Spring'19

CS 2520/TELCOM 2321 - WANs

Supplemental Homework and Solution

February 20, 2019

Problem 1

Consider the following design problem concerning the implementation of a network service. Using a virtual circuit, each data packet must have a 3-byte header, and each router set aside up to 8 bytes of storage for circuit identification. Using datagrams, 15-bytes headers are needed, but no router table space is required. Transmission capacity costs 1 cent per 10^6 bytes, per hop. Router memory can be purchased for 1 cent per byte and is depreciated over two years (business hours). The statistically average session runs over 1000 sec, in which time 200 packets are transmitted.

- Assuming that the packet requires 4 hops, on average. Which implementation is more cost effective and by how much?
- Assume that the packet requires N hops, on average. What value of N, if any, makes the datagram service cheaper.

Problem 1 Solution

Four hops means that five routers are involved. The virtual circuit implementation requires tying up $5 \cdot 8 = 40$ bytes of memory for $1,000$ sec. The datagram implementation requires transmitting $12 \cdot 4 \cdot 200 = 9,600$ bytes of header over and above what the virtual circuit implementation needs. Thus the question comes down to the relative cost of $40,000$ bytes-sec of memory versus 9600 bytes-hop of circuit capacity. If memory is depreciated over $2 \cdot 52 \cdot 40 \cdot 3,600 = 1.5 \cdot 10^7$ sec, a byte-sec costs $6.7 \cdot 10^{-8}$ cents, and 40,000 of them cost just over 2 millicents. If a byte-hop costs 10^{-6} cents, $9,600$ of them cost 9.6 millicents. Therefore, virtual circuits are cheaper for this set of parameters.

Problem 2

2.1 Give a simple heuristic for finding two paths through a network from a given source to a given destination that can survive the loss of any communication link (assuming two such paths exist and routers do not crash).

2.2 Show that your heuristic is correct and discuss its efficiency.

Problem 2 Solution

2.1 Use an all-path discovery packet to find all possible paths from the source to destination. The packet is replicated by the router over all interfaces, except the one the packet came through. The packet records the routers already visited since it left the source. The routers must also be careful not to circulate the all-path discovery packet undefinitely. They need to detect and discard packets they have already seen (This information is contained in the header of the packet. A router discards a packet when it sees that its name has already been recorded in its header). When the receiver receives all-path discovery packets, it can select two disjoint paths and send those paths back to the source.

2.2 The all-path discovery packet broadcasting eventually terminates. Assuming that at least two disjoint paths exist, the destination discovers those paths and sends them back to the receiver. The algorithm, however, can lead to high overhead due to broadcasting.

Problem 3

To control traffic admission in a network using virtual circuits internally, a router could refrain from acknowledging a received packet until (1) it knows its last transmission along the virtual circuit was received successfully, and (2) it has a free buffer. For simplicity, assume that each virtual circuit has one buffer dedicated to it for each direction of traffic.

- If it takes T sec to transmit a packet (data and acknowledgment) and there are n routers on the path, what is the rate at which packets are delivered to the destination host? Assume that transmission errors are rare, and that the host-router connection does not fail and is infinitely fast.
- Argue about the efficiency of such a scheme.

Problem 3 Solution

3.1 Let the time be slotted in units of T sec. In slot 1, the source router sends the first packet. At the start of slot 2, the second router has received the packet but cannot acknowledge it yet. At the start of slot 3, the third router has received the packet, but it cannot acknowledge it either. This causes all the routers along the path to remain hanging. The first acknowledgment can only be sent when the destination host takes the packet from the destination router. Now the acknowledgement begins propagating back. It takes two full transits of the subnet, $2(n-1)T$ sec, before the source router can send the second packet. Thus the throughput is one packet every $2(n-1)T$ sec.

3.2 The protocol exhibits a very poor performance. It forces all routers to operate sequentially. As a result, the throughput decreases rapidly as the number of routers, n, increases.

Problem 4

A best-effort network protocol allows routers to drop packets whenever they need to. The probability of a router discarding a packet is p. Consider the case of a source host connected to the source router, which is connected to the destination router, and then to the destination host. If either of the routers discards a packet, the source host eventually times out and tries again. Assume that host-router and router-router lines are counted as hops.

4.1 What is the mean number of hops a packet makes per transmission?

4.2 What is the mean number of transmissions a packet makes?

4.3 What is the mean number of hops required per received packet?

Problem 4 Solution

The probability of a router discarding a packet is p. Consider the case of a source host connected to the source router, which is connected to the destination router, and then to the destination host. If either of the routers discards a packet, the source host eventually times out and tries again. Assume that host-router and router-router lines are counted as hops.

4.1 Each packet emitted by the source host makes either 1,2, or 3 hops. The probability that it makes one hop is p. The probability that it makes two hops is $p(1-p)$. The probability that it makes 3 hops is $(1-p)^2$. The mean path length a packet can expect to travel is then the weighted sum of these three probabilities, or

$$p^2 - 3p + 3 \tag{1}$$

Notice that for $p = 0$, the mean is 3 hops and for $p = 1$ the mean is 1 hop.

4.2 With $0 < p < 1$, multiple transmissions may be needed. The mean number of transmissions can be found by realizing that the probability of a successful transmission all the way is $\alpha = (1-p)^2$. The expected number of transmission is just:

$$\alpha + 2\alpha(1-\alpha) + 3\alpha(1-\alpha)^2 + ... = 1/\alpha \tag{2}$$

4.3 The total hops used is just :

$$[1/(1-p)^2] \cdot (p^2 - 3p + 3) \tag{3}$$

The first term denotes the average number of transmission. The second term the average path length a transmission is expected to travel.

Problem 5

Consider a simple network of two nodes. A and B, directly connected by a link. A stop-and-wait protocol is used to flow control the two-way traffic between A and B. Assume that data frames are all of the same length and require D seconds for transmission. Acknowledgment frames require R seconds for transmission and there is a propagation delay P on the link. Assume that A and B both have an unending sequence of packets to send, assume that no transmission errors occur, and assume that the time-out interval at which a node resends a previously transmitted packet is very large. Finally, assume that each node sends new data packets and acknowledgments as fast as possible, subject to the rules of the stop-and-wait protocol.

5.1 Show that the rate at which packets are transmitted in each direction is $(D + R + 2P)^{-1}$. Show that this is true whether or not the starting time between A and B is synchronized.

5.2 Assume, in addition, that whenever a node has both an acknowledgment and a data packet to send, the acknowledgment is piggybacked onto the data frame (which still requires D seconds). Assume that node B does not start transmitting data until the instant that it receives the first frame from A (i.e., B's first frame contains a piggybacked acknowledgment). Show the rate in each direction is now $(2D+2P)^{-1}$. Is this rate always higher than that one computed above (i.e., 2.1)?

Problem 5 Solution

5.1 For simplicity, consider first the case in which A and B start at the same time, as depicted in Figure 1.

It can be seen that the above pattern is periodic with period $D+R+2P$, with one packet in each direction. Thus, the rate is $(D+R+2P)^{-1}$.

Next, without loss of generality, suppose that node B starts its first transmission after A. This behavior is depicted in Figure 2.

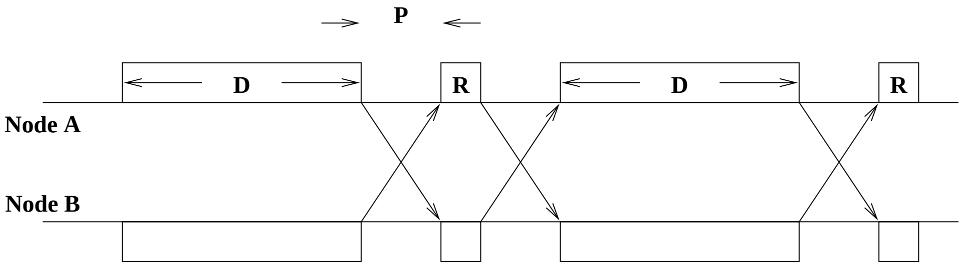

Figure 1: Synchronized Transmission

The figure shows that after the first frame in each direction, the pattern becomes periodic. In general, if B completes its first transmission at time t and A completes its transmission at time $\tau \leq t$, then B starts its first ACK transmission at $\max(t, \tau+P)$, since $\tau+P$ is the time at which B has completely received the first packet from A and t is the first time that the link is free from A to B. Node A starts to send its first ACK to B at $t+P$, which is thus received at B at $t+R+2P$. Similarly, node A receives the first ACK from B at $\max(t, \tau+P)+R+P$, at which time it starts to send its second packet. In this case also the period is $D+R+2P$. Thus, the rate is $(D+R+2P)^{-1}$.

5.2 The timing diagram is depicted in Figure 3. The diagram shows that the two way transmission is periodic with a period $2D+2P$. Therefore, the transmission rate is $(2D+2P)^{-1}$. If $D > R$, this rate is less than the one computed in 5.1.

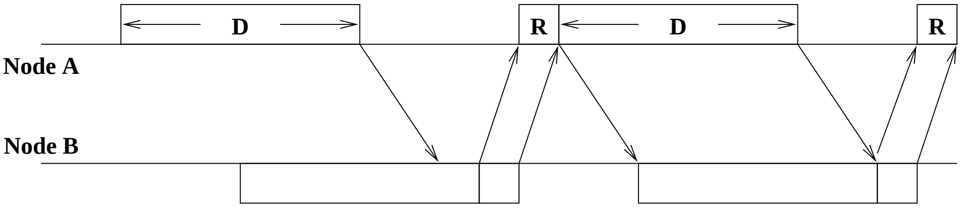

Figure 2: Random Transmission

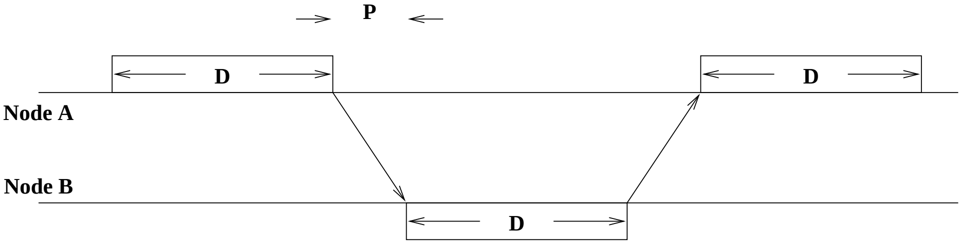

Figure 3: Two-way Transmission

Problem 6

Two nodes A and B use the stop-and-wait protocol for flow control. The time to send a packet from A to B or an ACK from B to A is equal to T. Acknowledgments are sent as soon as correct packets are received. The processing time is negligible. The transmission time of a a packet is $TRANS_P$, and the transmission time of an acknowledgment is $TRANS_A$. A fraction α of the packets and a fraction β of the ACKs are corrupted by transmission errors.

1. Find the a average time needed to send a correct packet from A to B.

Problem 6 Solution

1. Denote by p the probability that transmission errors corrupt a packet or its acknowledgment, or both. Then, we have:

   $$1 - p = (1 - \alpha)(1 - \beta) \tag{4}$$

   The average time, T, needed to send a correct packet from A to B, can then be expressed as:

   $$T = S(1 - p) + p(timeout\ +\ T) \text{ where} \tag{5}$$

   $$S = TRANS_P + 2PROP + TRANS_A \tag{6}$$

   The value of *timeout* can be chosen equal to $TRANS_P$, assuming the sender can send packet back to back, and to S if the sender and the receiver has to take turns sending traffic.

Problem 7

Consider the use of 1000-bit frames on a 1-Mbps satellite channel with 270-ms delay. We define the throughput, T, of a channel as follows as the number of bits transmitted per second. We assume that the channel is error free and the processing time of frames and acknowledgments is negligible. What is the maximum throughput (bits per second) for the following flow control schemes?

7.1 Stop-and-wait flow control.

7.2 Sliding window flow control with a window size of 7

7.3 Sliding window flow control with a window size of 127

7.4 Sliding window flow control with a window size of 255?

Problem 7 Solution

Let TF represent the ime to transmit a frame, UL represent the link utilization and W denote the window size. Assuming, $UL = \frac{W \times TF}{2D}$, where $D = 540$ msec is the one way satellite delay, and $TF = \frac{1000}{106} = 10^3$ sec, we have:

7.1 Stop-and-wait flow control, $W = 1$:

$$\begin{aligned} UL &= \frac{10^{-3}}{(540 \times 10^{-3})} \\ &= 0.0019 \end{aligned}$$

7.2 Sliding window flow control with a window size of 7, $W = 7$:

$$\begin{aligned} UL &= 7\frac{10^{-3}}{(540 \times 10^{-3})} \\ &= 0.013 \end{aligned}$$

7.3 Sliding window flow control with a window size of 127, $W = 127$:

$$\begin{aligned} UL &= 127\frac{10^{-3}}{(540 \times 10^{-3})} \\ &= 0.235185185 \end{aligned}$$

7.4 Sliding window flow control with a window size of 255, $W = 255$:

$$\begin{aligned} UL &= 255\frac{10^{-3}}{(540 \times 10^{-3})} \\ &= 0.47 \end{aligned}$$