceroute.org Lots of Sites
  http://www.traceroute.org
Networks Have Layers
Protocol “Layers”

Networks are complex!

• Many “pieces”:
  • Hosts
  • Routers
  • Links of various media
  • Applications
  • Protocols
  • Hardware, software

Question:
Is there a logical generic structure of a network?
Guess, Yes or No
Organization of air travel - Analogy

- A series of steps organized as functional layers

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

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

airplane routing
Layering of airline functionality

<table>
<thead>
<tr>
<th>Layer</th>
<th>Function</th>
</tr>
</thead>
<tbody>
<tr>
<td>ticket (purchase)</td>
<td>ticket (complain)</td>
</tr>
<tr>
<td>baggage (check)</td>
<td>baggage (claim)</td>
</tr>
<tr>
<td>gates (load)</td>
<td>gates (unload)</td>
</tr>
<tr>
<td>runway (takeoff)</td>
<td>runway (land)</td>
</tr>
<tr>
<td>airplane routing</td>
<td>airplane routing</td>
</tr>
</tbody>
</table>

**Layers:** each layer implements a service
- Via its own internal-layer actions
- Relying on services provided by layer below
Why implement a network in Layers?

Dealing with complex systems
- Explicit structure allows identification, relationship system’s pieces
  - Layered, standardized reference model
- 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
- What do we call this idea in programming?
  - Encapsulation or object oriented design
Today's Internet protocol stack

- **Application**: 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, LAN
  - PPP, Ethernet
- **Physical**: Bits “on the wire”
Original ISO/OSI reference model

- ISO – International Organization for Standardization
  - OSI – Open Systems Interconnection
- Two Additional Layers Proposed, 7 Layers
- Presentation: Allow applications to interpret meaning of data, e.g., encryption, compression, machine-specific conventions
- Session: Synchronization, checkpointing, recovery of data
- Internet stack “missing” these layers!
  - These services, if needed, must be implemented in application
Each layer offers service to layer directly above it.
Summary

- Looked at delay
  - Can be separated into parts, Process, Queueing, Transmission, Propagation
  - Examined for where the bottleneck is happening within a given network
- Measure Delay and path with Traceroute or tracert for Windows
- Network as Layers
  - OSI Model and today's model
  - Layers hide details from each other
  - Useful for extensibility of network
First Lab will be
Intro to Wireshark – Read it ahead of time
Assignment 2 is History Quiz
Will be graded in class on Friday.