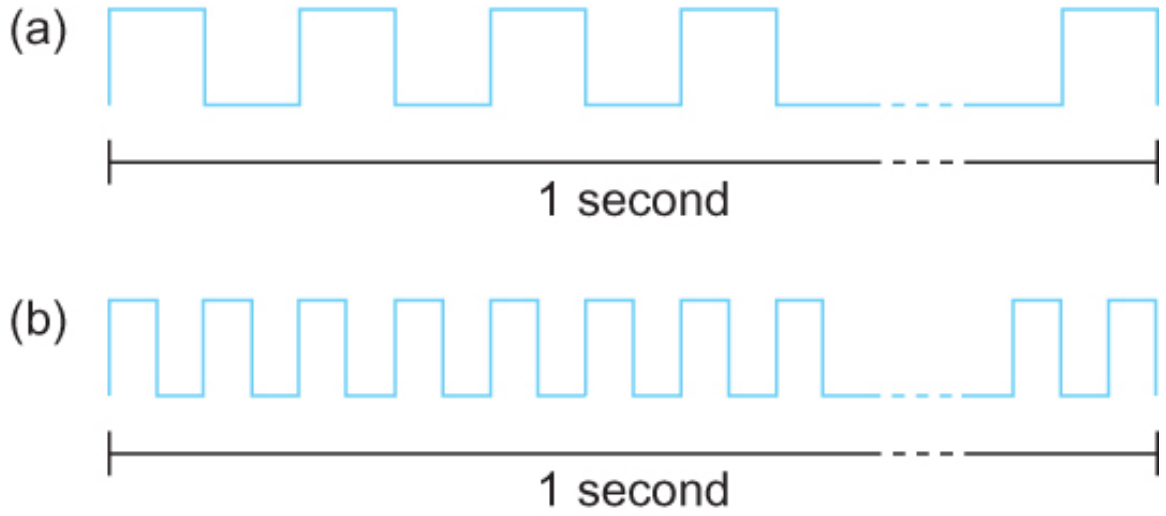
Lecture 3

- Outline
  - Network Performance
  - Evaluating the performance of computer networks
    - Key metrics
      - Latency (Delay)
      - Bandwidth (Data Rate)
    - Key parameters

Bandwidth

- Definitions (use)
  - Width of the frequency band (Hz) [exact, EE]
  - Number of bits per second that can be transmitted over a communication link (b/s) [liberally…]
- Examples
  - 1 Mbps: 1 x 10^6 bits/second ~= 1x2^{20} bits/sec
    - 1 x 10^{-6} seconds to transmit each bit
    - imagine a timeline: each bit occupies 1 micro second (length)
  - on a 2 Mbps link: each bit occupies 0.5 micro second
- The smaller the width, more bits will be transmitted per unit time

Illustration of Bandwidth (Data Rate…)



Bits transmitted at a particular bandwidth can be regarded as having some width:

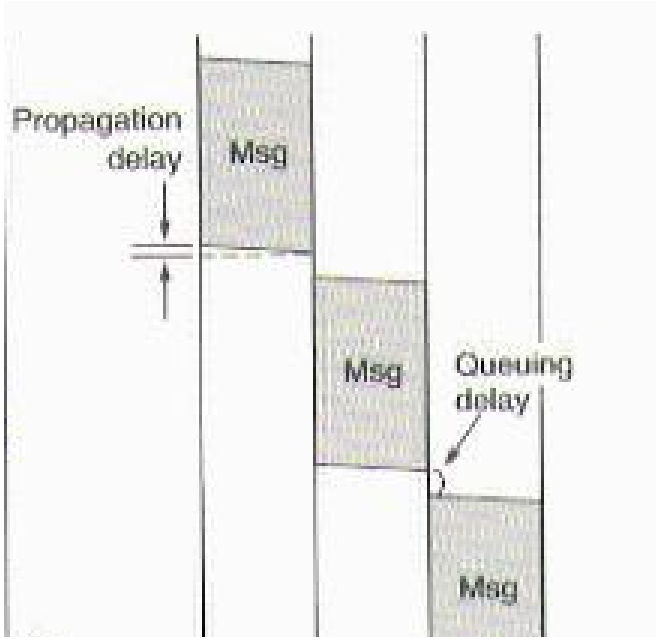
(a) bits transmitted at 1Mbps (each bit 1 μs wide);

(b) bits transmitted at 2Mbps (each bit 0.5 μs wide).

Latency (Delay)

- Latency = propagation + transmission + queueing (delay)

- Propagation delay = distance/speed of light (propagation)
- Transmission delay = packet size / data rate
  - (the data rate is often called bandwidth)

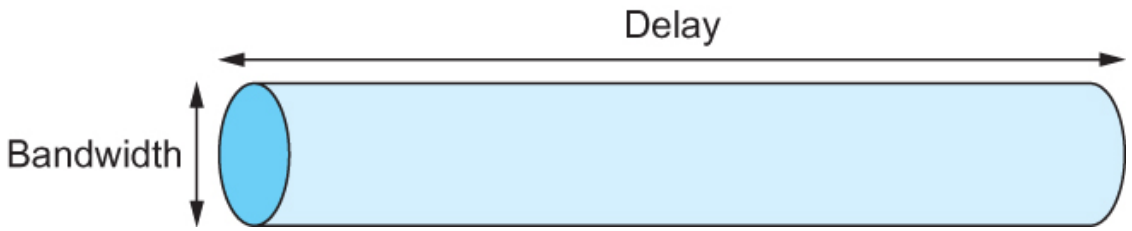


- Important for the
- transmission of…
  - **1 bit** => propagation delay
  - (very) **many** bits => bandwidth

Delay-Bandwidth Product

- Think of the channel (between a pair of processes) as a hollow pipe
  - **Latency** (delay) is the length of the pipe
  - **Bandwidth** is the width of the pipe
- Delay of 50 ms and bandwidth of 45 Mbps
  - ⇒ 50×10^{-3} s x 45×10^{6} b/s
  - ⇒ 2.25×10^{6} bits = 280 KB data

channel as a pipe



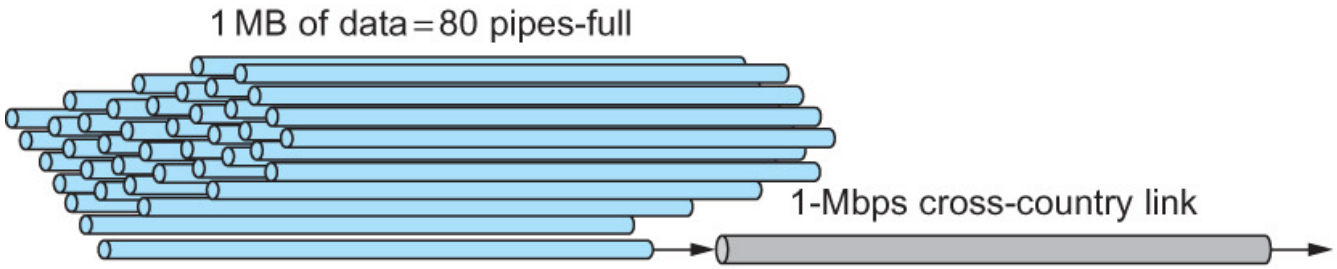
- The **delay-bandwidth product** shows how much **information** is 'stored' **in the pipe** (channel)

Delay x Bandwidth

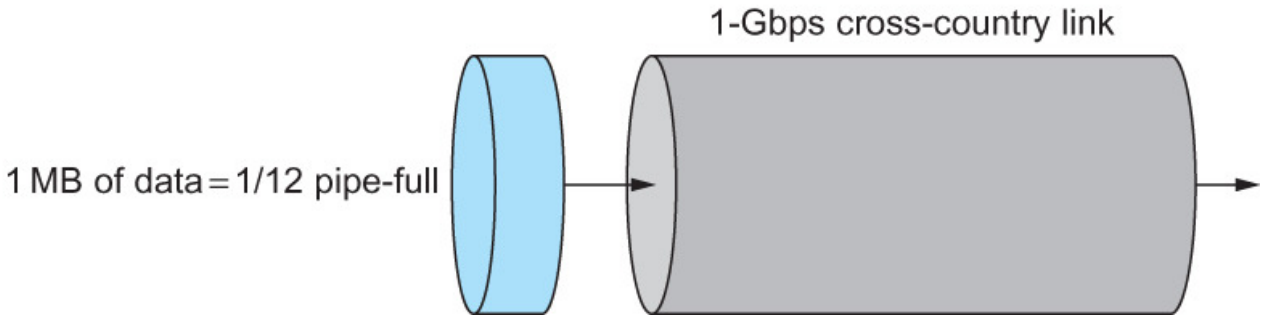
- How many bits the sender must transmit before the first bit arrives at the receiver if the sender keeps the pipe full
- It takes another one-way latency to receive a response from the receiver…
- If the sender does not fill the pipe—send a whole delay × bandwidth product's worth of data before it stops to wait for a signal—the sender will not fully utilize the channel (network)

- Infinite bandwidth
  - Round-Trip Time (RTT) dominates
  - Throughput = Transfer Size / Transfer Time
  - Transfer Time = RTT + 1/Bandwidth x Transfer Size
- It's all relative
  - 1-MB file to 1-Gbps link looks like a 1-KB packet to 1-Mbps link

Bandwidth-Latency Relationship



Note: assuming cross-country propagation delay = **100 ms**



A 1-MB file would fill the 1-Mbps link 80 times,
but only fill the 1-Gbps link 1/12.5 of one time

Delay vs. Bandwidth

- Relative importance of bandwidth and latency (delay) depends on application
  - For large file transfer, bandwidth is critical
  - For small messages (HTTP, NFS, etc.), latency is critical
  - Variance in latency (jitter) can also affect some applications (*e.g.*, audio/video conferencing)

Summary

- We have discussed two performance metrics using which we can analyze the performance of computer networks
  - latency (delay)
  - bandwidth (data rate)