Data Communication Networks
HW 2: Data Link Layer

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Introduction

By working on this assignment you achieve some theoretical and practical knowledge on some of the concepts discussed in the data link layer section of the course. This homework comprises two major sections. The first section includes some theoretical problems about interleaving, link utilization measurements and ATM cell boundary detection. The other section which is mainly a practical assignment, focuses on the applications of ARQ and error correction coding in data transmission technologies.

Theoretical Problems

This section is comprised of three theoretical problems that aim at helping you build an intuition about some concepts within data link layer technologies and protocols.

Burst Errors and Interleaving

Suppose that the sequence of bits $b_0 b_1 ... b_{n-1}$ is the result of encoding a w-bits binary message using a repetition code for which the repetition order is $r = 2k + 1$ for some integer $k > 0$. Consequently, we have

$$b_{mr} = b_{mr+1} = ... = b_{mr+r-1} \quad \forall m \in \{0, 1, ..., w-1\}.$$

Before transmission, the bits are interleaved to form the following sequence which is then sent over a bursty channel:

$$b_0 b_r ... b_{(w-1)r} b_1 b_{r+1} ... b_{(w-1)r+1} ... b_{r-1} b_{2r-1} ... b_{(w-1)r+r-1}.$$

When this sequence is transmitted, the channel alters a single burst of bits with length B. The receiver performs de-interleaving and decoding in order to extract the w message bits.

1. **(8 pts)** What is the maximum size of B for which the transmission system can work with no errors? (*Hint:* Recall that the repetition decoder uses majority vote on the received encoded bits to decide on the transmitted bit.)

2. **(2 pts)** Suppose we use the interleaving system in previous question, and assume that the channel keeps causing a single error burst per transmission. As we observed, for a fixed value of B, there is a minimum safe (in terms of bit error) value for w. What is the drawback of using a w, larger than this minimum?

Link Utilization

3. **(10 pts)** Frames of 32 KB are sent over a 100 Mbps link with a propagation delay of 3 ms. Four bits are allocated for frame sequence numbering. The frame error probability is 8×10^{-2}. Compute link utilization in the case of using:

   - Stop and Wait
   - Go-Back-N
   - Selective Repeat

ATM Cell Boundary Detection

4. **(6 pts)** Explain the structure of ATM cells, and the way in which cell boundaries are recognized in ATM.

5. **(7 pts)** According to the notations used in the course, the system enters the SYNCH state, after δ consecutive correct HECs are experienced at the PRESYNCH state. At times that the detector finds the actual head of a cell and enters the PRESYNCH state, there is still a probability of P_1 that the δ consecutive correct HECs do not happen. Also there is a probability P_2 for entering a fake SYNCH state i.e. entering SYNCH when the cell boundary is not recognized correctly. Let us restrict P_1 and P_2 to be less than 5×10^{-8} and 10^{-9} respectively. Assuming a bit error probability of 10^{-12} find an interval for δ that satisfies the conditions for P_1 and P_2. You are allowed to make reasonable simplifying assumptions or to use approximations.

6. **(2 pts)** Are there any other considerations to be taken into account when tuning the value of δ?

Practical Problems

In this section, you will implement simple error control and channel coding systems. As you know, these are implemented to make communication systems more reliable by checking for errors in received data (usually applying an error detection code like CRC) and if error is indeed detected, ordering the transmitter to retransmit the frame. Also, in many designs the system first attempts to correct the errors as much as possible.

Note: For each section, a list of MATLAB functions will be given to you, **you may only use these functions to implement your code**. Since there are some distinctions between different implementations of the communication toolbox in MATLAB, this restriction is made so that your results can be evaluated accurately. We suggest you also see the documentations of these functions.

ARQ

ARQ systems use coding to make a certain level of errors detectable at the receiver. In the case of detecting error occurrence in the received frame, the receiver requests the transmitter to resend the frame. As a block diagram, the system that you are going to implement here is depicted in Figure 1.

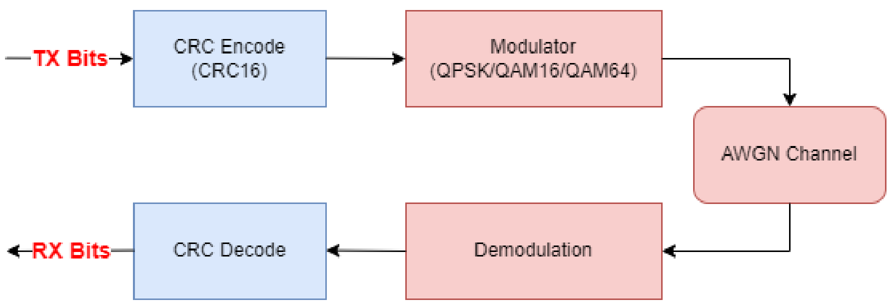

Figure 1: A simple block diagram of the data transmission system used in the ARQ section of this assignment.

The MATLAB functions that you will need for carrying out this section are `qammod()`, `qamdemod()`, `awgn()`, `lteCRCEncode()`, `lteCRCDecode()`.

7. **(5 pts)** Explain how an ARQ system will behave at different levels of SNR. What situation deos ARQ suffer at low SNR levels?

8. **(15 pts)** We first try to examine the effect of different channel conditions on the bit error rate, so there is no need to use any coding and ARQ procedures at this question. Create 10 random frames, each 1000 bits. Transmit these frames through an AWGN channel using QPSK modulation (or equivalently, QAM4). You should sweep SNR values from -5 dB to 20 dB. You may choose the number of points in this interval as you see fit. It is also recommended that you run each experiment a few times to get smoother results.

   You must deliver the following:

   - A plot of bit error rate (BER) versus SNR, both in dB.
   - A plot of channel throughput versus SNR, both in dB.

   Explain the behavior of each curve. Do the ultimate values of curves make sense? Please bear in mind that channel throughput is defined as "the number of bits that have been successfully transmitted through the channel per unit time", you may safely assume that you have enough bandwidth and a full transmission of each frame takes exactly one second if no retransmission is needed.

9. **(7 pts)** Using the BER curve that you found in the previous question, find the minimum SNR value that we need, so that with a probability of at least 90%, we can transmit a frame with at most 2 retransmissions.

10. **(18 pts)** Implement ARQ, this time restrict yourself to a 4 dB interval (2 dB at each side) around the value that you found in the question 9. To detect transmission error, you must append CRC to your frame before sending it, the receiver may only rely on the outcome of CRC decode to decide whether or not the frame has an error.

    You must deliver the following:

    - A plot of the total number of bits that were sent (regardless of whether or not they were correctly received, this only concerns the transmitter's view point) in dB versus SNR, also in dB.

    Is this system stable? In other words, does a small change in SNR result in a rather small loss of efficiency?

Error Correction Coding

ARQ faces many difficulties, yet, it is a necessary feature in a communication system. Hybrid ARQ (HARQ) combines ARQ with error correction, in an attempt to combat some of it's inherent difficulties. Using error correction codes, HARQ mechanisms first try to correct the error within the received frame, and if this was unsuccessful, request for a retransmission. In order to get familiar with error correction codes, you will work with Low Density Parity Check (LDPC). LDPCs like Hamming codes are linear block codes, but they have far more error correction capacity thanks to their sparse generation matrix. The standard implementation of LDPC has a fixed encoded block length of **64800** bits, yet different code rates exist. As a block diagram, the system that you are going to implement here is the following:

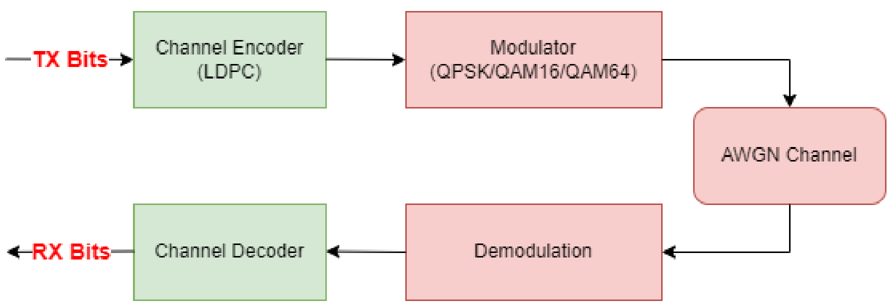

Figure 2: A simple block diagram of the data transmission system used in the error correction coding section of this assignment.

The detailed mechanisms of LDPC as a whole are beyond the scope of this assignment, hence you may freely use the code below for utilizing LDPC in your work:

```
enc = comm.LDPCEncoder(dvbs2ldpc(codingRate));
encodedMessage = enc(message);

% Rest of your code

dec = comm.LDPCDecoder(dvbs2ldpc(codingRate));
decodedMessage = dec(receivedMessage);
```

11. **(15 pts)** Repeat part 8, this time using LDPC code of rate $\frac{3}{5}$. Be sure to choose the number of data bits such that the transmitter attempts to send exactly one LDPC block of data. Compare the results of these two implementations, how are the results different?

Note: Be careful about how you demodulate received symbols in this part regarding soft decision or hard decision!

12. **(5 pts)** An efficient transmission will get the most out of channel capacity, resulting in a higher throughput. Assume that you are free to use any code rate and any M-QAM modulation, where $M = 2^k$ for some positive integer k. How can these values effect the maximum possible throughput?

13. **(12 extra pts)** Repeat part 11, and this time use QPSK, 16-QAM and 64-QAM modulations and 3 different coding rates of $\frac{2}{5}$, $\frac{3}{5}$ and $\frac{4}{5}$.

    You must deliver the following:

    - A plot of bit error rate (BER) versus SNR, both in dB for all 9 combinations of code rates and modulations.
    - A plot of channel throughput versus SNR, both in dB for all 9 combinations of code rates and modulations.

    You are allowed to freely decrease the number of points in the -5 to 20 dB interval and the number of experiments for each point if at any stage you think that your code is taking too long. The final plots should only show the trends for each evaluation and do not necessarily need to be very smooth.

14. **(3 extra pts)** If you were asked to produce an optimal modulation and coding rate choice for this system at any given SNR value, how would you do that? A simple explanation suffices and no code/plot is needed.

Required Output

For the practical section, you must upload all m-files generating the results of each part. Also, prepare a report file in pdf format that involves plots and answers to the questions. For the theoretical section, pictures of your answers should be submitted. Compress all files and rename the compressed file to DN_HW2_StudentID.zip.