UNIVERSITY OF DUBLIN
TRINITY COLLEGE

Faculty of Engineering, Mathematics and Science

School of Computer Science & Statistics

Integrated Computer Science Program **Michaelmas Term 2014**
Year 1 Supplemental Examination

CS1031 – Telecommunications I

day *date*$^{\textbf{th}}$ **month year**

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Instructions to Candidates

Answer all questions.

The mark assigned is shown at the end of each question.

Answers that do not provide an explanation or show the intermediate steps leading up to the solution will receive zero marks.

Permitted Materials

Non-programmable calculators are permitted for this examination. Please indicate the make and model of your calculator on the front of your first answer book.

1. You need to design a system for the transmission of 20 Ultra High Definition TV channels. Each video channel has 3840 x 2160 pixels, a colour depth of 24 bits and a rate of 24 frames per second. In addition, each channel uses a compression algorithm to reduce its final transmission rate by 75 times.

   (a) Calculate the total bit rate required by each individual channel. [5 marks]

   The rate per channel is found by multiplying the total number of pixels by the number of bits per pixel and by the frame rate, finally dividing by the compression factor. So: 3840 x 2160 = 8,294,400 x 24 = 199,065,600 x 24 = 4,777,574,400 / 75 = 63.7 Mb/s.

   (b) Calculate the total bandwidth required by the system if the 20 channels are multiplexed with a Frequency Division Multiplexing system, and transmitted around a 1GHz carrier frequency. The channels are modulated using a 64-QAM scheme and the guard interval between channels is 500KHz. [5 marks]

   A multi-level modulation will decrease the bit rate by a number equal to the log of the number of states. In this case the rate per channels is reduced by n=log64=6 times. The bit rate is thus 63.7 / 6 = 10.6Mb/s. Since the signal is transmitted over a high frequency, the bandwidth is equal to the data rate = 10.6MHz. Applying the number to 20 channels with 19 guard band, the total bandwidth required is: 212MHz + 9.5 = 221.5 MHz

   (c) Calculate the total bandwidth required if the 20 channels are multiplexed with a Time Division Multiplexing system, transmitted around a 1GHz carrier frequency and using a 64-QAM modulation. [5 marks]

   In a TDM system we first find the overall system rate = 20 x 63.7 = 1.274Gb/s, then divide by log64 = 212 Mb/s, which becomes 212MHz. This is indeed the same rate of the FDM system, but without the guard intervals.

2. A transmission link over copper cable is required to achieve a minimum Bit Error Rate (BER) of 10^{-4}. The total link length is 700m and the loss of the cable 0.1 dB/m. The

receiver sensitivity is -65 dBm and its noise figure is 2dB. The maximum symbol rate for the transmitter is 20 Mbaud, the transmission power is 8 mW and the Signal-to-noise ratio (SNR) is 85dB.

(a) Taking into consideration the BER curves in figure 1, are the requirements satisfied if the system uses a QPSK modulation? What bit rate is achieved? [10 marks]

Since the modulation to be used and the BER rate of 10^{-4} are given in advance, the student can calculate directly what is the available SNR at the end of the link. The power budget and SNR equations show that the link can be satisfied. Power budget = 9 dBm - 700 x 0.1 dB= -61 dBm, which is higher than the receiver sensitivity of -65 dBm. SNR = 85 - 70 - 2 = 13dB. This satisfies the QPSK threshold of 8 dB. QPSK achieves a rate 2 times higher than the baud rate. Thus the rate achieved is 40Mb/s.

(b) Taking into consideration the BER curves in figure 1, can the bit rate be increased without adding any amplifiers or regenerator? What is the maximum bit rate achievable? [5-marks]

Since the SNR threshold is 13 dB, from the curves it is clear that also a 16-QAM can be used. This will increase the maximum bit rate to 80 Mb/s

(c) Taking into consideration the BER curves in figure 1, re-design the system with any amplifier and/or regenerator required to achieve a bit rate of 160Mb/s. [10 marks]

The only way to achieve 160 Mb/s is to use a 256-QAM, which achieves a bit rate 8 times higher than the baud rate, but it requires more than 21dB of SNR to work at a BER of 10^{-4}. The power budget will not change from the previous exercise. The previous SNR budget of 13dB however is too low for the 256-QAM. The SNR needed is 22 dB, so a regenerator needs to be placed at a location where the SNR is higher than 22 dB, i.e. 9 dB, or 90 meters before the end of the link. So a regenerator needs to be placed after 610 meters.

3. You want to digitalise a voice conversation in order to be able to record it on a memory

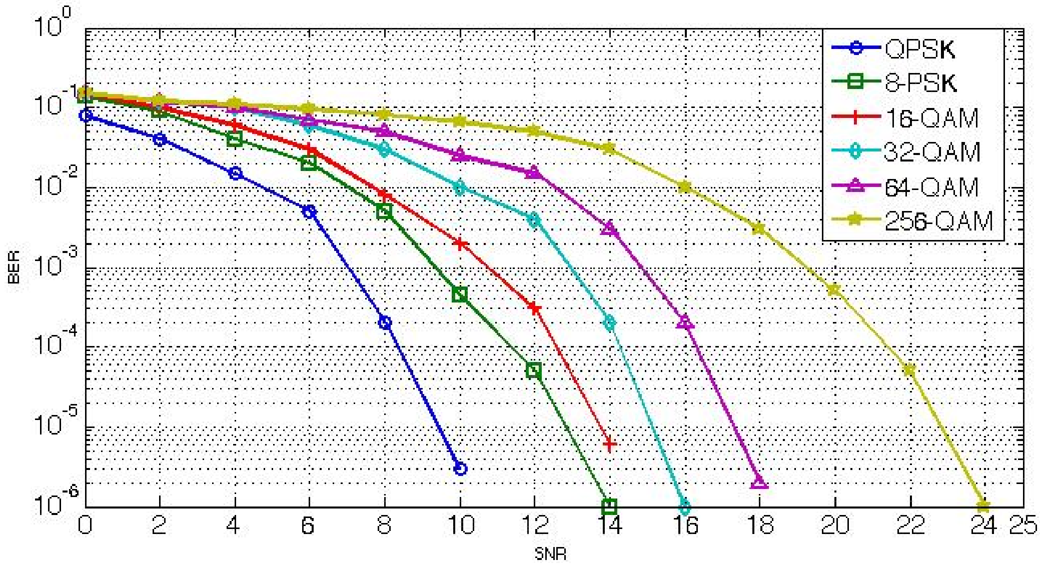

Figure 1: SNR-BER plots for different modulations

stick. Assume that the highest frequency of the voice is 10KHz and you encode it using 16 bits per sample.

(a) What are the minimum correct sampling frequency and the minimum bit rate required by your system? [2-marks]

The minimum rate is obtained by sampling at twice the max frequency and multiplying by the bits per sample, thus: 20KHz x 16 = 320Kb/s

(b) Draw the spectrum of the digitalised signal obtained using the minimum correct sampling frequency, assuming the spectrum of the original analogue voice signal is like the one in figure 2. [4-marks]

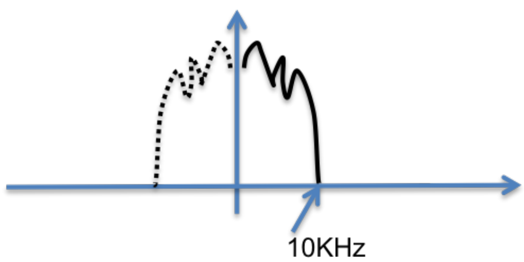

Figure 2: Spectrum of the original analogue voice signal

The spectrum should look like the one in the figure

(c) Draw the spectrum of the digitalised signal, when the frequency used to sample the

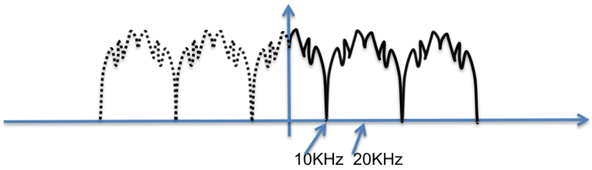

Figure 3: Spectrum of the original analogue voice signal

voice is 30 KHz. [4-marks]

The spectrum should look like the one in the figure

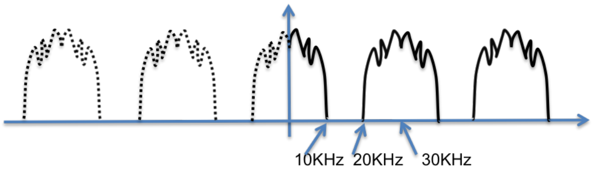

Figure 4: Spectrum of the original analogue voice signal

(d) Draw the spectrum of the digitalised signal, when the frequency used to sample the voice is 15 KHz. Then explain what is the issue with using this sampling frequency. [5-marks]

The spectrum should look like the one in the figure

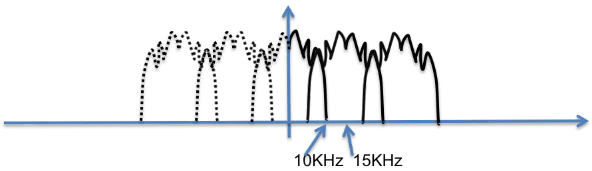

Figure 5: Spectrum of the original analogue voice signal

4. You need to transmit the following sequence of bits over a transmission channel: 111010001001.

   (a) Draw a plot of the modulated signal in the time domain when using an 8-FSK digital modulation. [5-marks]

   The first step is to break the sequence into groups of 3: 111 010 001 001. The student should then assign a different frequency (i.e. a sinusoidal wave of different frequency) to different triplets. The total number of different levels allowed will be 8.

(b) Draw a plot of the modulated signal in the time domain when using a 4-PSK digital modulation. [5-marks]

Now the sequence must be split into groups of 2 bits: 11 10 10 00 10 01. The student should use a sinusoid of just one frequency but change the phase after each symbol (for example one cycle could correspond to one symbol). This will thus show a discontinuity in the phase of the signal after each symbol. Here the maximum number of levels is 4.

5. An analogue Frequency Modulation (FM) radio system is being designed to provide multiple radio stations in the frequency band between 130 MHz and 135 MHz. The system should be able to reproduce an acceptable quality for the transmission of music, covering frequencies up to 22KHz over two separate channels for stereo sound.

(a) What is the maximum guard band you can use in the system if the total number of stations to be transmitted is 10 and each signal is modulated with an FM modulation with a β modulation parameter equal to 4? [6-marks]

The first thing is to calculate the bandwidth required by each channel using the FM modulation formula 2(1+β)Bandwidth = 10x22KHz x 2= 440 KHz. Then we can calculate the capacity that is left by subtracting the capacity required for the transmission to the capacity available = 5MHz - (440KHz x 10) = 600KHz. This should be divided by the 9 guard intervals required= 66.7KHz

(b) Explain what would happen if you tried to transmit 15 channels within the same bandwidth, drawing a diagram of the frequency spectrum of the entire system. [4-marks]

The diagram should show overlapping between the channels because there is not enough space to fit them all. Due to the overlap the channels will be mixed and cannot be properly separated at the receiver, generating a distorted signal at the receiver.

6. Given the following representation of the Internet protocol stack provide a description of

the functions carried by each of the 5 layers in figure 6. [10 marks]

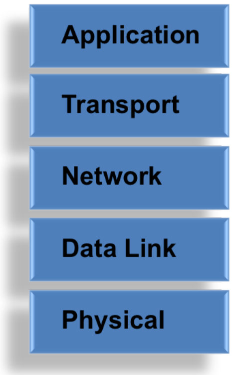

Figure 6: Layers of the Internet protocol stack

Application: Protocols that are used directly from the applications: e.g., http for web browsers; FTP for file-transfer applications. Transport: Allows multiple applications flow to be transmitted to/from the same machine, TCP also adds reliability to the link; Network: Routes packets to the correct destination from source machine to destination machine, through the entire Internet; Data Link: Regulates access to a shared transmission medium; allows to send information through one link, from one node to the next; Physical: Takes care of the physical transmission of the signal, either through air (wireless), through a copper cable (guided electronic transmission) or through optical fibre (guided optical transmission). 2 marks per layer description.

7. Describe the following multiplexing techniques showing appropriate diagrams and at least one example of application for each technique:

   (a) Time Division Multiplexing (TDM). [5 marks]

   (b) Time Division Duplexing (TDD). [5 marks]

   (c) Frequency Division Multiplexing (FDM). [5 marks]