1. **General Networking**

a. 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 on the same port.

b. Why is determining and handling byte order left up to the programmer and not handled by the operating system? Give an example of what could go wrong.
   The system doesn’t have access to knowledge about the user’s data

c. Suppose packets on a wireless link consist of $N$ data bits and $H$ header bits each, where $H$ is fixed. Suppose bits are received in error with probability $P$, independently of each other, and that $N$ is adjusted to maximize the throughput of data in bits per second. If $P$ gets smaller, does the optimal value of $N$ get larger or smaller? Why?
   As $P \to 0$, $N \to \infty$ monotonically, so $N$ gets larger. Intuitively, overhead is more important than loss for smaller $P$.

2. **Physical Layer, Framing and Encoding**

a. What is the relationship between bit rate and baud rate?
   Bitrate = baudrate * number of bits per symbol

b. Explain how a receiver detects the end of a frame with length-based framing. Explain what will happen if the length indicator gets corrupted.
   The length is indicated in the header of the frame. The sender and receiver will lose all synchronization.

c. The data rate of a QAM system using M-ary symbols does not change if the bandwidth is increased while M and the baud rate are held constant. What, if anything, is the benefit of using more bandwidth?
   Fewer bit errors, less erasures, less misinterpreted symbols, cleaner/clearer symbols, less dispersion
   Tolerates more noise, tolerates lower s/n (i.e., since we now have fewer errors, we can introduce errors and maintain the same error rate as the original system)

d. What properties of NRZI encoding make it a good choice for pairing with 4B/5B encoding? Explain why.
   Because NRZI guarantees no long sequences of 0s and NRZI guarantees no long sequences of 1s.

3. **Error Control (both sides of sheet)**
a. How does the Internet checksum detect an error? What could cause the checksum algorithm to fail to detect an error?
   It adds up all of the bytes and transmits the sum. And set of bytes that adds up to the same sum will be considered correct.

b. Given a code with Hamming distance n,
   i. how many errors can be detected in the presence of three erasures?
      \( n - 4 \)
   ii. how many errors can be corrected in the presence of three erasures?
      \( \lfloor (n-4)/2 \rfloor \) or \( \lceil (n-5)/2 \rceil \)

c. Consider a frame consisting of three characters of four bits each. Assume that the probability of error is \( 10^{-4} \), independent for each bit. What is the probability that the frame is received correctly? How might adding a parity bit to each character improve the framing scheme?
   \( (1 - 10^{-4})^{12} \)
   If you add parity chances of bit errors increase, but chances of undetected errors decrease.

4. Medium Access
   a. Give two reasons why a CSMA/CD-type protocol cannot be used in a wireless environment.
      Wireless devices are not full duplex, so they can’t check the channel state and transmit at the same time. Additionally, due the non-symmetric nature of the medium, it is not guaranteed that a collision can be detected at both ends.

   b. During backoff, Ethernet used fixed time slots. How long are these timeslots? What could go wrong if the fixed slots were not used?

   c. Consider a 5-hop wireless network with one sender at one end and one receiver at the other end. Give two reasons why the sender cannot utilize the full link bandwidth on all links at the same time.

   d. Why does Ethernet have a minimum packet size? How is it determined?
      To ensure that all nodes can detect a collision. It is based on the maximum distance between two nodes.

5. Packet Switching
   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. Explain two drawbacks of datagram-based forwarding.
      Each packet must contain full destination address,
Router must maintain global state,
Large amount of forwarding information
6. 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.

![Network Diagram]

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?
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. Immediately after the spanning tree configuration is complete, the three hosts send consecutive messages (i.e. assume that each message crosses all necessary LAN’s before the next message is sent). Answer the following for the following sequence: Mars sends a message to Venus, Jupiter sends a message to Mars, 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
7. Error Detection with Cyclic Redundancy Checks – 13 points

Use the CRC generator polynomial \( C(x) = x^4 + x^3 + x + 1 \) (i.e., check sequence 11011) for all parts of this problem.

a) (4 points) What is the shortest pattern of error bits (equivalently, the polynomial of smallest degree) that can go undetected with \( C(x) \)?

\[ 11011, \text{ which is } C(x), \text{ since all undetected burst errors must be a multiple of } C(x). \]

b) (5 points) What is the shortest two-bit error that can go undetected with \( C(x) \)?

Find the first multiple of \( C(x) \) that begins and ends with 1's, and contains only 0's between the 1's.

\[
\begin{array}{c}
11011 \\
11011 \\
------- \\
101101 \\
11011 \\
------- \\
1000001 = x^6 + 1
\end{array}
\]

c) (4 points) Can a five-bit error go undetected with \( C(x) \)? Give an example or explain why no such example exists.

No 5-bit error can go undetected since \( C(x) \) has an even number of 1's or since \( C(x) \) has a factor of \((x + 1)\).
8. 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 **40 Mbps**, how long must packets be to guarantee collision detection by the transmitter?

Longest link = $4 \times 15 = 60$ 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 40 Mbps, we get:

$$(40 \times 10^6 \text{ bps}) \times 200 \mu\text{sec} = 16000 \text{ bits}$$

$$= 2000 \text{ bytes}$$

(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

i) **(2 points)** $p = 1/2$?

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

ii) **(2 points)** $p = 2/3$?

$$5 \times (2/3) \times (1 – 2/3)^4 = 10 / 243$$
For the last part of the problem, assume that each packet requires \textbf{200 bytes} of header/trailer and \textbf{1000 bytes} of data. Also assume the probability of successful transmission calculated for part (b)(i) (using $p=1/2$).

(c) \textbf{(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)

$1000 + 200 \text{ B} < 2000 \text{ B}$, so, only one slot is needed for transmission.

Throughput $= \frac{5}{32} \times \left(\frac{1000}{2000}\right) \times 40 \text{ Mbps} = 3.125 \text{ Mbps}$
9. Switch Fabrics – 13 points

Banyan and Batcher networks are two types of self-routing fabrics often used to construct large switches from simpler components. A single stage of a $n \times n$ Banyan network consists of $n/2$ switches of dimension $2 \times 2$. An $n \times n$ Batcher network can be made from two Batcher networks of size $n/2 \times n/2$ plus a merge network with $n/2 \log_2 n$ switches.

a. For $n = 16$, how many stages are required to route packets from the inputs to the outputs of a Banyan Network?

For a Banyan network with $n$ inputs, we need to have $\log_2 n$ stages. This is true because the first stage examines the most significant bit, the second stage examines the second most significant bit and so on so that the last stage examines the least significant bit. If we have $n$ inputs, we need $\log_2 n$ bits to represent the inputs. Thus for $n = 16$, we need $\log_2 16 = 4$ stages.

b. How many $2 \times 2$ switches are required for the network in part a)?

At each stage, there needs to be $n/2$ switches. For $n = 16$, we will need 16 switches at each of the 4 stages for a total of 64 switches.

c. Write down a recurrence relation $T(n)$ for the number of switches in a Batcher network of size $n \times n$.

This can be written immediately from the description of the Batcher Network above. The number of switches in a Batcher network of size $n \times n$ is given by the recurrence relation $T(n) = 2 \times T(n/2) + n/2 \log_2 n$, for $n > 2$ and $T(2) = 1$.

d. Give the number of switches required for $n = 16$.

The number of switches required for the Batcher network with $n = 16$ is $T(16) = 80$. 