This is a closed book (and notes) examination. Answer all questions on the exam itself. Take the number of points assigned to each problem and the amount of space provided for your answer as a measure of the length and difficulty of the expected solution. The exam totals 100 points.

_Potentially_ useful formulas:

- Nyquist rule for a noiseless channel:
  \[
  \text{max data rate} = 2H \log_2 V \text{ bps where } H \text{ is the bandwidth and } V \text{ is the number of states encoded.}
  \]

- Shannon’s theorem for channels with noise:
  \[
  \text{max data rate} = H \log_2(1 + S/N) \text{ where noise is measured in decibels (db) and}
  \text{db} = 10 \log_{10} S/N
  \]
1. (18 points) This entire question (parts a-d) refer to the network of routers shown in the following figure.

(a) (5 points) Compute and show the sink tree for router E in the space given in the figure. The numbers shown for each link indicate the delay (bidirectional) for that line.

(b) (3 points) If router E receives a packet sent from packet A destined for router F, what does router E do with this packet?
(c) (5 points) Assume that the link between routers $G$ and $H$ is cut resulting in an infinite delay on the line between these routers. Using a link-state routing algorithm, how does router $E$ find out about this change and how does it update its routing tables accordingly?

(d) (5 points) Assume that the link between routers $G$ and $H$ is cut resulting in an infinite delay on the line between these routers. Using a distance-vector routing algorithm, how does router $E$ find out about this change and how does it update its routing tables accordingly?

2. (8 points) What is backward learning as it applies to network routing? What are its advantages and disadvantages? Give an example where it is used.
3. (12 points) Fragmentation of packets.
   
   (a) Why does the Internet Protocol (IP) have fields pertaining to fragmentation in its header?

   (b) What are these fields and how are they used?

   (c) Which entities (sending host, sending gateway, intermediate routers, receiving gateway, receiving host) in the network can fragment IP packets?

   (d) Which entities (sending host, sending gateway, intermediate routers, receiving gateway, receiving host) in the network can reassemble IP packets?

   (e) What if a fragment is lost? What is retransmitted and by which entity?
4. (8 points) Draw a protocol stack diagram showing the relationships of the following eight protocols: TCP, UDP, IP, ICMP, HTTP, FTP, DNS, ARP.

Indicate which of these protocols are used in each of the following network actions:

(a) Executing the command ping.

(b) Sending a segment in the TCP protocol.

(c) Mapping a host name to its Internet address.

(d) Sending a request to a Web server.

5. (10 points) TCP uses a sliding window protocol in providing reliable, in-order delivery of data. We previously discussed sliding window protocols for providing reliable, in-order delivery in the Data Link Layer. How does the sliding window protocol in TCP work and how is it different or the same as the sliding window protocols we discussed in the Data Link Layer?
6. (8 points) Routing protocols.

(a) Explain the difference between an exterior and interior gateway routing protocol.

(b) Name and briefly explain the primary exterior gateway protocol in current use on the Internet.

(c) Name and briefly explain the primary interior gateway protocol in current use on the Internet.

7. (8 points) Slow start is a mechanism used as part of the TCP mechanism. What is it and why is it used?
8. (13 points) Binary exponential backoff.

(a) Briefly explain how binary exponential backoff works in the CSMA/CD Ethernet protocol.

(b) Suppose two stations are using CSMA/CD with a modified version of the binary exponential backoff algorithm. In the modified algorithm, each station will always wait 0 or 1 time slots regardless of how many collisions have occurred. Assume two stations have just sent transmissions that have collided.

(c) What is the probability that contention ends on the first round of retransmissions?

(d) What is the probability that contention ends on the second round of retransmissions?

(e) What is the probability that contention ends on the third round of retransmissions?

(f) In general how does this algorithm compare with the normal binary exponential backoff algorithm in terms of performance under different types of load?
9. (8 points) Congestion control.

(a) Techniques can be used to avoid or control congestion in the network. Name and briefly describe a technique for avoiding or controlling congestion.

(b) Other techniques can be used to handle congestion in the network once it does occur. Name and briefly describe a technique for handling congestion if it does occur.

(c) Name a technique that is used to control or handle congestion on the Internet today.

10. (7 points) The Data Link Layer in today’s Internet does not ensure the IP packets are delivered reliably or in-order and consequently transport protocols, such as TCP, which guarantee these semantics, must implement their own mechanisms for reliability. Assume that the underlying network was changed so that all packets were delivered reliably on each of the Data Link Layer links in the Internet. How could or would a reliable transport protocol, such as TCP, change if it was built on a Data Link Layer known to be reliable?