Problem Set #1 – CSCI 5273

Assume that 1 Kbps = 103 bits/sec, 1 Mbps = 106 bits/sec, 1 Gbps = 109 bits/sec, and 1MB = 106 x 8 bits. The capital ‘B’ typically means ‘byte’ while the lowercase ‘b’ indicates ‘bit’.

1. What advantage does a circuit-switched network have over a packet-switched  
network?  
Circuit switched networks allow for more reliable communication with predictable  
performance due to allowing a single connection to monopolize resources. This results in  
simpler forwarding and removes the need for packet headers, since once a connection is  
established in a circuit-switched network, no other communication can take place over  
the same data link.

2. What advantage does TDM have over FDM in a circuit switched network?  
In circuit-switched networks, reliable and predictable performance is critical. Time-  
division multiplexing (TDM) provides this; when a node is given a timeslot, it is allowed  
to use the full available bandwidth on the link, guaranteeing the expected performance is  
attained. Frequency-division multiplexing (FDM), while allowing for multiple nodes to  
communicate simultaneously over the link, limits the bandwidth of any given node by  
some function of the number of nodes, which means that the performance becomes  
unpredictable

3. We consider sending real-time voice from Host A to Host B over a packet-switched network. Host A converts analog voice to a digital 65kbps bit stream and send these bits into 56-byte packets. There is one link between Hosts A and B and the transmission rate is 1 Mbps and its propagation delay is 20 msec. As soon as Host A gathers a packet, it sends it to Host B. As soon as Host B receives an entire packet, it converts the packet’s bits into an analog signal. How much time elapses from the time a bit is created (from the original analog signal at Host A) until the bit is decoded (as part of the analog signal at Host B)?

We are given that the propagation delay 𝐷 = 20  
ms = 0.02  
s. The transmission time is  
given as 𝑃/𝑅, where 𝑃 = 56  
B = 448  
bits is the packet size and 𝑅 = 1  
Mbps = 106 bits/s is the transmission rate.

The time to transfer a single packet is given by the  
end-to-end delay, 𝐷𝑒 = 𝐷 + 𝑃 𝑅⁄ = 0.02 s + 448 bits106bits s⁄ = 0.020448 s.

The analog-to-digital conversion time is 448 𝑏 65 𝐾𝑏𝑝𝑠 ≈ 0.0069 𝑠 per packet. Thus, the total  
time from the creation of the first bit to the decoding of the first bit is 448 𝑏 65 𝐾𝑏𝑝𝑠 + 𝐷𝑒 =  
0.02734 𝑠 = 27.34 𝑚𝑠.

4. Consider a Go-Back-N sliding window algorithm (1 packet is 250 bytes long)  
running over a 100km point-to-point fiber link with bandwidth of 100 Mbps.  
a. Compute the one-way propagation delay for this link, assuming that the speed of  
light is 2 x 108 m/s in the fiber .  
The propagation delay is 𝐷 = 𝑀𝑆 , where 𝑀 = 100 𝑘𝑚 is the link length and 𝑆 =2 × 108 𝑚𝑠 is the link propagation speed. So, 𝐷 = 100 𝑘𝑚 2 × 108 𝑚𝑠 = 1 × 105 2 × 108 𝑚𝑠 = 0.5 𝑚𝑠.

b. Suggest a suitable timeout value for the algorithm to use. List factors you need to  
consider.  
In order to determine a suitable timeout value, we must first determine the RTT.  
The RTT on this link is at least twice the propagation delay, 2(0.5 𝑚𝑠), plus the  
forward transmission time 250⋅8 𝑏𝑖𝑡𝑠 100 𝑀𝑏𝑝𝑠 = 2 × 10−5 𝑠 = 20 𝜇𝑠.

Assuming reverse transmission time, since the size of the acknowledgement packet should  
be small relative to the size of data packets, the RTT is about 1.02 𝑚𝑠. Thus, a  
suitable timeout would be slightly longer than that, in order to account for minor  
delays and processing time. For example, a timeout of 1.1 𝑚𝑠 to 1.25 𝑚𝑠 would likely be reasonable.

c. Suggest N to achieve 100% utilization in this link.

Since the link has a round-trip BDP of 100 𝑀𝑏𝑝𝑠 ⋅ 2(0.5)𝑚𝑠 = 100 𝐾𝑏, the link can fit a total of 100 𝐾𝑏 250 ⋅ 8 𝑏𝑖𝑡𝑠 𝑝𝑎𝑐𝑘𝑒𝑡 ⁄ = 50 packets at any given time. Thus, a send window size of 𝑁 = 50 packets would achieve 100% utilization.

(9pts) Suppose a 1-Gbps point-to-point link is being set up between the Earth and a new  
lunar colony. The distance from the moon to the Earth is approximately 385,000 km, and  
data travels over the link at the speed of light—3×108 m/s.

1. Calculate the minimum RTT for the link.

The minimum RTT is the RTT for transmitting a single bit, given as

𝑅𝑇𝑇 = 2 (𝑀/𝑆 + 1/𝑅) = 2 (3.85 × 108 𝑚 /3 ⋅ 108 𝑚𝑠 + 1 𝑏/1 𝐺𝑏𝑝𝑠) ≈ 2.567𝑠.

1. Using the RTT as the delay, calculate the delay × bandwidth product for the link.

The BDP (using the RTT) is 2.567 𝑠 ⋅ 1 𝐺𝑏𝑝𝑠 = 2.567 𝐺𝑏

1. What is the significance of the delay × bandwidth product computed in (b)?  
   The BDP represents the amount of data which could be in transit across the link at  
   any given time. To fully utilize this link, we would need to have  
   2.567 𝐺𝑏, or about 320 𝑀𝐵, in transit at any given time.

6. Host A wants to send a 1,000 KB file to Host B. The Round Trip Time (RTT) of the Duplex Link between Host A and B is 160ms. Packet size is 1KB. A handshake between A and B is needed before data packets can start transferring which takes 2xRTT. Calculate the total required time of file transfer in the following cases. The transfer is considered complete when the acknowledgement for the final packet reaches A.

a. The bandwidth of the link is 4Mbps. Data packets can be continuously transferred  
on the link.  
The transmit time of each 1 𝐾𝐵 packet over the link is 1 𝐾𝐵 / 4 𝑀𝑏𝑝𝑠 = 2 𝑚𝑠. The total transmission time is equal to the sum of the handshake time, the propagation delay of the first data packet, the combined transmission time of all 1000 data packets, and the reverse propagation time of the final acknowledgement. The two propagation delays along with the transmission time of the first packet and last acknowledgement can be combined as a single 𝑅𝑇𝑇, thus the total time required  
for file transfer is 3 ⋅ 160 𝑚𝑠 + 999 ⋅ 2 𝑚𝑠 = 2.478 𝑠.

b. The bandwidth of the link is 4Mbps. After sending each packet, A need to wait one RTT before the next packet can be transferred. Again, the transmit time is 2 𝑚𝑠. In this case, where A waits one RTT before sending the next packet, each packet requires one RTT plus the 2 𝑚𝑠 transmit time. Thus, the total transmission time is the sum of the initial handshake time and the time for each of the 1000 packets sent.

The total time is then: 2 ⋅ 160 𝑚𝑠 + 1000 ⋅ 162 𝑚𝑠 = 162.32 𝑠.

c. Assume we have “unlimited” bandwidth on the link, meaning that we assume  
transmit time to be zero. After sending 50 packets, A need to wait one RTT before  
sending next group of 50 packets.

In this case, we only consider the initial handshake and the single RTT every 50  
packets. Since the transmit time is zero, the RTT of waiting after the first group of  
50 packets effectively begins right after the handshake is complete, overlapping  
with the forward propagation delay of the first bit sent. Further, the ack for the  
last packet will arrive at the end of the RTT wait on the last group of 50 packets.  
Thus, the total time is 2 ⋅ 160 𝑚𝑠 + 160 𝑚𝑠 = 3.520 𝑠.

d. The bandwidth of the link is 4Mbps. During the first transmission A can send one  
(21-1) packets, during the 2nd transmission A can send 22-1 packets, during the 3rd  
transmission A can send 23-1 packets, and so on. Assume A still need to wait for 1  
RTT between each transmission.

Note that 1000 < 29 + 28 + ⋯ + 2 + 1 = 1023, thus it will require a total of ten  
transmissions to complete the transfer. The transmit time for the 𝑘th transmission  
is 2 𝑚𝑠 ⋅ 2𝑘−1 = 2𝑘 𝑚𝑠. So, the total time for the 𝑘th transmission (excluding  
𝑘 = 10) is (2𝑘 + 160) 𝑚𝑠. The final transmission does not use the full 512  
available packets, instead only sending 1000 − 511 = 489 packets. Thus, the  
total time is  
𝑇 = 2 ⋅ 160 + (2 + 160) + (22 + 160) + ⋯ + (29 + 160) + (2 ⋅ 489 + 160) 𝑚𝑠 = 12 ⋅ 160 + 2 ⋅ 1000 𝑚𝑠 = 3.920 𝑠.  
7. (5pts) Determine the width of a bit on a 10 Gbps link. Assume a copper wire, where the  
speed of propagation is 2.3 ∗ 108 m/s.  
The width of a bit is 1 𝑏 10 𝐺𝑏𝑝𝑠 ⋅ 2.3 × 108 𝑚𝑠 = 2.3 × 108 𝑚𝑠  
10 × 109 1𝑠 = 2.3 × 10−2 𝑚 = 2.3 𝑐𝑚.

8. (12 pts) Suppose two hosts, A and B, are separated by 20,000 kilometers and they areconnected by a direct link of R=1Gbps. Suppose the propagation speed over the link is 2.5 x 108 meters/sec.

1. Calculate the bandwidth delay product (BDP) of the link.  
   The BDP is given as 𝑅 ⋅ 𝐷, where 𝐷 = 𝑀 𝑆⁄ is the propagation delay, 𝑀 =  
   20,000 𝑘𝑚 = 2 × 107 𝑚 is the length of the link, and 𝑆 = 2.5 × 108 𝑚𝑠 is the link  
   speed. That is, 𝐷 = 2×107 𝑚2.5×108𝑚 𝑠⁄ = 0.08 𝑠 = 80 𝑚𝑠. Thus, the one-way BDP is  
   𝑅 ⋅ 𝐷 = 1 𝐺𝑏𝑝𝑠 ⋅ 0.08 𝑠 = 80 𝑀𝑏s

If the two-way BDP is desired, it is 2 ⋅ 𝑅 ⋅ 𝐷 = 160 𝑀𝑏.

b. Consider sending a file of 800,000 bits from Host A to Host B as one large  
message. What is the maximum number of bits that will be in the link at any given time?

Since the (one-way) BDP is 80 𝑀𝑏, the entire message will fit in the link. Note  
that the transmit time of the message is 8×105 𝑏1×109 𝑏 𝑠⁄ = 8 × 10−4 𝑠 = 0.8 𝑚𝑠. Since 0.8 𝑚𝑠 < 𝐷 = 80 𝑚𝑠, the entire message will be transmitted before the first bit is received; that is, the entire 800,000 𝑏𝑖𝑡𝑠 will be in the link at the same time .

c.What is the width (in meters) of a bit in the link?  
The width of a bit is 𝑆𝑅 = 2.5×108 𝑚 𝑠⁄109 𝑏𝑖𝑡 𝑠⁄ = 0.25 𝑚𝑏𝑖𝑡.

d. Suppose now the file is broken up into 20 packets with each packet containing 40,000 bits. Suppose that each packet is acknowledged by the receiver and the transmission time of an acknowledgement packet is negligible. Finally, assume that the sender cannot send a packet until the preceding one is acknowledged.How long does it take to send the file?

Here, the transmit time for each packet is 4×104 𝑏1×109 𝑏 𝑠⁄ = 4 × 10−5 𝑠 = 40 𝜇𝑠.

Assuming negligible transmit time on the acknowledgement packet, the RTT is 2𝐷 + 40 𝜇𝑠 = 160.04 𝑚𝑠. Since the sender must wait for the preceding ack  
message to send the next packet, each sent packet requires one RTT. That is, the total time to send the file is 20 ⋅ 160.04 𝑚𝑠 = 3.2008 𝑠.

9. (9 pts) Suppose there is a 10 Mbps microwave link between a geostationary satellite and its base station on Earth. Every minute the satellite takes a digital photo and sends it to the base station. Assume a propagation speed of 2.4 x 108 meters/sec. Geostationary satellite is 36,000 kilometers away from earth surface

a. What is the propagation delay of the link?  
The propagation delay is 3.6×107 𝑚2.4×108 𝑚 𝑠⁄ = 0.15 𝑠 = 150 𝑚𝑠.

b. What is the bandwidth-delay product, R x (propagation delay)?  
The BPD is 10 𝑀𝑏𝑝𝑠 ⋅ 0.15 𝑠 = 1.5 𝑀𝑏.

c. Let x denote the size of the photo. What is the minimum value of x for the  
microwave link to be continuously transmitting?  
Since a photo is sent once per minute and the link bandwidth is 10 𝑀𝑏𝑝𝑠, the size of the photo must be 𝑥 ≥ 10 𝑀𝑏𝑝𝑠 ⋅ 60 𝑠𝑚𝑖𝑛 ⋅ 1 𝑚𝑖𝑛 = 600 𝑀𝑏 = 75 𝑀𝐵.

10. (6pts) Explain collision domain and broadcast domain with respect to a hub, switch, and a router.

The collision domain is all hosts whose messages have the possibility of colliding in the shared medium. The broadcast domain is the set of all hosts whose broadcast traffic will reach other hosts in that set.  
*Hub*: For hubs, the collision and broadcast domains are both all hosts connected to the  
link, making hubs not ideal for network organization. Hubs do not segment the broadcast  
domain or collision domain, so all hosts will receive all messages sent in the medium  
(usually discarding those not addressed to them).  
*Switch*: Switches allow for the collision domain to be segmented by ports, that is, non-  
broadcast traffic sent from a host connected to port A of the switch to another host  
connected to port B will only have the possibility of colliding with other traffic from  
hosts connected to port A or port B, assuming the forwarding table in the switch has  
accurate entries for both hosts. However, broadcast traffic (as well as traffic from hosts  
not present in the address table) will still reach all of the hosts connected to the switch,  
regardless of what port they are connected to; that is, switches do not usually segment the  
broadcast domain. Switches can sometimes segment broadcast domains through the use  
of VLANs, though.  
*Router*: Routers serve to interconnect separate networks. Like switches, routers segment  
the collision domain. Unlike switches, routers also segment the broadcast domain;  
broadcast messages will not leave the network from which they originate

4. Consider the GBN protocol with a sender window size of N=4 and a sequence  
number range of 1,024. Suppose that at time t, the next in-order packet that the receiver  
is expecting has a sequence number of k. Assume that the medium does not reorder  
messages. Answer the following questions:

(a) What are the possible sets of sequence numbers inside the sender’s window at time t?  
Justify your answer. (2 pts)  
All sequence numbers are modulo 210. If the next in-order packet expected has  
sequence number 𝑘, then the receiver has received and sent acknowledgement for 𝑘 −  
4, 𝑘 − 3, 𝑘 − 2, and 𝑘 − 1. Suppose all these ACKs have been received by the  
sender. Then, the sender’s LAR is 𝑘 − 1 and the sequence numbers inside the  
sender’s window are [𝑘, 𝑘 + 3]. On the other hand, if none of the ACKs have been  
received, the sender’s LAR is 𝑘 − 5, leading to a window of sequence values  
[𝑘 − 4, 𝑘 − 1]. Since these are the two extreme cases, the sender’s window could be  
any 4 consecutive sequence numbers in [𝑘 − 4, 𝑘 + 3].

(b) What are all possible values of the ACK field in all possible messages currently  
propagating back to the sender at time t? Justify your answer. (2 pts)  
All sequence numbers are modulo 210. Since the receiver is expecting sequence  
number 𝑘, it must have received sequence number 𝑘 − 1. For sequence number 𝑘 − 1  
to be sent, the sender must have received an ACK for 𝑘 − 5. Since the medium does  
not reorder packets, all ACKs currently in transit must have been sent after the first  
ACK with 𝑘 − 5 was sent. Depending on implementation, however, there may have  
been more than one ACK with sequence number 𝑘 − 5 sent.  
Suppose that at 𝑡0 < 𝑡, the sender sends seq 𝑘 − 8, ... , 𝑘 − 5. At 𝑡1, with 𝑡0 < 𝑡1 < 𝑡,  
the receiver sends ACKs for 𝑘 − 8, ... , 𝑘 − 5. Suppose the sender reaches a timeout  
before receiving the ACKs, causing the packets for 𝑘 − 8, ... , 𝑘 − 5 to be resent.  
Right after, the sender receives the delayed ACKs sent at 𝑡1, causing the sender to  
update its window and send packets 𝑘 − 4, ... , 𝑘 − 1. Since packets are not reordered,  
the receiver will first get the duplicate packets 𝑘 − 8, ... , 𝑘 − 5, most likely sending a  
cumulative ACK for 𝑘 − 5. Then, it receives packets 𝑘 − 4, ... , 𝑘 − 1, updating its  
expected sequence number to 𝑘 and sending an ACK for each of 𝑘 − 4, ... , 𝑘 − 1. If  
time 𝑡 is before the cumulative ACK for 𝑘 − 5 is received by the sender, then ACKs  
for [𝑘 − 5, 𝑘 − 1] will all be propagating back to the sender simultaneously.

11. (5pts) Consider the following networked computers connected by Bridge X and Y. Bridge  
X has interface 1,2 and 3. Bridge Y has interface 1 and 2. Assume at the beginning the  
address tables of Bridge X and Y are all empty. Write down the address tables of Bridge  
X and Y after the following communication finished (Assume that the receiver does not  
respond to the packet sent by the sender.).  
1. A send a packet to C  
2. B send a packet to D  
3. C send a packet to E  
4. E send a packet to A  
5. D send a packet to A

A diagram of a bridge

Description automatically generated

Bridge X Address Interface Bridge Y Address Interface   
A 1 A 1  
B 1 B 1  
C 2 C 1  
E 3 E 2  
D 3 D. 1

12. (5pts) Given the extended LAN shown in Figure 2, indicate which ports are not selected by the spanning tree algorithm. Note that the bridge with the smallest ID becomes a root. See each step of the distributed MST algorithm shown below. In the final MST, the retained paths are shown in green, while the removed paths are crossed out with a red X. Note that in general, only one side of a link is removed, as the other side is required to maintain a path to downstream hosts.

A diagram of a network

Description automatically generated

A diagram of steps and steps

Description automatically generated