CPSC 471: Computer Communications

Network Performance

Figures from Computer Networks: A Systems Approach, version 6.02dev (Larry L. Peterson and Bruce S. Davie)

Performance: Bandwidth/Throughput

- Also called data rate
- Number of bits that can be transmitted over the network in a certain period of time
  - E.g., 10 Mbps (Megabits per second or million bits per second)
    - Takes 0.1 μs (microsecond) to transmit each bit
- Mbits != MB
  - Mbits = 10^6 bits per second
  - MB (megabyte) = 2^{20} bits

Pulse Width of Bits

- (a) Bits transmitted at 1 Mbps
  - Each bit is 1 μs wide
- (b) Bits transmitted at 2 Mbps
  - Each bit is 0.5 μs wide

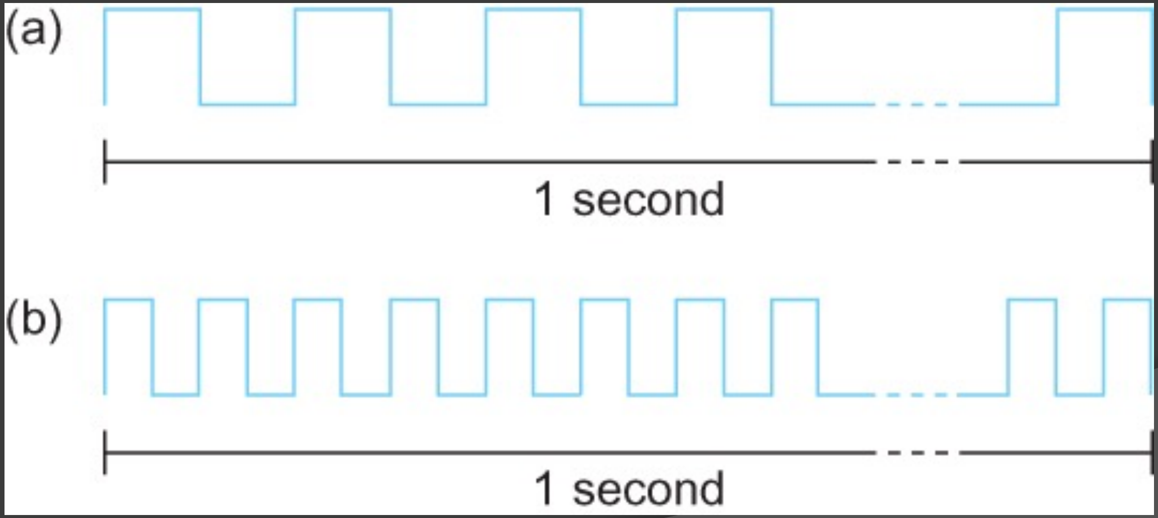

Figure 16

Bandwidth continued

- Analyze bandwidth of
  - Network as a whole
  - Single physical link
  - Logical process-to-process channel
    - Influenced by how often software that handles the channel must handle/transform the data

Bandwidth Definitions

- Bandwidth can also refer to range of signals that can be accommodated
  - Expressed in frequency
- **Throughput**: the measured performance of a system
  - E.g., A link with 10 Mbps may have a lower actual throughput
- Bandwidth Requirements
  - The number of bits per second an application needs to perform acceptably

Performance: Latency/Delay

- How long it takes a message to travel from source to destination
- Latency of
  - Single link
  - End-to-end channel
- Measured using time
  - Transcontinental network may have latency of 24 ms (one-way)
- Round-Trip Time (RTT) is often more useful

Components of Latency

- Speed of light propagation delay
  - Propagation delay: time for signal to propagate from one end of link to other
  - 3×10^8 m/s in vacuum
  - 2.3×10^8 m/s in a copper cable
  - 2×10^8 m/s in an optical fiber
  - Propagation = Distance / Speed_of_Light

Components of Latency

- Transmit Delay
  - Amount of time it takes to transmit a unit of data
  - Transmit = Packet_Size / Bandwidth
- Queuing Delays
  - Switches usually need to store packets for some time before forwarding them on
- Latency = Propagation + Transmit + Queue

Length of Bit Example

- How wide is a bit on a 100-Mbps link?
- Assume this link is a copper wire with a propagation speed of 2.3×10^8 m/s

Solution to Length of Bit Example

- 100 Mbps link = 100 x 10^6 bps = 10^8 bits/s
- Therefore, 10^{-8} s/bit:
  - Each bit is 10^{-8} s or 10 ns wide
- If copper wire has a propagation speed of 2.3 x 10^8 m/s:
  - 10^{-8} s/bit * 2.3 x 10^8 m/s = 2.3 m/bit
- Each bit is 2.3 m long in this wire

Example Latency Problem

- Assume that hosts A and B are connected by a switch S: A-------S-------B
- Assume that the links have a bandwidth of 1 Gbps and a propagation delay of 15 μs
- Assume that the switch is a store-and-forward device and forwards the received packet 25 μs after receiving it
- Create a timeline of sending two consecutive 100,000-bit packets

Solution to Example Latency Problem (1/2)

- First, calculate the transmission delay: 100,000 bits / 1 Gbps = 100 μs
- At t=0 μs: A starts transmitting Packet 1 to S
- At t=15 μs: 1st bit of Pkt 1 arrives at S
- At t=100 μs: A finishes transmitting Pkt 1 to S
A starts transmitting Packet 2 to S
- At t=115 μs: Last bit of Pkt 1 arrives at S
1st bit of Pkt 2 arrives at S
- At t=140 μs: S starts transmitting Pkt 1 to B

Solution to Example Latency Problem (2/2)

- At t=200 μs: A finishes transmitting Pkt2 to S
- At t=215 μs: Last bit of Pkt 2 arrives at S
- At t=240 μs: 1^{st} bit of Pkt 1 arrives at B
  S finishes transmitting Pkt 1 to B
  S starts transmitting Pkt2 to B
- At t=255 μs: Last bit of Pkt 1 arrives at B
  1^{st} bit of Pkt 2 arrives at B
- At t=340 μs: S finishes transmitting Pkt 2 to B
- At t=355 μs: Last bit of Pkt 2 arrives at B

Bandwidth and Latency Impact on Applications

- Latency dominates for small messages
- Bandwidth dominates for large messages
- Example: Consider message size for different applications

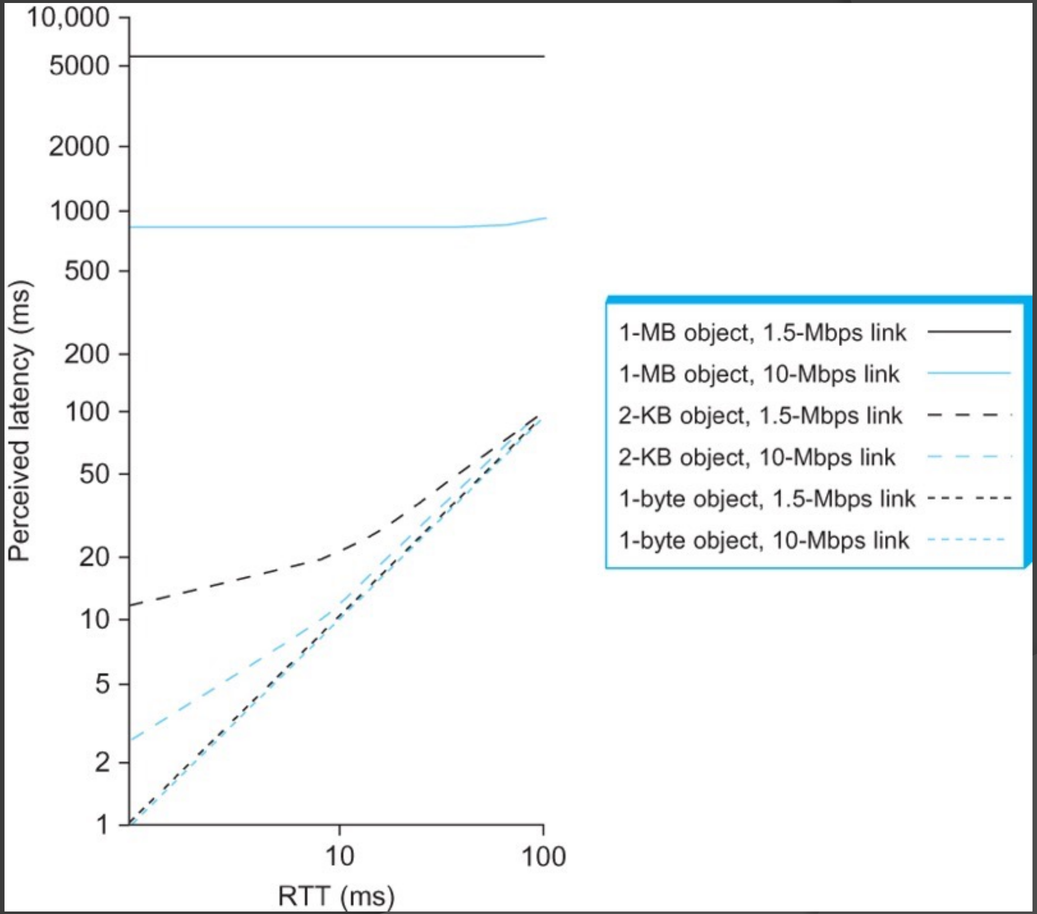

Figure 17

Delay x Bandwidth Product

- Number of bits that can be in transit (in flight) at a given instant
- How many bits the sender must transmit before the first bit arrives at the receiver
- Usually uses the RTT delay

Figure 18

Delay x Bandwidth Products

Link Type	Bandwidth	One-Way Distance	RTT	RTT x Bandwidth
Wireless LAN	54 Mbps	50 m	0.33 μs	18 bits
Satellite	1 Gbps	35,000 km	230 ms	230 Mb
Cross-country fiber	10 Gbps	4,000 km	40 ms	400 Mb

Table 1

Example Performance Problem

- Suppose a 128-kbps point-to-point link is set up between the Earth and a rover on Mars. Assume the distance between Earth and Mars is 55 million kilometers and data travels over the link at the speed of light (3×10^8 m/s).
  a. First, how quickly can a 5 MB image taken by the rover be transmitted to Earth?
  b. Next, calculate the delay-bandwidth product for this link. Use the RTT of part a's delay.

Solution to Example Performance Problem (part a)

a. One-way latency = Propagation Delay + Transmit Delay + Queuing Delay
   - Assuming Queuing Delay = 0 seconds
   - Prop. Delay = 55×10^9 m / 3×10^8 m/s
     Propagation Delay = 183.33 seconds
   - Image Size = 5 MB = $5 * 2^{20}$ B = 5 * 1,048,576 B
     Image Size = 5,242,880 B * 8 bits/Byte
     = 41,943,040 b or approx. 41.9 Mb
   - Transmit Delay = 41,943,040 b / 128×10^3 b/s
     = 327.68 s
   - One-way latency = 183.33 + 327.68 = 511.01 s
     or approx. 8.52 minutes

Solution to Example Performance Problem (part b)

b. Delay-Bandwidth Product
   - RTT = 2 * One-way delay = 2 * 511.01 s
     = 1022.02 s or approx. 17.03 minutes
   - RTT * Bandwidth = 1022.02 s * 128 x 10^3 b/s
     = 130,818,560 b or approx. 130.8 Mb
     = 16,352,320 B or approx. 15.59 MB

High-Speed Networks

- Bandwidth can increase for high-speed networks, but usually latency stays constant
  - Latency starts to dominate

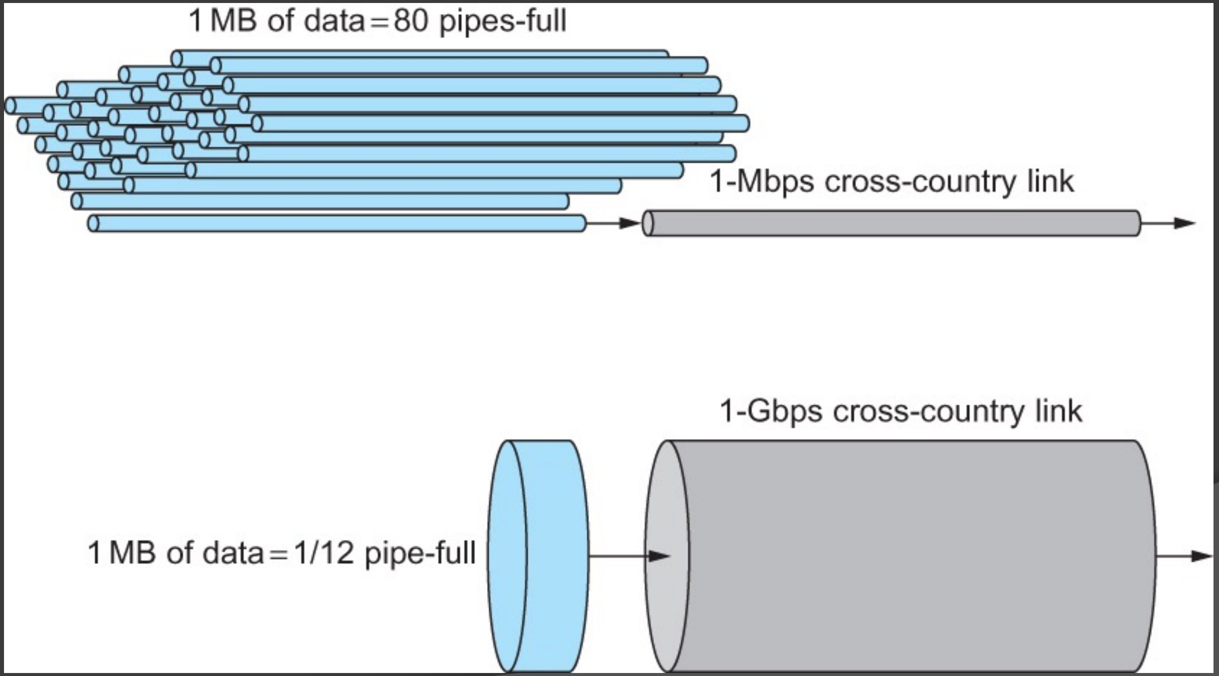

Figure 19

Effective Throughput

- Effective/Measured Throughput (end-to-end)
  = Transfer_Size / Transfer_Time

- Transfer_Time =
  RTT + 1/Bandwidth x Transfer_Size

Application Performance Needs

- E.g., Video Applications
  - Have a resolution
    - E.g., ¼ of standard def. (352 x 240 pixels)
  - Have a color depth
    - E.g., 24-bit color
  - Requires 247.5 KB per frame
  - Have a frame rate
    - If frame rate is 30 fps, may need throughput rate of 75 Mbps

Average Bandwidth

- Can be misleading
- Example: An application has average bandwidth of 2 Mbps and the maximum channel bandwidth is 2 Mbps
  - What happens if application's actual bandwidth varies between 1 and 3 Mbps?

Peak Rate

- Need to know the peak rate or burst
- Can allocate storage/buffer capacity to handle a burst
  - Depends how large and how frequent the bursts are
- Need to consider queueing theory

Jitter

- Variation in latency
- A problem for video applications
- If spacing between packets (interpacket gap) varies, jitter is introduced into packet stream
  - Can happen due to different queuing delays

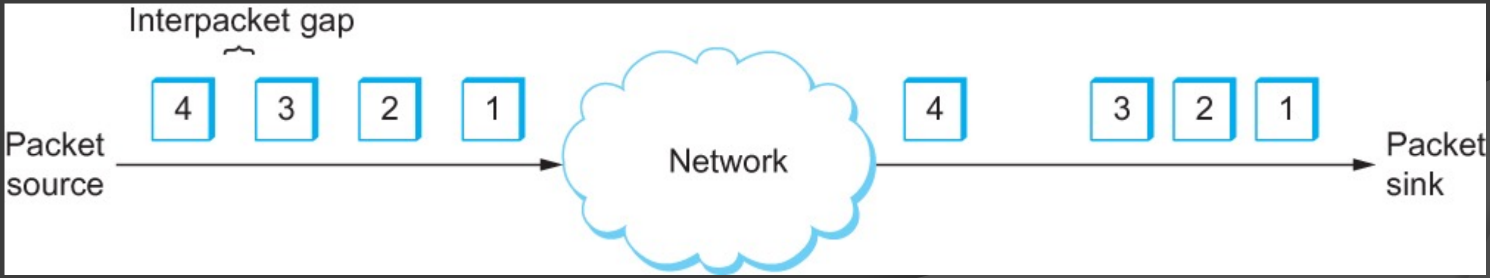

Figure 20