Fundamentals of Computer Networks
ECE 478/578

Lecture #3
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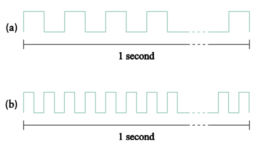
Network Performance Metrics

Bandwidth

- Amount of data transmitted per unit of time; per link, or end-to-end
- Units 1KB = 2^{10} bytes, 1Mbps = 10^6 bits per sec
- How many KB/sec is a 1Mbps line? How many MB/sec?

Throughput

- Data rate delivered by the a link, connection or network
- Per link or end-to-end, same units as Bandwidth



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Latency or Delay

Time for sending data from host A to B (in sec, msec, or μsec)

Per link or end-to-end

- Usually consists of
  - T_t: Transmission delay
  - T_p: Propagation delay
  - T_q: Queuing delay

Round Trip Time (RTT) : time to send a message from A to B and back

- Important for flow control mechanisms

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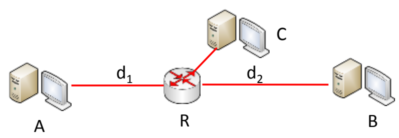
Delay Calculation

T_t : Transmission Delay: file size/bandwidth

T_p : Propagation Delay: time needed for signal to travel the medium, Distance / speed of medium

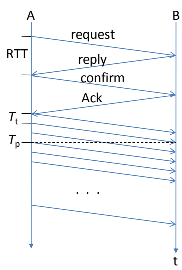
T_q: Queuing Delay: time waiting in router's buffer



Example: Problem 1.6 from Book

Transfer 1,5 MB file, assuming RTT of 80 ms, a packet size of 1-KB and an initial "handshake" of 2xRTT

Bandwidth is 10 Mbps and data packets can be sent continuously



RTT = 80 ms

T_t = 1024x8 bits/10^7 bits/s = 0.8192 ms

T_p = 40 ms

# of packets = 1536 (1.5 x 1024)

D = 2xRTT + 1536xT_t + T_p

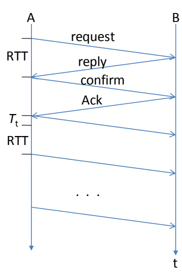
= 160 + 1258.29 + 40 ms

= 1.458 s

Example: Problem 1.6 from Book

Transfer 1,5 MB file, assuming RTT of 80 ms, a packet size of 1-KB and an initial "handshake" of 2xRTT

After sending each packet must wait one RTT



RTT = 80 ms

T_t = 1024x8 bits/10^7 bits/s = 0.8192 ms

T_p = 40 ms

# of packets = 1536 (1.5 x 1024)

D = 2xRTT + 1535x(T_t +RTT)+ T_t+T_p

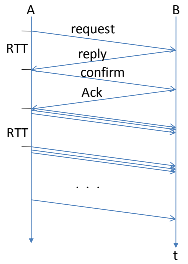
= 160 + 124,057 + 0.8192 + 40 ms

= 124.258 s

Example: Problem 1.6 from Book

Transfer 1,5 MB file, assuming RTT of 80 ms, a packet size of 1-KB and an initial “handshake” of 2xRTT

Only 20 packets can be send per RTT, but infinitely fast



RTT = 80 ms
T_t = 0 ms
T_p = 40 ms
\# of packets = 1536 (1.5 x 1024)

D = 2xRTT + 76xRTT + T_p
= 160 + 6080 + 40 ms
= 6.28 s

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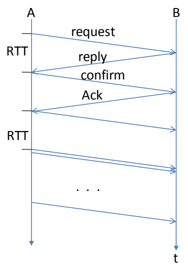
Example: Problem 1.6 from Book

Transfer 1,5 MB file, assuming RTT of 80 ms, a packet size of 1-KB and an initial “handshake” of 2xRTT

1st RTT one packet, 2 RTT two packets … Infinite transmission rate



RTT = 80 ms
T_t = 0 ms
T_p = 40 ms
\# of packets = 1536 (1.5 x 1024)
\# of waits (1+2+…2^n = 2^{n+1} -1)
2^{11} -1 =2047 packets, n = 10

D = 2xRTT + 10xRTT + T_p
= 160 + 800 + 40 ms
= 1 s

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Latency vs. Bandwidth

Importance depends on application

- 1 byte file, 1ms/1Mbps vs. 100ms/100Mbps
- 1 ms + 8µs = 1.008ms,
- 100ms + 0.08µs =100 ms.

- 1GB file, 1ms/1Mbps vs. 100ms/100Mbps
- 1ms + 1024^3 x 8 /106 = 2.38h + 1ms,
- 100ms + 85 s

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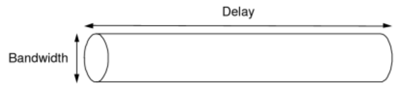
Bandwidth x Delay Product

The amount of data (bits or bytes) “in the pipe”

Example: 100Mbps x 10ms = 1 Mbit



The amount of data sent before first bit arrives

Usually use RTT as delay: amount of data before a reply from a receiver arrives to the sender

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High-Speed Networks

Link Type	Bandwidth	Distance	RTT	Delay x BW
Dial-up	56 kbps	10 km	87 µs	5 bits
Wireless LAN	54 Mbps	50 m	0.33 µs	18 bits
Satellite link	45 Mbps	35,000 km	230 ms	10 Mb
Cross-country fiber	10 Gbps	4,000 km	40 ms	400 Mb

Infinite bandwidth

- Propagation delay dominates
- Throughput = Transfer size/Transfer time
- Transfer time = RTT + Transfer size/Bandwidth
- 1MB file across 1Gbps line with 100ms RTT, Throughput is 74.1 Mbps

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Computing Application Bandwidth

FTP can utilize entire BW available

Video-on-demand may specify upper limit (only what’s needed)

Example: res: 352x240 pixels, 24-bit color, 30 fps

- Each frame is (352 x 240 x 24)/8 =247.5 KB
- Total required BW = 352 x 240 x 24 x 30 = 60.8 Mbps

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Network Jitter

Variability in the delay between packets

Video-on-demand application: If jitter is known, application can decide how much buffering is needed

Example: jitter is 50ms per frame and 10s video at 30fps must be transmitted.

If Y frames buffered, video can play uninterrupted for Y x 1/30s.

The last frame will arrive 50 x (10 x 30 – Y) ms after video start, worst case

$$Y/30 = 50 \times (300 - Y) \rightarrow Y = 180 \text{ frames}$$

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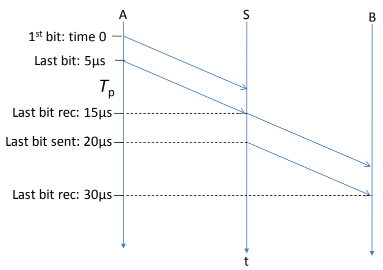
Example: Problem 1.19 from Book

1 – Gbps Ethernet with a s-a-f switch in the path and a packet size of 5,000 bits. T_p = 10 µs, switch transmits immediately after reception



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Example: Problem 1.19 from Book

1 – Gbps Ethernet with a s-a-f switch in the path and a packet size of 5,000 bits. T_p = 10 µs, 3 switches in between A and B

4 links equal to 4 T_p delay

4 transmissions equal to 4 T_t delay

Total: $4T_p + 4T_t$ = 60 µs

Three switches, each transmits after 128 bits are received

Total: $4T_p + T_t + 3\text{x}128/10^9$ = 40µs + 5µs + 0.384µs = 45.384µs

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