UNIVERSITY OF DUBLIN
TRINITY COLLEGE

Faculty of Engineering, Mathematics and Science

School of Computer Science & Statistics

Integrated Computer Science Program **XXX Term 20XX**
Year 1 Examination

CS1031 – Telecommunications I

Day, date, month, year **location** **xx:xx – xx:xx**

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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 a resolution of 3840 x 2160 pixels, a colour depth of 24 bits and a frame 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 using Frequency Division Multiplexing, and transmitted at 1GHz. The channels are modulated using a 64-QAM modulation 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 using Time Division Multiplexing, transmitted at 1GHz 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. You need to design an optical transmission system working at a BER of 10^{-4}. The fibre loss is 0.2 dB/km, the transceiver baud rate 10GBaud, the receiver sensitivity -18 dBm and the transmission power 0.5 mW. The SNR/BER relationship is shown in the figure below. Consider a 3 dB margin for power budget and 3 dB margin for OSNR (where applicable) and answer the following questions.

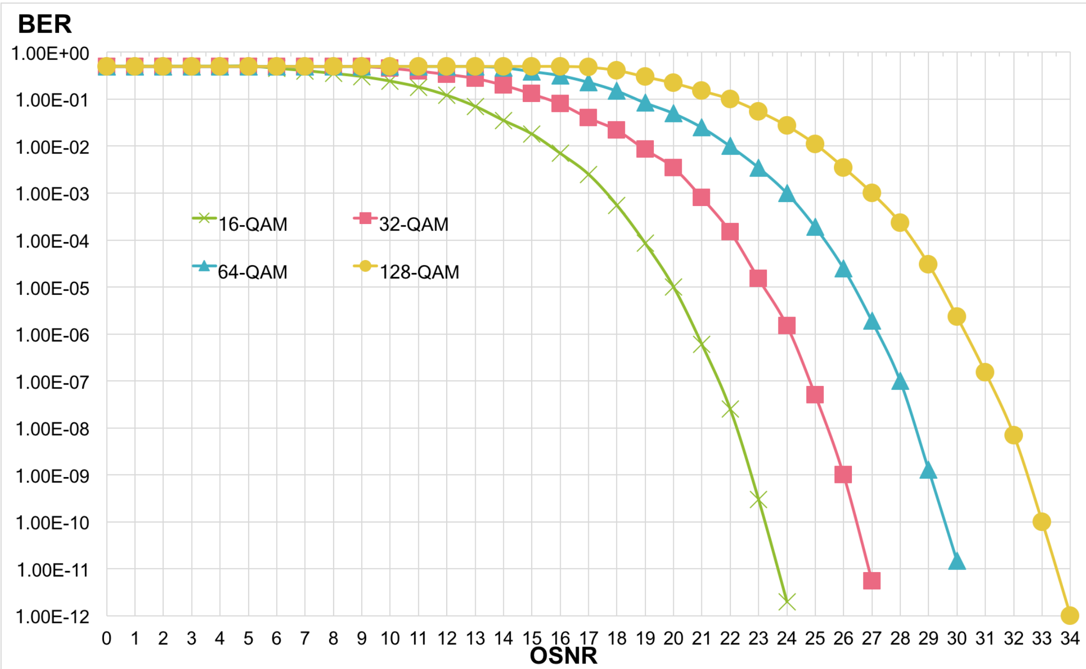

Figure 1: OSNR-BER plots for different modulations

(a) Calculate the maximum distance for the system to work without any amplification. [7 marks]

Since we are not using amplifiers, the system is power limited so we only need to check whether the power is higher than the receiver sensitivity at the end.

$Precv = Plaunch - loss - powerMargin > sensitivity$. The power needs to be converted into dB, so $0.5mW = 1/2 = 0 - 3 = -3dBm$.

The loss is not known $= 0.2 * l = xdB$

$Precv = -3 - x - 3 > -18$. This means that the maximum loss is $x < 18 - 3 - 3 = 12dB$. The maximum length $l = 12/0.2 = 60km$.

(b) Assume you need to extend the system reach to 600 Km using optical amplifiers, with noise figure of 7 dB and gain of 23dB. Provide a solution that achieves 50Gb/s using the smallest number of amplifiers, stating number of amplifiers and their spacing. [10 marks]

Because there are amplifiers the system is likely OSNR limited so the OSNR is the equation to check first. The OSNR required, from the figure above, considering 32 QAM (i.e. for n=5 so that we achieve 50Gb/s from at 10Gbaus system), and BER of 10^{-4}, is 22 dB. The OSNR equation is: $OSNRrecv = Plaunch[dBm] - \alpha[dB/km]Lspan[km] - NFampl[dB] - 10log10(n) + 58[dB] - M$.
With a 80 km spacing we get $OSNR = -3 - 0.2x80 - 7 - 9 + 58 - 3 = 20 < 22$, so it doesn't work.

Decreasing the span only changes the span loss and the 10log10(n) values. Trying 70 km: $OSNR = -3 - 0.2x70 - 7 - 9.5 + 58 - 3 = 21.5 < 22$, so this doesn't work either. Notice that 10 km less span distance improved by 1.5 dB.

As we assume that span changes only occur by 10km increment or decrement we now try 60 km: $OSNR = -3 - 0.2x60 - 7 - 10 + 58 - 3 = 23 > 22$. So the number of amplifiers needed is 10 and the span is 60 km.

We also do a quick check that the power would be enough:
$Precv = -3 - 120(totalloss) + 23(gain)x10(amplifiers) - 3(margin) = -3 - 120 + 230 - 3 = 104 >> -18$. So this works.

(c) Check whether the system can support a maximum distance of 2500 km. If not provide a solution that satisfies the requirements. [8 marks]

Using an amplifier span of 50 km (the minimum we use), we have $OSNR = -3 - 0.2x50 - 7 - 17 + 58 - 3 = 18 < 22$. So it won't work and will need regeneration.

One regenerator will reduce the distance to 1250 km:
$OSNR = -3 - 0.2x50 - 7 - 14 + 58 - 3 = 21 < 22$. So it still doesn't work.

Two regenerators will reduce the distance to 834 km (17 amplifiers per span):
$OSNR = -3 - 0.2x50 - 7 - 12.3 + 58 - 3 = 22.7 > 22$. So this will work

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

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

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

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

4. You want to digitise a voice conversation in order to record it on a memory stick. Assume that the highest frequency component of the voice signal is 10KHz and you encode it using 16 bits per sample.

   (a) What are the minimum 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 sampling frequency, assuming the spectrum of the original analogue voice signal is like the one in Figure 2. [4 marks]

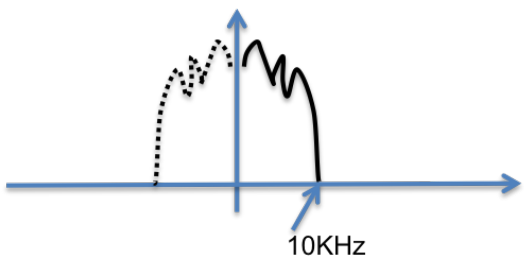

Figure 2: Spectrum of the original analogue voice signal

The spectrum should look like the one in the figure

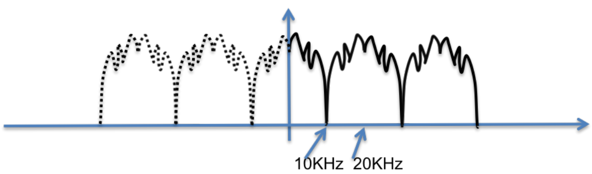

Figure 3: Spectrum of the original analogue voice signal

(c) Draw the spectrum of the digitalised signal, when the sampling frequency is 30 KHz. [4 marks]

The spectrum should look like the one in the figure

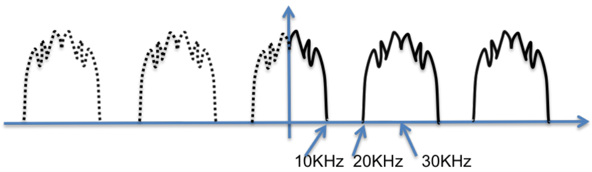

Figure 4: Spectrum of the original analogue voice signal

(d) Draw the spectrum of the digitalised signal, when the sampling frequency is 15 KHz. Then explain what is the problem created by this sampling frequency. [5 marks]

The spectrum should look like the one in the figure

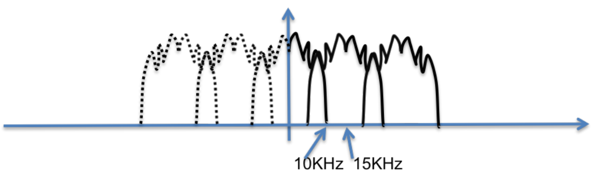

Figure 5: Spectrum of the original analogue voice signal

5. 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.

6. Given the representation of the Internet Protocol stack given in Figure 6, provide a description of the functions carried out by each of the 5 layers. [10 marks]

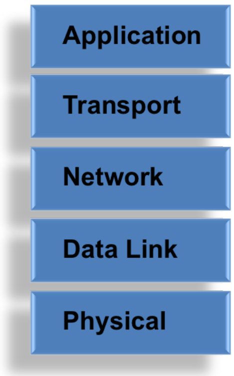

Figure 6: Layers of the Internet protocol stack

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).

7. 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 $2(1+\beta)$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, and draw 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.