Course Overview

- **Fundamental Question:**
  - How is data transferred through the Internet?
- **Principles to develop**
  - Reliable data transfer, to the correct recipient
  - Fast & error-free data transfer
  - Security and privacy safeguards
- **Implementation**
  - Network layers & Protocols

Internet Layers: Services (first glimpse)

- **Application layer:**
  - User interface
- **Transport layer:**
  - Reliable data transfer
- **Network layer:**
  - Find the best path through the network
- **Link layer:**
  - Transfer frames along shared links
- **Physical layer:**
  - Transfer bits along one link

Network Applications

Programs that
- run on different end systems and
- communicate over a network.
Transport services and protocols

- Logical communication between application processes running on different hosts

Network Layer

- Routing (path selection)
- Find the 'best' path through the network for each packet

Data Link Layer

- Tasks:
  - Sharing a broadcast channel
  - Multiple access → All laptops and phones in one room access the internet via the same access point
- Examples
  - Ethernet
  - Wireless, 802.11

Four sources of packet delay

Find an analogy for each category below in the caravan example.
Moving Fast Through Lines!

  - Still Image
  - Video (4’ 30")

Caravan analogy

- car~bit; caravan ~ packet
- Toll booth takes 8 sec to service car (processing time)
- Cars “propagate” at 100 km/hr
- Q: How long until the caravan is lined up before 2nd toll booth?

\[ \text{Time for entire caravan to pass thru toll booth plaza onto highway} = 8 \times 10 = 80 \text{ sec} \]

\[ \text{Time for last car to “propagate” from 1st to 2nd toll both?} \]

\[ \text{A: 61 minutes, 20 sec} \]

Queuing Delay & Packet Loss

- A queue, a buffer in a router, has finite capacity
- A packet arriving to a full queue is dropped (aka lost)
- A lost packet may be retransmitted, or not → Reliability

Four sources of packet delay

1. nodal processing
   - Read & interpret packet header
   - Error checking
   - Determine which output link to use

2. queuing
   - Time waiting at a router for transmission
   - Depends on congestion level of router (how many packets are already in the router RAM)
Nodal packet 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
  - \( = d/s \)

Packet Switching: store-and-forward

- takes \( L/R \) seconds to transmit (push out) packet of \( L \) bits on to link at \( R \) bps
- Store and Forward: entire packet must arrive at router before it can be transmitted on next link
- delay = \( 3L/R \) (assuming zero propagation delay)

Example:
- \( L = 7.5 \) Mbits
- \( R = 1.5 \) Mbps
- transmission delay = ? seconds

Delay in packet-switched networks

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

4. Propagation delay:
   - \( d = \) length of physical link
   - \( s = \) propagation speed in medium (~2x10^8 m/sec)
   - propagation delay = \( d/s \)

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

Packet delay: The life of a packet

1. A packet arrives at a router, and...
2. If other packets got there first and are waiting in the output buffer, there is:
3. The rate at which the router can unload the bits onto the physical link =
4. The time to travel from one router to the next router =

Which of these delays are constant and which are variable?
Discussion Question

- Text problem: Exploring propagation delay and transmission delay.
- Consider 2 hosts, A and B, connected by a single link of rate $R$ bps. Suppose that the two hosts are separated by $d$ meters and the propagation speed is $s$ m/s. Host A sends a packet of size $L$ to Host B.
  - Find $d_{\text{prop}}$ (using what information?)
  - Find $d_{\text{trans}}$ (using what information?)
  - Ignoring $d_{\text{proc}}$ and $d_{\text{queue}}$, what is the total end-to-end delay

Chapter 1 - what to read

- Read through entire chapter, but...
- Section 1.3
  - Emphasize 1.3.1 over 1.3.2
- Section 1.4 - Delay, Loss
  - Know this in detail, including the calculations
  - ... In order to really know the various sources of delay, and some causes of packet loss
- Section 1.5 - the Layers
  - We will spend all semester on these layers
  - Be sure to start internalizing this structure

Office Hours

- Monday
- Thursday

Summary

- Review
  - New terms and definitions, including
    - Message; packet; frame; bit ...
- Begin internalizing “the layers”
  - How do the layers communicate with each other?
    - How do they work together to become the Internet?
- What are the sources of delay?
  - How do we determine and/or calculate these?