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:
  max data rate = \( 2H \log_2 V \) bps where \( H \) is the bandwidth and \( V \) is the number of states encoded.

- Shannon’s theorem for channels with noise:
  max data rate = \( H \log_2(1 + S/N) \) where noise is measured in decibels (db) and \( \text{db} = 10 \log_{10} S/N \)
1. (23 points) This entire question (parts a-e) refer to the network of routers shown in the following figure.

(a) (5 points) Compute and show the sink tree for router A 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 H receives a packet sent from router A destined for router I, what does router E do with this packet?
(c) (5 points) A packet is sent by router A and received by router D. If flooding is being used to route packets then which router(s) is the packet sent to by router D? Give the algorithm a router uses when it processes an arriving packet.

(d) (5 points) A packet is sent by router A and received by router D. If reverse path forwarding is being used to route packets then which router(s) is the packet sent to by router D? Give the algorithm a router uses when it processes an arriving packet.

(e) (5 points) Assume that the set of routers are divided into two sets by drawing an imaginary line down the center of the figure. Routers A, B, C and G are in the left set and routers C, E, F, H and I are in the right set. The two sets use hierarchical routing with routers B and E at the top of the hierarchy in each set. All traffic between routers in different sets must must pass on the link between routers B and E and not on any other links between the two sets. What is an advantage of this routing approach for the routers? What is a disadvantage of this routing approach for the routers?
2. (10 points) Consider a public key encryption system in which each user K has a private key and a public key. Let $K_{pub}$ denote encryption using K’s public key and $K_{priv}$ denote encryption using K’s private key where:

$$Message = K_{priv}(K_{pub}(Message)) = K_{pub}(K_{priv}(Message))$$

(a) What is the difference between a secure and an authenticated message exchange?

(b) To send a secure and authenticated message to B, what steps would user A perform on message $M$ prior to sending it to $B$?

(c) When receiving a secure and authenticated message $M$ from $A$, what operations would user $B$ perform on $M$ to extract the message contents?

3. (8 points) Why does the Internet Protocol (IP) have a time-to-live field? How is this field typically used? How is this field specifically used by the traceroute command?
4. (8 points) Assume machines machine A wants to transfer a large file to machine B using either UDP or TCP and regardless of which transport protocol is used, all IP packets sent by A are reliably delivered to B without any being lost.

(a) Assuming A and B are on the same local area network, will there be any difference in performance between using TCP or UDP as the transport protocol? Explain.

(b) Assuming A and B are at different sites on the Internet, will there be any difference in performance between using TCP or UDP as the transport protocol? Explain.

5. (8 points) The Domain Name System (DNS) is used to map host names to IP addresses. In the simplest case, each unique host name maps to a unique IP address.

(a) Is it possible for a unique host name to map to multiple IP addresses? If so then give an example where such a technique is used.

(b) Is it possible for multiple host names to map to the same IP address? If so then give an example where such a technique is used.
6. (9 points) IP address space.
   (a) How many bits is a machine address in the current Internet protocol?

   (b) These bits are divided into two parts within an address. What are these parts?

   (c) What is subnetting?

   (d) What is classless interdomain routing (CIDR)?

7. (14 points) TCP flow and congestion control.
   (a) What mechanism is used by TCP to handle flow control? Is this mechanism defined as part of the TCP standard (must all TCP implementations use this same mechanism)?

   (b) What mechanism is used by TCP to handle congestion control? Is this mechanism defined as part of the TCP standard (must all TCP implementations use this same mechanism)?
8. (10 points) This question refers to the following figure showing five Ethernet networks (LAN A-E) connected to a backbone Ethernet network.

Assume that each of the bridges shown are spanning tree bridges that initially have no knowledge about hosts on the network. Indicate on which of the network(s) the following frames will be transmitted. The frames are sent in the order shown with the source and destination corresponding to hosts in the figure.

(a) Src Host: 3, Dest Host: 7

(b) Src Host: 7, Dest Host: 3

(c) Src Host: 6, Dest Host: 7

(d) Src Host: 1, Dest Host: 3

(e) Src Host: 8, Dest Host: 1
9. (10 points) For some network applications (such as transmitting an MPEG video), all packets are not equally important. Now consider developing a modified version of TCP called mixed TCP where the sending application classifies each TCP segment as RELIABLE or BEST-EFFORT. For example, consider the following sequence of segments being sent:

<table>
<thead>
<tr>
<th>Segment</th>
<th>Byte Range</th>
<th>Classification</th>
</tr>
</thead>
<tbody>
<tr>
<td>S0</td>
<td>0–99</td>
<td>RELIABLE</td>
</tr>
<tr>
<td>S1</td>
<td>100–299</td>
<td>BEST-EFFORT</td>
</tr>
<tr>
<td>S2</td>
<td>300–349</td>
<td>BEST-EFFORT</td>
</tr>
<tr>
<td>S3</td>
<td>350–499</td>
<td>RELIABLE</td>
</tr>
<tr>
<td>S4</td>
<td>500–599</td>
<td>BEST-EFFORT</td>
</tr>
<tr>
<td>S5</td>
<td>600–649</td>
<td>RELIABLE</td>
</tr>
</tbody>
</table>

The mixed TCP protocol must deliver all RELIABLE segments (in this case S0, S3 and S5) to the recipient application. It also delivers all BEST-EFFORT segments to the recipient application if they are available, but it does not guarantee they will be delivered nor does it take steps to increase the reliability of their delivery. The mixed TCP protocol must not deliver any segments out of order to the recipient application, but it can leave “gaps” if a BEST-EFFORT segment is not received or is received too late.

Describe any necessary changes to the TCP header, the sender TCP implementation or the receiver TCP implementation to implement the mixed TCP protocol. You may assume that the first and last segment are always marked as RELIABLE.