1. **General Networking (both sides of sheet) – 6 points**
   This question has **TWO** parts. Answer each of these parts with **TWENTY-FIVE** words or less.
   
   a. Although connect() is typically associated with TCP sockets, explain the effect of using connect() on a UDP socket?
      
      It forces the server to receive data only from one client.
   
   b. In traditional client-server communication using TCP, a new socket is created. Explain why. How would it hurt performance if only one socket is used?
      
      The server would not be able to accept incoming connections from other clients.

2. **Physical Layer (both sides of sheet) – 9 points**
   This question has **THREE** parts. Answer each of these parts with **TWENTY-FIVE** words or less.
   
   a. A wireless Node A can successfully receive a message from another Node B, but not from Node C. However, transmissions from both Nodes B and C interfere with transmissions from Node A. Explain the property of wireless signals that causes this situation.
      
      Node A and Node B are in transmission range and the signal can be decoded. Node A and Node C are in carrier sensing/interference range and the signal is too weak to be decoded.
   
   b. Explain the impact of attenuation and noise on a communication signal.
      
      The signal to noise ratio must be above a threshold for a signal to be received correctly. Attenuation reduces the strength of the signal and reduces the signal to noise ratio and more noise reduces the signal to noise ratio.
   
   c. Describe the benefits of error correction over error detection.
      
      Offers a quicker recovery, at the cost of more overhead
      
      Detection
      
      Pro: Overhead only on messages with errors
      
      Con: Cost in bandwidth and latency for retransmissions
      
      Correction
      
      Pro: Quick recovery
      
      Con: Overhead on all messages

3. **Encoding and Framing (both sides of sheet) – 6 points**
   This question has **TWO** parts. Answer each of these parts with **TWENTY-FIVE** words or less.
   
   a. What properties of NRZI encoding make it a good choice for pairing with 4B/5B encoding?
      
      Because NRZI guarantees no long sequences of 0s and NRZI guarantees no long sequences of 1s.
b. Why is byte stuffing necessary with some sentinel-based framing schemes? Is a byte of all zeros a good choice for a sentinel? Justify your answer.

The sentinel may occur in the data.
Zero is very common in data.
Would have to stuff a lot (excessive overhead).

4. Error Control (both sides of sheet) – 9 points
This question has TWO parts. Answer each of these parts with TWENTY-FIVE words or less.

a. Under what circumstances will error detection using CRC fail?

When the error pattern is an exact multiple of the CRC generator sequence

b. How many errors can an n-bit Hamming distance detect? correct?

detect: \( n - 1 \)
correct: \( \left\lfloor \frac{n-1}{2} \right\rfloor \)

5. Medium Access (both sides of sheet) – 9 points
This question has FOUR parts. Answer each of these parts with TWENTY-FIVE words or less.

a. Explain what would happen if node in IEEE 802.11 did not suspend its collision counter when it detects that the medium is busy.

All the nodes with expired timers will try to transmit as soon as the channel is IDLE, causing more collisions

b. How does a sender detect a collision for the following schemes:
   i. Ethernet

   Transceiver sees sum of voltages (Outgoing signal + Incoming signal)
   Transceiver looks for voltages impossible for only outgoing signal.

   ii. IEEE 802.11

   No CTS/ACK is returned.

c. Ethernet frames must be at least 64-bytes long to ensure that the transmitter is still going in the event of a collision at the far end of the cable. Fast Ethernet has the same 64-byte minimum frame size but can get the bits out ten times faster. How is it possible to maintain the same frame size?

   The maximum wire length in fast Ethernet is 1/10 as long as in Ethernet.

d. Why is it ineffective to use and ACK for broadcast and multicast communication in wireless networks?

   ACK implosion problem, too many ACKs for the same packet.

6. Packet Switching (both sides of sheet) – 9 points
This question has THREE parts. Answer each of these parts with TWENTY-FIVE words or less.
a. In the Perlman distributed spanning tree algorithm, why does the root bridge periodically send messages even after the tree is determined?

   As a heartbeat to verify the tree and make sure none of the links or bridges on the tree have failed.

b. Distance vector routing protocols can be enhanced to detect loops using techniques like split horizon and poisoned reverse. Explain what types of loops are detected and what types are not.

   Only loops of length two or less are detected. All others go undetected.

c. Explain two drawbacks of datagram-based forwarding.

   Each packet must contain full destination address,
   Router must maintain global state,
   Large amount of forwarding information
7. Spanning Tree Algorithm for Intelligent Bridges – 13 points
Suppose the Perlman spanning tree algorithm and the bridge learning algorithm for forwarding are used for the network shown below.

a) (7 points) Fill in the tables below indicating the root port for each bridge (as a LAN) and the designated bridge for each LAN.

<table>
<thead>
<tr>
<th>Bridge</th>
<th>Root port LAN</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td></td>
</tr>
<tr>
<td>2</td>
<td>E</td>
</tr>
<tr>
<td>3</td>
<td>F</td>
</tr>
<tr>
<td>4</td>
<td>D</td>
</tr>
<tr>
<td>5</td>
<td>D</td>
</tr>
<tr>
<td>6</td>
<td>H</td>
</tr>
<tr>
<td>7</td>
<td>E</td>
</tr>
<tr>
<td>8</td>
<td>E</td>
</tr>
<tr>
<td>9</td>
<td>H</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>LAN</th>
<th>Designated Bridge</th>
</tr>
</thead>
<tbody>
<tr>
<td>A</td>
<td>4</td>
</tr>
<tr>
<td>B</td>
<td>5</td>
</tr>
<tr>
<td>C</td>
<td>6</td>
</tr>
<tr>
<td>D</td>
<td>8</td>
</tr>
<tr>
<td>E</td>
<td>1</td>
</tr>
<tr>
<td>F</td>
<td>2</td>
</tr>
<tr>
<td>G</td>
<td>9</td>
</tr>
<tr>
<td>H</td>
<td>1</td>
</tr>
</tbody>
</table>
a) (3 points) After the spanning tree has converged:
   i) (1 point) Which bridge transmits configuration messages onto LAN D?
     8
   ii) (1 point) Which bridge(s) listen for such messages?
     3, 4, 5, 8
   iii) (1 point) Which bridge(s) forward such messages?
     4, 5

b) (3 points) Suppose after the configuration is complete, host Mars attaches to LAN B, host Venus attaches to LAN H and host Jupiter attaches to LAN F. Suppose Mars sends a message to Venus, then Jupiter sends a message to Mars, then Venus sends a message to Jupiter.
   i) (1 point) Mars sends a message to Venus
     All
   ii) (1 point) Jupiter sends a message to Mars
     B, D, E, F
   iii) (1 point) Venus sends a message to Jupiter
     C, E, F, G, H

8. Forwarding Tables

Consider the network shown in the figure below. The links are labeled with relative costs. The three parts of this problem deal with circuit-switched forwarding, datagram forwarding and source-routed forwarding, respectively.

![Network Diagram]

a) (3 points) Fill in the following table for the datagram routing table at switch S2, assuming least-cost paths are used.

<table>
<thead>
<tr>
<th>Switch 2:</th>
<th>Host</th>
<th>Output Port</th>
<th>Distance</th>
</tr>
</thead>
<tbody>
<tr>
<td>A</td>
<td>3</td>
<td>2</td>
<td></td>
</tr>
<tr>
<td>B</td>
<td>1</td>
<td>0</td>
<td></td>
</tr>
<tr>
<td>C</td>
<td>3</td>
<td>2</td>
<td></td>
</tr>
<tr>
<td>D</td>
<td>3</td>
<td>1</td>
<td></td>
</tr>
</tbody>
</table>
b) Now assume the use of source routing for the network. For each of the following packets, indicate the sequence of absolute port identifiers (from left to right) that must be included in the header to route the packet along the least-cost path.

i) (1 point) from B to E.

3.2,1,2,2

ii) (1 point) from F to A.

3.0,0,0

c) Suppose virtual circuit forwarding is used for the network shown above with the routing tables shown below. When setting up a new virtual circuit on a given output port, a switch assigns the smallest unused virtual circuit identifier for that port.

Indicate the changes to the routing tables after the following three (cumulative) events:

i) (2 points) Tear down the entire virtual circuit starting at switch 1 with incoming port 0 and incoming VCI 0. Cross out all appropriate entries in all switches in the tables above.

ii) (3 points) Add a new circuit from host B to host F using a least cost path. Fill in the above tables with any new entries (use row for Part ii where necessary).

iii) (3 points) Add a new circuit from host A to host E using a least cost path. Fill in the above tables with any new entries (use row for Part iii where necessary).
9. Medium Access Control – 13 points

Consider the problem of medium access control using carrier sense multiple access with collision detection (CSMA/CD, the algorithm used with Ethernet) for the network shown below. There is exactly 15km between neighboring stations. Assume that signals travel directly from any sender to all receivers, propagating at the speed of light in a fiber: $3 \times 10^8$ m/sec.

(a) (4 points) If a transmitter sends at 20 Mbps, how long must packets be to guarantee collision detection by the transmitter?

Longest link = 4*15 = 60 km, so maximum one-way delay is:

$(60 \times 10^3 \text{m}) / (3 \times 10^8 \text{ m/s}) = 20 \times 10^{-5} \text{ sec}
= 200 \mu \text{sec}$

Therefore, maximum RTT is 400 µsec. So at a rate of 20 Mbps, we get:

$(20 \times 10^6 \text{ bps}) \times 400 \mu \text{sec} = 8000 \text{ bits}$

= 1000 bytes

(b) Divide time into slots the length of the maximum round-trip propagation delay in the network. One packet may be transmitted each time slot. Assume that each of the hosts attempts to transmit with probability $p$ in each time slot. What is the probability of a successful transmission in any given slot if

iv) (2 points) $p = 1/2$?

$5 \times (1/2) \times (1 - 1/2)^4 = 5 / 32$

v) (2 points) $p = 2/3$?

$5 \times (2/3) \times (1 - 2/3)^4 = 10 / 243$
(c) **(5 points)** A packet transmission may require more than one slot to complete. Assume that other hosts sense the continuation of the transmission (carrier sense) and simply discard any packets that arrive during those slots. Calculate the average throughput for the network. (Hint: use cycle analysis)

\[
\begin{align*}
[1200 \text{ B} / 1000 \text{ B}] &= 2 \text{ slots to transmit} \\
C: \text{ competition, F: finish transmit} \\
\text{Success} &= CF \text{ with no collisions}
\end{align*}
\]

<table>
<thead>
<tr>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>C-&gt;C</td>
<td>27/32</td>
<td>C failure</td>
<td>1</td>
<td>0</td>
<td>27/32</td>
</tr>
<tr>
<td>C-&gt;F</td>
<td>5/32</td>
<td>CF success</td>
<td>2</td>
<td>1</td>
<td>5/32*1</td>
</tr>
<tr>
<td>F-&gt;C</td>
<td>1</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

average length of cycle = 1 \times 27/32 + 2 \times 5/32 slots = 37/32 slots
average messages sent per cycle = 0 \times 27/32 + 1 \times 5/32
average messages sent per slot = (5/32) / (37/32) = 5/37
average throughput per slot is 1000 \text{ B} x 5/37 = 5000/37 \text{ B} = 40000/37 \text{ bit}
average throughput = 40000/37/\text{slot time} = 40000/37 / (400 \mu\text{sec}) = 2.7 \text{ Mbps}
10. Workstations as Switches

You are entrusted with the purchase of a workstation to serve as a switch between two high-speed local area networks (LAN's). One of the networks is a RingMaster, a 2 Gbps LAN with 100 bytes of total overhead (headers and trailers) required for each frame. The other network is a GigaNet, a 1 Gbps LAN with 150 bytes of overhead required for each frame.

Assume that all packets must be switched. Further assume that all packets sent on either network have exactly 1,500 bytes of data, which in this case includes TCP and IP headers, but not RingMaster or GigaNet headers/trailers.

After some research, you narrow the options to the two architectures described in the table below.

<table>
<thead>
<tr>
<th>Name</th>
<th>Orbus</th>
<th>PDQ</th>
</tr>
</thead>
<tbody>
<tr>
<td>CPU handles</td>
<td>60,000 packets/second</td>
<td>90,000 packets/second</td>
</tr>
<tr>
<td>Number of I/O buses</td>
<td>4</td>
<td>1</td>
</tr>
<tr>
<td>I/O bus bandwidth</td>
<td>600 Mbps</td>
<td>1.2 Gbps</td>
</tr>
<tr>
<td>Memory bus bandwidth</td>
<td>2.4 Gbps</td>
<td>1 Gbps</td>
</tr>
<tr>
<td>Price</td>
<td>$15,000</td>
<td>$4,000</td>
</tr>
</tbody>
</table>

a) (5 points) Pick one. Justify your decision, showing all work.

<table>
<thead>
<tr>
<th>Name</th>
<th>Orbus</th>
<th>PDQ</th>
</tr>
</thead>
<tbody>
<tr>
<td>CPU Bottleneck</td>
<td>60,000 x 1500 x 8 = 720 Mbps</td>
<td>90,000 x 1500 x 8 = 1.08 Gbps</td>
</tr>
<tr>
<td>I/O Bottleneck</td>
<td>600 Mbps x 2 / 2 = 600 Mbps</td>
<td>1.2 Gbps / 2 = 600 Mbps</td>
</tr>
<tr>
<td>Memory Bottleneck</td>
<td>2.4 Gbps / 2 = 1.2 Gbps</td>
<td>1 Gbps / 2 = 500 Mbps</td>
</tr>
<tr>
<td>Overall Bottleneck</td>
<td>600 Mbps</td>
<td>500 Mbps</td>
</tr>
</tbody>
</table>

I pick PDQ. Although it has slightly lower capacity, it has a much better price per Mbps.
b) (3 points) Draw a block diagram of the workstation architecture that you have chosen in part (a), labeling all components with appropriate names and data rates.

![Block Diagram](image)

- **Processor**
- **Memory**

**Memory Bus 1 Gbps**

- **RingMaster Network Adaptor**

**I/O Bus 1.2 Gbps**

- **GigaNet Network Adaptor**

---

c) (5 points) At the maximum sustainable bandwidth (i.e., with no packets dropped), what is the transmission rate - the total number of bits per second, including headers and trailers - sent over each network link (the RingMaster and the GigaNet)?

- RingMaster = \(500 \text{ Mbps} \times \frac{1600}{1500} = 533.33 \text{ Mbps}\)
- GigaNet = \(500 \text{ Mbps} \times \frac{1650}{1500} = 550 \text{ Mbps}\)