L2: Bandwidth and Latency

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Acknowledgements

- Some pictures used in this presentation were obtained from the Internet
- The instructor used the following references
  - Larry L. Peterson and Bruce S. Davie, Computer Networks: A Systems Approach, 5th Edition, Elsevier, 2011
  - Andrew S. Tanenbaum, Computer Networks, 5th Edition, Prentice-Hall, 2010
  - James F. Kurose and Keith W. Ross, Computer Networking: A Top-Down Approach, 5th Ed., Addison Wesley, 2009
  - Larry L. Peterson's (http://www.cs.princeton.edu/~llp/) Computer Networks class web site

Review

- What to build?
  - Computer Network
    - General purpose
    - Cost-effective network sharing
    - Fair network link allocation
    - Robust connectivity
- How to build?
  - Layered architecture
- *How good is it? Does it meet application needs?*
  - Performance Metrics
  - Application performance needs

Performance Metrics

- Bandwidth
  - Data ***can*** be transmitted per time unit
  - Notation
    - Kbps = 10^3 bits per second (bps)
    - Mbps = 10^6 bits per second (bps)
    - Gbps = 10^9 bits per second (bps)
  - *Question: how is memory storage capacity (the amount of data) measured?*
- Latency (delay)
  - Time to send message from point A to point B
  - Components
    - Latency = propagation + transmit + queue + …
    - Propagation (i.e., propagation delay or propagation time) = distance / speed of signal
    - Transmit (i.e., transmit time) = size / bandwidth
    - queue (i.e., queueing delay) = the time when the message stays in the buffer before it is forwarded.
  - One-way versus round-trip time (RTT)

Link versus End-to-End

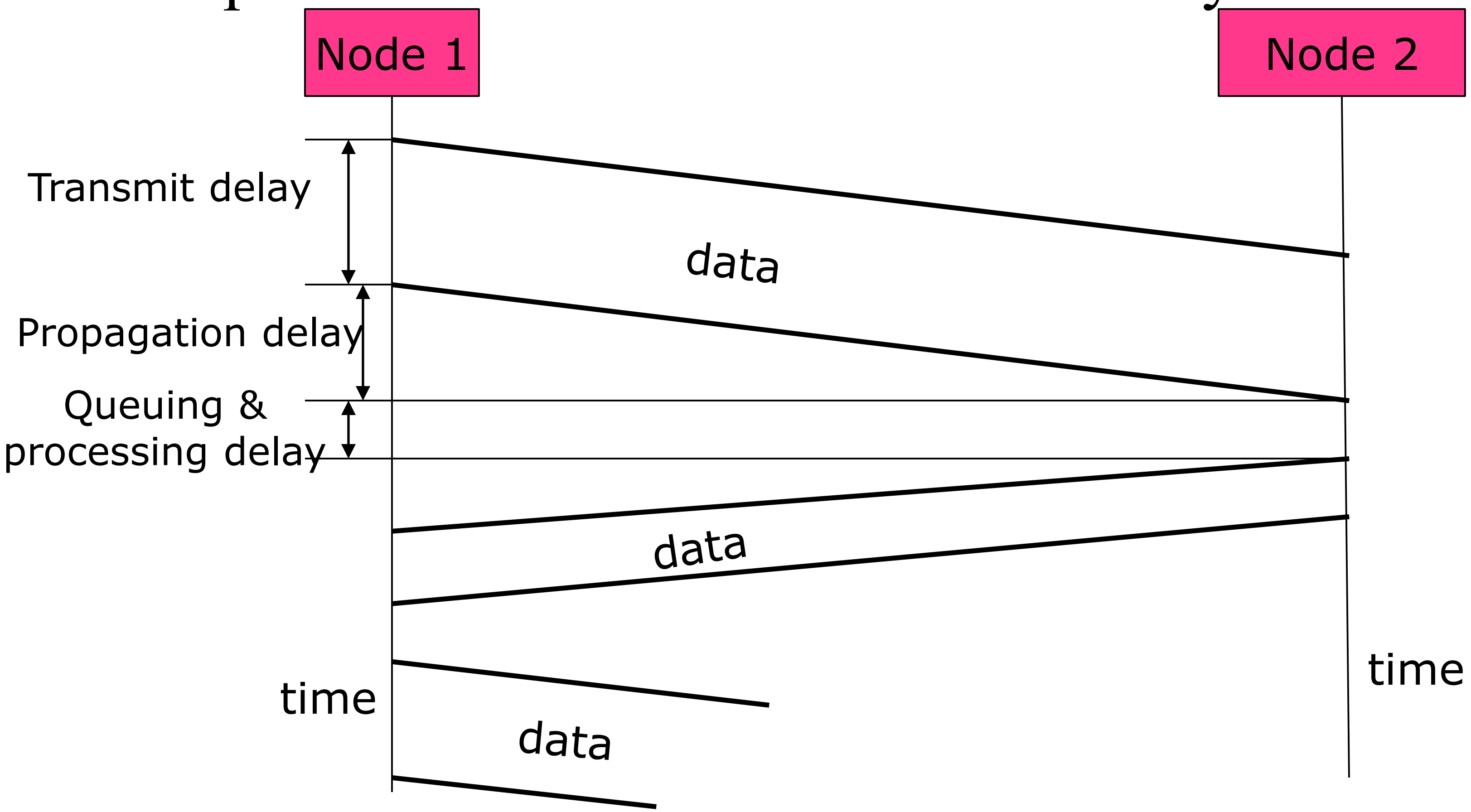
- End-to-End bandwidth
  - Throughput
  - All things considered
- Observations
  - Bits move “fast” but nodes may be slow
    - Fiber optics
    - Routing nodes made by “electronic” processors
    - Bandwidth limited by the nodes: optical routing
  - Bits move “slow” but nodes may be fast
    - Plain old telephone line
    - Fast routing nodes
    - Bandwidth limited by the link: replace the link

Latency = Propagation + Transmit + Queue + …

- Many factors are in play
  - Node
  - Communication channel (link)
  - Interference
  - ……

Latency = Propagation + Transmit + Queue + …

- Simple scenario: two nodes connected by a link



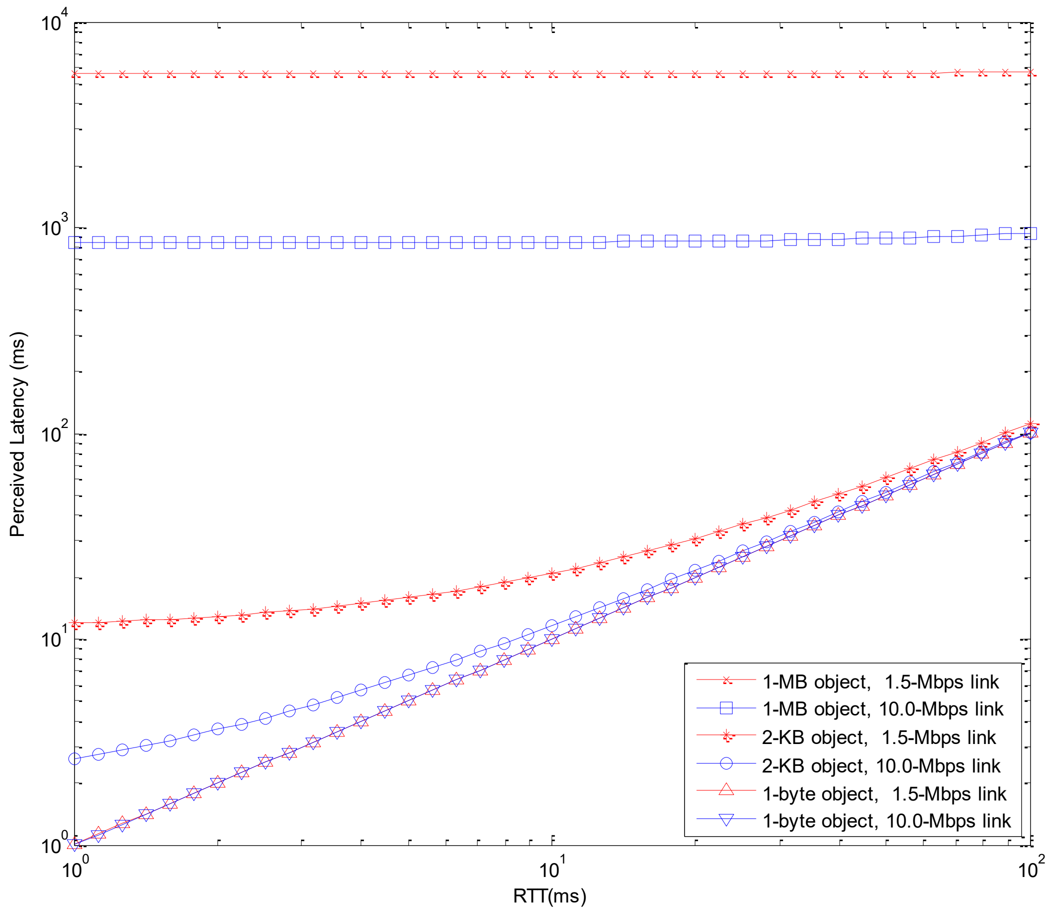
Exercise L2-1

- Consider a fiber optic link 4400 km in length.
  - How much is the propagation delay of the link?
- Compute the time for transmitting 4 MB of data
  - Transmit data at the bandwidth of 56 kbps
  - Transmit data at the bandwidth of 100 Mbps
  - Transmit data at the bandwidth of 10 Gbps

Bandwidth versus Latency

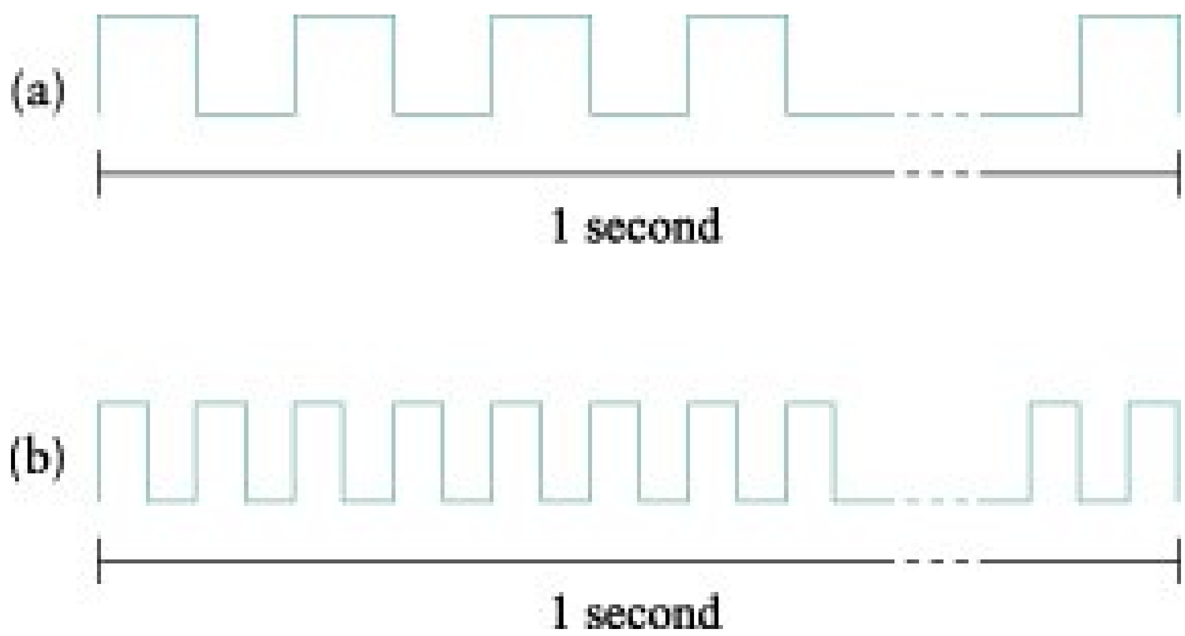
- Bandwidth and latency
  - Throughput = Transfer Size / Transfer Time
- Example
  - Ignore queuing & processing delay. Acknowledgement takes no time.
  - Transfer Time = RTT + Transfer Size / Bandwidth
  - Throughput = Transfer Size / Transfer Time
  - Two networks: compute RTT and throughput
    - RTT = 1 ms; bandwidth = 1 Mbps
    - RTT = 100 ms; bandwidth = 100 Mbps
  - Send 1 byte
    - RTT dominates, bandwidth insignificant
  - Send 25 Mbytes
    - Bandwidth dominates, RTT insignificant

Bandwidth & Latency: Relative Importance



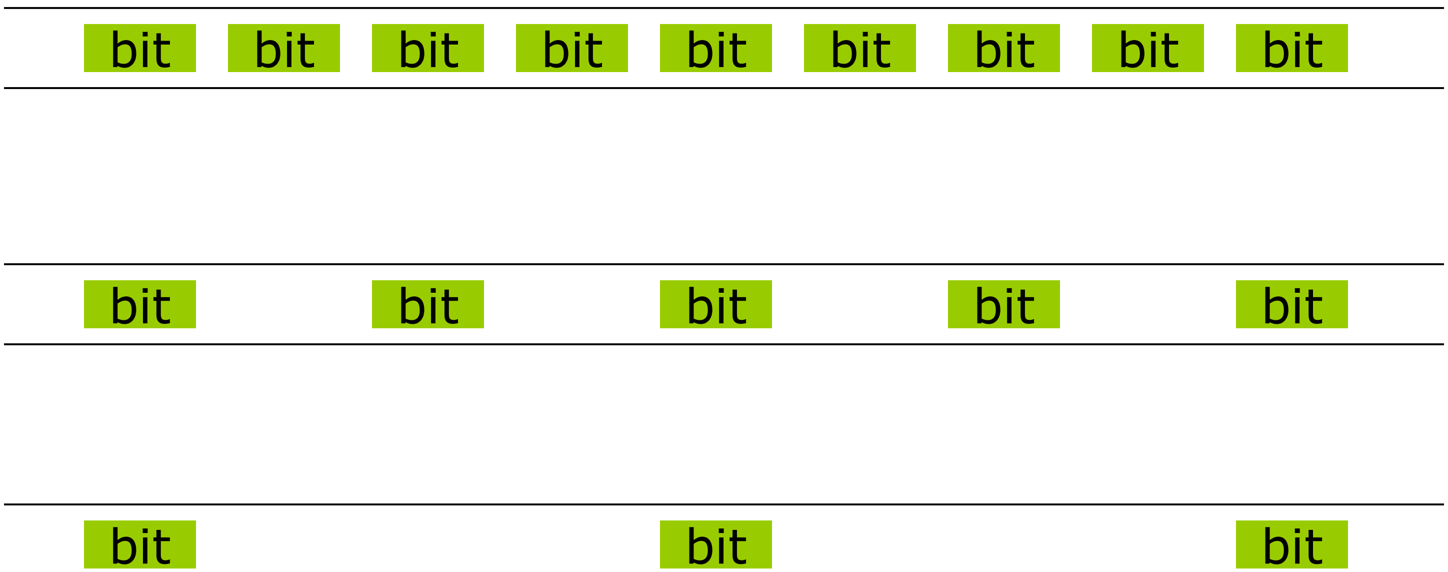
How wide is a bit?

- Consider a link as a pipe full of bits, one after another



Link Utilization

- Do bits have “width? How wide is a bit?
- Consider following cases: what do you observe, assume the links are of the same?



Delay × Bandwidth Product

- Amount of data "in flight" or "in the pipe"
- Example: 100 ms × 45 Mbps = 560 KB

Link Type	Bandwidth (Typical)	Distance (Typical)	Round-trip Delay	Delay × BW
Dial-up	56 Kbps	10 km	87 μs	5 bits
Wireless LAN	54 Mbps	50 m	0.33 μs	18 bits
Satellite	45 Mbps	35,000 km	230 ms	10 Mb
Cross-country fiber	10 Gbps	4,000 km	40 ms	400 Mb

Exercise L2-2

- Show step-by-step how delay × bandwidth is calculated in previous slide (also included below). Choose one of the four.

Link Type	Bandwidth (Typical)	Distance (Typical)	Round-trip Delay	Delay × BW
Dial-up	56 Kbps	10 km	87 μs	5 bits
Wireless LAN	54 Mbps	50 m	0.33 μs	18 bits
Satellite	45 Mbps	35,000 km	230 ms	10 Mb
Cross-country fiber	10 Gbps	4,000 km	40 ms	400 Mb

- Calculate delay × bandwidth for the following links
  - A wireless link of 56 kbps between Earth and the moon, provided signal travels at the speed of light (3×10^8 m/s) and the distance between the two is 384,403 km.

Application Performance Needs

- Uncompressed video: sequences of frames
  - ¼ NTSC = 352 × 240 pixels
  - True color: 24 bits for 1 pixel
  - 1 frame = 352 × 240 × 24 = 2027520 bits
  - 30 fps (frames/second)
    - 2027520 bits/frame × 30 fps = 60825600 bits / second = 60825600 bps = 60825.6 Kbps = 60.8256 Mbps
- Compressed video: constant rate versus varied rate
  - Average bandwidth requirement suffices?
- Delay and Jitter

Exercise L2-3

- Assume no compression is done. Calculate the bandwidth necessary for transmitting in real time
  - High-definition video at resolution of 1920 x 1080, 24bits/pixel, 30 frames/seconds

Summary

- Performance metrics
  - Bandwidth
  - Latency
  - Relative importance
  - Delay × Bandwidth Product
- Application needs
  - Bandwidth requirement
  - Delay requirement