CSCE 463/612
Networks and Distributed Processing
Fall 2023

Introduction II
Dmitri Loguinov
Texas A&M University

August 31, 2023
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
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!
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
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:
   - \( R \) = link rate (bps)
   - \( L \) = packet length (bits)
   - Time to send bits into link = \( L/R \)

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

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)

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

Three delay measurements at first hop

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 reponse (probe lost, router not replying)
18  *    *    *    *
19 fantasia.eurecom.fr (193.55.113.142)  132 ms 128 ms 136 ms
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 $R = 10$ Mbps and total arrival rate of traffic is 11 Mbps
  - Q: What’s the average loss rate on the link?
  - A: About 9%
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
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

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