1. In class, we saw that “pipelined” protocols, also known as “sliding window” protocols, are a type of ARQ (Automatic Repeat Request) protocols that use a “window” to control the amount of data they inject into the network.

(a) What is the window size in stop-and-wait ARQ? How many unique sequence numbers does Stop-and-Wait need? How many bits are needed to represent Stop-and-Wait’s unique sequence numbers? Explain.

(b) What is the main advantage of requiring a smaller number of bits to represent the range of unique sequence numbers employed by a protocol?

(c) For a 100Mbits/sec channel with 100ms propagation delay, what is the channel utilization when sending 2KByte frames if Stop-and-Wait is used?

(d) How can you increase channel utilization 10-fold?

(e) Describe the additional complexity of your solution compared to Stop-and-Wait.

2. Suppose that a sender and a receiver are using ARQ to perform reliable data delivery.

(a) In a Go-Back-N ARQ protocol, the window size is 6. Frames with sequence numbers 1, 2, 3, 4 and 5 have been sent. The sender just received an ACK for frame 1. Frames 6, 7, 8, 9 and 10 are waiting to be sent. Draw the time diagram showing this scenario.

(b) Which frame(s) can the sender send before it must wait for the next ACK from the receiver? Explain.

(c) Some time later, the sender transmitted frames 20, 21, 22, 23, 24, and 26; however, frame 22 got lost. If Go-Back-N is used, what frame(s) would the sender have to retransmit? Explain.

(d) Suppose the same situation as above but sender and receiver use Selective-Repeat ARQ. What frame(s) would the sender need to retransmit? Explain.

(e) Can Selective-Repeat ARQ use cumulative ACKs? Explain.

(f) What are the trade-offs between Go-Back-N ARQ and Selective-Repeat ARQ?

3. Link-state routing requires routing updates to be flooded to all participating routers. Besides the actual routing update, a link-state packet carries the node id, a sequence number, and a time-to-live. Why do you think this extra information (overhead) is necessary?

4. Why are datagrams said to be “self-contained”? 
5. Given the following hierarchies on the same topology, compare (quantitatively):

(a) Path lengths.
(b) Routing table sizes.

**Area Hierarchy**

```
          A(2.1)
          |\    
          | \   
          |  \  
          B(2.2)
          / \  
         /  \ 
        /    \ 
       F----E  C(3.1)
      (1.1) (1.2)  \  
         \   \   
          \   D(3.2)
```

**Landmark Hierarchy (r0 = 1, r1 = 2)**

```
          A(E.A)
          |\    
          | \   
          |  \  
          B(B.B)
          / \  
         /  \ 
        /    \ 
       F----E  C(B.C)
      (E.F) (E.E)  \  
         \    \   
          \   D(B.D)
```
6. For the adjacency matrix below, use link-state routing to find the shortest-path between nodes 1 and 9. Show each step of the algorithm using the topology graph. Assume nodes already have the latest topology snapshot which is given by the adjacency matrix below.

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