

Basic Concepts (II)

Common Functions

- Different layers perform different combinations of common functions.
- **Encapsulation and decapsulation**
 - Each layer may add control information. Receiver removes them in reverse order.
- **Error Control**
 - Networks are imperfect. Bits can be corrupted, lost, duplicated, delivered out of order. Different layers use mechanisms to detect or recover from these problems.
 - encoding/decoding for data integrity (A), out of order detection (T)m cyclic redundancy check (CRC) (L)
- **Traffic Management**
 - flow control (protects a receiver from being overwhelmed by a faster sender), congestion control (protects the shared network infrastructure from collapsing under too much traffic)
 - sliding window (T), conflict detection (L)
 - Congestion control remains a huge problem in the public Internet, cellular networks, WiFi, cloud computing, and AI data centers. Thousands of GPUs communicating simultaneously can produce extremely intense traffic bursts. The fundamental problem is the same one we're introducing here.
- **Addressing**
 - Different layer user different identifiers. Why? Because different identifiers solve problems at different layers. This will become much clearer later this semester when we study DNS and IP.
 - Hostname (A), port (T), IP address (N), MAC (L)

Basic Devices

- **Router**
 - primarily a network layer device (examines IP addresses)
 - route packets among LANs or WANs
 - primarily care about where should this IP packet go next?
- **Switch**
 - primarily a link layer device (examines MAC addresses)
 - forward packets between LAN segments

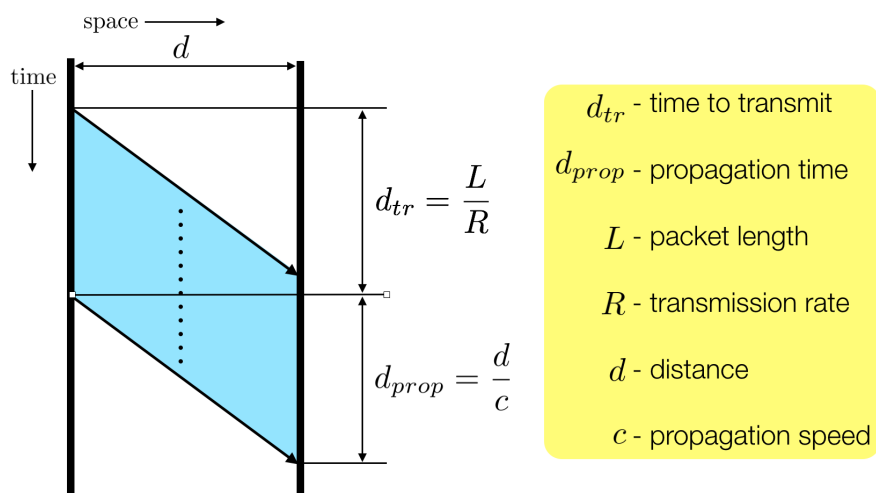
Performance Measures

- **Throughput** — number of bits/bytes/packets delivered per second (Mbps, Gbps)
 - Example: a 1GB (8Gb) file downloaded in 10 seconds, the throughput is $8 \text{ Gb} / 10 \text{ s} = 0.8 \text{ GB/s}$ 0.8 Gbps
 - Bandwidth vs. Throughput

- **bandwidth/capacity**: how much a link can potentially carry
- throughput: how much data is actually delivered
- suppose your WiFi link advertises 1Gbps but your download achieves 350 Mbps. Then link capacity $\sim$ 1Gbps, actual throughput is 350 Mbps
- The difference can arise from shared medium, congestion, protocol overhead, interference, server limitations, bottlenecks elsewhere.
- **Latency** — time to deliver a packet
 - typically measured from the first bit transmission to the last bit reception
 - usually measured in milliseconds (ms)
 - **RTT** (round-trip-time) — two-way latency
 - Ping is a typical RTT example.
 - **Jitter**: variation in packet delay
 - Average latency may look acceptable, but the user may experience frozen video, broken audio, lag. Applications such as video conferencing, gaming, AR/VR, real-time control care strongly about predictable latency, not only average latency.
- **Packet Loss Rate**
 - The percentage of unreceived packets during a period of time
 - loss rate = # lost packets / # sent packets * 100%
 - packet loss can result from congestion, wireless interference, faulty links, queue overflow

Time-Space Diagram

- End-to-end delay (latency) = $d_{tr} + d_{prop}$ over a direct link
- d_{tr} : transmission delay, time to push all packet bits onto the link
- d_{prop} : propagation delay, time between the moment the last bit onto the link and the moment it's received (time the last bit travels through the medium)
- R : the width of the door
- d : the distance between the two ends
- c : the speed of bits (m/s)



- Example: How long does it take to deliver three packets back-to-back to the destination?
Assume that the packet length is L , the distance between the source and destination is d , the transmission rate is R , and the propagation speed is C .
 - $3 * d_{tr} + d_{prop} = 3L/R + d/c$
- Question: If I upgrade a transatlantic link from 100 Gbps to 800 Gbps, will signals travel across the Atlantic eight times faster?
 - No. Higher transmission rate reduces d_{tr} , but does significantly change d_{prop} . The signal still has thousands of kilometers to travel.
- What if the link between two ends goes over several routers, what else need to be considered in the latency calculation?
 - Queuing delay.
 - Each router has its queue for the incoming packets. Depending on the load of a router, the queuing delay can be long or short.
- Processing delay is another factor plays in the latency, which is the time for hosts to process the packets (e.g., encapsulation and decapsulation). Comparing with other factors, this delay is minor, based on the processing ability of modern computers.

Disclaimer: Notes adapted from the textbook and online resources.