Data Networks
HW 2: Data Link Layer

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NOTE: The theoretical problems have no points. They are only provided to help you get familiar with the theoretical problems of this layer.

Practical Problems (100 pts)

Flow Control Protocols

The Data-link Layer is the second layer from the bottom in the OSI network architecture model. It is responsible for the node-to-node delivery of data. Its major role is to ensure error-free transmission of information. DLL is also responsible to encode, decode and organize the outgoing and incoming data. A function of DLL is Flow Control. If the receiver's receiving speed is lower than the sender's sending speed, then this can lead to an overflow in the receiver's buffer and some frames may get lost. So, it's the responsibility of DLL to synchronize the sender's and receiver's speeds and establish flow control between them. Major flow control protocols: Stop and Wait, Go Back N, and Selective Repeat.

Stop and Wait

The sender sends the packet and waits for the ACK (acknowledgement) of the packet. Once the ACK reaches the sender, it transmits the next packet in a row. If the ACK is not received, it re-transmits the previous packet again.

Go Back N

The sender sends N packets which are equal to the window size. Once the entire window is sent, the sender then waits for a cumulative ACK to send more packets. On the receiver end, it receives only in-order packets and discards out-of-order packets. As in case of packet loss, the entire window would be re-transmitted.

Selective Repeat

The sender sends packets of window size N and the receiver acknowledges all packets whether they were received in order or not. In this case, the receiver maintains a buffer to contain out-of-order packets and sorts them. The sender selectively re-transmits the lost packet and moves the window forward.

Simulation

Consider an unideal channel with P_{loss} (probability of frame error), T_f (frame length), T_p (propagation delay) and a transmitter with W (window size) and T_t (timeout).
Note that $a = T_p/T_f$
Provide a code to implement this system for the above mentioned protocols. You must deliver the following:

1. **Stop and Wait (15 pts)**
    - A plot of Normalized throughput versus a
    - A plot of Normalized throughput versus P_{loss}
    - A plot of Normalized throughput versus T_t
2. **Selective Repeat (15 pts)**
    - A plot of Normalized throughput versus a for different windows
    - A plot of Normalized throughput versus P_{loss} for different windows
    - A plot of Normalized throughput versus T_t for different windows
3. **Go Back N (15 pts)**
    - A plot of Normalized throughput versus a for different windows
    - A plot of Normalized throughput versus P_{loss} for different windows
    - A plot of Normalized throughput versus T_t for different windows

Explain the behavior of each curve and compare these protocols.

Error Detection and Error Correction

Beginning Notes

Transmissions over most channels are subject to error, for example due to noise or channel variations. Different techniques are used to guarantee reliable delivery of data in such channels. In general, retransmission and coding are two main techniques used for this purpose. The objective of this exercise is to get familiar with some of these techniques

Retransmission

In a retransmission scheme, the receiver uses an error-detection code, typically a Cyclic Redundancy Check (CRC), to detect if the received packet is in error or not. If an error is detected, the receiver notifies the transmitter to resend the packet. In this section, we want to use CRC codes and analyze performance of retransmission scheme in an AWGN wireless channel.

1. **(5 pts)** Explain the purpose of CRC and its basics. Use g_{CRC24A} generator polynomial and write a code to calculate CRC for given binary data.

$$g_{CRC24A(D)} = [D^{24} + D^{23} + D^{18} + D^{17} + D^{14} + D^{11} + D^{10} + D^{7} + D^{6} + D^{5} + D^{4} + D^{3} + D + 1] \quad (1)$$

2. **(15 pts)** (Simulation) Consider the case we need to send 12.8 KB (kilo bytes) of random data over AWGN channel using 1024-bit packets. Use retransmission for error handling, g_{CRC24A} for error detection and QPSK as modulation scheme (look at this example). Change SNR in a reasonable range and plot the total number of bytes sent (12.8KB + CRC overhead + retransmission overhead) versus SNR.
3. **(5 pts)** Calculate theoretical number of retransmissions needed as a function of SNR and compare with simulation results.

Hybrid ARQ

Forward Error Correction (FEC) codes are another way of handling channel errors. In fact, all modern communication systems employ a combination of FEC and Automatic Repeat reQuest (ARQ, which is a retransmission mechanism), known as hybrid ARQ. Hybrid ARQ uses forward error correction codes to correct a subset of all errors and relies on error detection to detect uncorrectable errors. In case of uncorrectable errors, the receiver requests retransmission. In this section we want to analyze Hybrid ARQ performance with a simple repetitive code as FEC.

1. **(15 pts)** (Simulation) Use a repetitive code of length 3 for error correction and simulate previous scenario with FEC. Change SNR and plot the actual number of bytes sent (12.8kB + CRC overhead + FEC overhead + retransmission overhead). By the way, which one should be done first? CRC attachment or FEC (if you are not sure, simulate both cases!). Compare and explain the results.
2. **(15 pts)** Calculate theoretical number of retransmissions needed in this case and compare with simulation results.

Theoretical Problems (0 pts)

Problem 1

The following data fragment occurs in the middle of a data stream for which the byte-stuffing algorithm described in the text is used: A B ESC C ESC FLAG FLAG D. What is the output after stuffing?

Problem 2

An upper-layer packet is split into 10 frames, each of which has an 80% chance of arriving undamaged. If no error control is done by the data link protocol, how many times must the message be sent on average to get the entire thing through?

Problem 3

A bit stream 10011101 is transmitted using the standard CRC method. The generator polynomial is $x^3 + 1$. Show the actual bit string transmitted. Suppose that the third bit from the left is inverted during transmission. Show that this error is detected at the receiver's end. Give an example of bit errors in the bit string transmitted that will not be detected by the receiver.

Problem 4

The distance from the earth to a distant planet is approximately 9 × 1010 m. What is the channel utilization if a stop-and-wait protocol is used for frame transmission on a 64 Mbps point-to-point link? Assume that the frame size is 32 KB and the speed of light is 3 × 108 m/s.

Problem 5

Suppose we want to transmit the message 1011001001001011 and protect it from errors using the CRC8 polynomial $x^8 + x^2 + x^1 + 1$.
(a) Use polynomial long division to determine the message that should be transmitted.
(b) Suppose the leftmost bit of the message is inverted due to noise on the transmission link. What is the result of the receiver's CRC calculation? How does the receiver know that an error has occurred?

Problem 6

Draw a timeline diagram for the sliding window algorithm with **Sender Window Size = Receiver Window Size = 4** frames in the following two situations. Assume the receiver sends a duplicate acknowledgment if it does not receive the expected frame. For example, it sends DUPACK[2] when it expects to see Frame[2] but receives Frame[3] instead. Also, the receiver sends a cumulative acknowledgment after it receives all the outstanding frames. For example, it sends ACK[5] when it receives the lost frame Frame[2] after it already received Frame[3], Frame[4], and Frame[5]. Use a timeout interval of about $2 \times RTT$ where RTT is the Round-Trip-Time.
(a) Frame 2 is lost. Retransmission takes place upon timeout (as usual).
(b) Frame 2 is lost. Retransmission takes place either upon receipt of the first DUPACK or upon timeout. Does this scheme reduce the transaction time?

Problem 7

Consider an error-free 64-kbps satellite channel used to send 512-byte data frames in one direction, with very short acknowledgments coming back the other way. What is the maximum throughput for window sizes of 1, 7, 15, and 127? The earth-satellite propagation time is 270 msec.

What Should I Do?

You must upload the simulation m.files generating the results of each part separated in specific folders. Also, prepare a report file in pdf format that involves plots and answers to questions. Compress all files and rename the compressed file to DN_HW2_StudentID.zip.
If you have any questions regarding the problem statement or understanding the concept, feel free to ask in Telegram Channel.