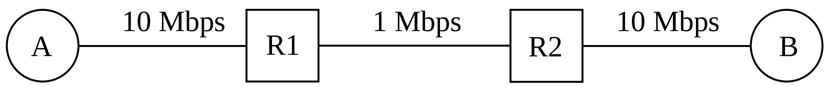
CS421 HW#1, due 11:59PM on Nov. 21, 2021

1. Assume that there are 3 links on a path connecting hosts A and B passing through routers R1 and R2 as shown in the following figure. Each link has a distance of 400 km and the transmission rate of each link is shown in the figure. We are transmitting a file composed of **five packets** from node A to node B using datagram packet switching. Each packet has a length of 1250 Bytes including all headers. Assume that the processing and queuing delays in each intermediate node are negligible and the propagation speed is 2×10^5 km/s. Calculate the total delay incurred in transferring the file from host A to host B.



2. Consider a connection with a 1**0msec** roundtrip, delay (including all delays incurred within the network, but excluding the packet transmission time of the sender). We want to transfer a file composed of **16 segments** (with sequence numbers from 1 to 16), where each segment has a transmission time of **1msec**. Assume that ACK segments have negligibly small size and there is no processing delay at the receiver. Assume also that the processing delay at the sender after an ACK is received is negligible. We assume that the communication between the sender and receiver is full duplex, i.e., sender can send data segments while receiving an ACK segment. **Selective Repeat** protocol is used with a window size of **N = 8** segments. Assume that all data segments are received correctly while the **first transmissions** of the **data segments** with sequence numbers **6 and 11,** and **ACK segments** with acknowledgment numbers **12 and 15** are errored, whereas **all other data** and **ACK segments are fully reliable**. The timeout for each data segment is set to **15msec starting from the end of the transmission of the segment**. How much time is required to complete the transfer of the whole file and receive the **final ACK** at the sender?

3. Answer the above Question 1. when **Go-Back-N** protocol is used with a window size of **N = 8** segments. Each window of the sender has a timeout of **15msec starting from the time when the window is set by the sender**.

4. Suppose a TCP connection experiences round-trip times (RTT) of 30 msec for 90% of its segments, and 100 msec for 10% of its segments. Suppose no packets are lost. Assume that the estimated RTT (according to the exponential weighted moving average) is equal to the true (ensemble) average of RTT, i.e., EstimatedRTT = average value of RTT = E[SampleRTT], where E[ ] corresponds to the expected value of a random variable. TCP estimates both the mean and the mean deviation, and sets the timeout.

   i) Assume that TCP sets the TimeOut = 2 x EstimatedRTT. What fraction of the segments will be assumed lost by the TCP sender?

   ii) Now assume that TCP sets TimeOut = EstimatedRTT + 4 x devRTT. Assume that the devRTT measured by TCP is equal to the ensemble average of devRTT, i.e., devRTT = E[|SampleRTT-EstimatedRTT|]. What fraction of the segments will be assumed lost by the TCP sender?

5. Suppose that you are given the task of building a reliable acoustic communication link between two underwater terminals, where TCP is going to be used as the transport layer protocol. Assume that layers 1 and 2 (the physical and link layers) have already been designed so you do not need to worry about how to physically get a packet between the terminals. Assume that the underwater link has a capacity of 100Kbps and a distance of 6km. Note that acoustic signals propagate at a speed of 1500m/s under the water. In this task, you have the flexibility of changing any part of TCP. Propose **two modifications** to TCP so that you can obtain a higher throughput over this underwater link. You need to justify each proposal. Make sure that your proposals do not harm the reliability of TCP.

6. At time *t*, a TCP connection has CongWin=5000Bytes, ssthresh=9000Bytes and no unacknowledged segments. The sender sends five more segments between *t* and *s* (*s* > *t*) each containing 1000Bytes (with sequence numbers 7500, 8500, 9500, 10500 and 11500). TCP sender receives three ACK segments between *t* and *s* with acknowledgement numbers 8500, 9500 and 10500.

   i) Assume that the last ACK segment contains a Receive Window of 3000Bytes. How many more bytes can the TCP sender send at time *s*?

   ii) Assume that the last ACK segment that the sender received contains a Receive Window of 12000Bytes. How many more bytes can the TCP sender send at time *s*?

7. Three TCP connections are sharing a link with capacity of 100Mbps (100×10^6bps). Assume that the bandwidth bottleneck for all three connections is this shared link. The roundtrip times for the connections are 5ms, 10ms and 30ms, respectively. Calculate the maximum throughputs achieved by each connection.

8. A TCP connection passes through a 10Mbps link which does not buffer any packets. Suppose that there are no other connections using this link and this link is the only congested link for the given connection, i.e., all other links along the connection have much larger available capacity. Assume that the TCP sender has a huge file to send. The receive buffer at the TCP receiver can be assumed infinitely large. The round-trip delay for this connection is 10ms.

   i) Calculate the maximum window size, in bytes, that this TCP connection can achieve.

   ii) Now assume that the link has a capacity of 100Mbps. Calculate the maximum window size, in bytes, that this TCP connection can achieve.

9. Assume that there is a TCP connection between two processes, one running at Host A and the other at Host B in order to transfer a very large file from Host A to Host B. The slowest link in the network along this connection has a transmission rate of 100 Mbps. The application running at Host A can write data to its TCP send buffer at a rate of 70 Mbps, whereas the application running at Host B can read data from its TCP receive buffer at a rate of 60 Mbps.

   i) What is the average rate of data transfer from the application at Host A to the application at Host B? Justify your answer.

   ii) Which of the TCP flow control and congestion control algorithms limits the data transfer rate in your answer above? How does this algorithm limit the transfer rate?

   iii) Now assume that the slowest link along this connection has a transmission rate of 50 Mbps. Which of the TCP flow control and congestion control algorithms now limits the data transfer rate? How does this algorithm limit the transfer rate?

10. Suppose that a file composed of 40 segments, each with a size of 1250Bytes, will be transferred over a TCP connection with a round-trip delay of 10 ms and bandwidth of 10 Mbps, i.e., $10x10^6$ bps. Assume that no loss event occurs during the entire file transfer. Further assume that the slow start threshold (ssthresh) at the beginning of the TCP connection is infinitely large. Ignore all processing and queueing delays and assume that ACK messages have a negligibly small transmission time. How long does it take to transmit the entire file and receive the final ACK?