

EE 533 TELECOMMUNICATION NETWORKS
HOMEWORK QUESTIONS AND ANSWERS

Homework Question 1

Allocated channel bandwidth for commercial TV is 6 MHz.

- a. Find the maximum number of analog voice channels that can be transmitted in one commercial TV channel.
- b. Using 8 bits to represent one sampled value, find the minimum bit rate required in digitally transmitting a TV signal.
- c. Find the minimum bit rate required in digitally transmitting a TV signal, if 1024 levels are used to represent one sampled value.
- d. Find the maximum number of digital voice channels that can be transmitted in one digital TV channel given in 1.b above.
- e. Which level of E-Carrier European (CEPT) do you need to carry the bit rate you found in 1.c above?

Answer to Homework Question 1

- a. One analog voice channel bandwidth is 4 KHz = 4×10^3 Hz.
In 6 MHz band, there are $(6 \times 10^6 \text{ Hz}) / (4 \times 10^3 \text{ Hz}) = 1500$ times 4 KHz.
So, maximum number of analog voice channels that can be transmitted in one commercial TV channel = 1500
- b. Sampling by twice the maximum frequency $\Rightarrow 6 \text{ MHz} \times 2 = 12 \text{ M samples per second}$
Minimum Bit Rate = $12 \text{ M samples per second} \times 8 \text{ bits / sample} = 96 \text{ Mbps}$
- c. Sampling by twice the maximum frequency $\Rightarrow 6 \text{ MHz} \times 2 = 12 \text{ M samples per second}$
To represent the sample with 1024 levels means 10 bits / sample
Minimum Bit Rate = $12 \text{ M samples per second} \times 10 \text{ bits / sample} = 120 \text{ Mbps}$
- d. One digital voice channel at the same number of bits representing one sample is 64 Kbps
In 96 Mbps, there are $96 \text{ M} / 64 \text{ K} = 1500$.
So, the maximum number of digital voice channels that can be transmitted in one digital channel is 1500, the same answer in 1.a above
- e. Fourth level (E-4) 139.264 Mb/s (1920 Ch.)

Homework Question 2

In a library there exists 448000 books, each book has average 500 pages, each page has average 500 words, each word has average 5 letters, each letter is encoded by 8 bits.

- a. Find the total number of bits that will present the total information content in the library.
- b. Find the time (in years) needed to transmit the total information content in the library when a standard 56 Kbps modem is used (assume full rate can be utilized).

Answer to Homework Question 2

- a. The total number of bits that will present the total information content in the library = $448000 \times 500 \times 500 \times 5 \times 8 = 4480 \times 10^9$ bits = 4480 Gbits=4.48 Tbps
- b. The time needed to transmit the total information content in the library when a standard 56 Kbps modem is used (assuming full rate can be utilized) = $4480 \text{ Gbits} / 56 \text{ Kbps} = 80.000.000 \text{ sec} = 2.54 \text{ year}$

Homework Question 3

Write eight points to be seen in the new public network.

Answer to Homework Question 3

- End-to-end digitalization
- End-to-end optical or photonic networking
- Intelligent programmable network
- Very high bandwidth infrastructure
- Low-latency network, i.e. networks with minimum delays
- Networks to be able to follow multiprotocol
- QoS (Quality of Service) guarantees: Meeting bandwidth, latency, loss requirements
- Encryption and security

Homework Question 4

Comparing the carriers of microwave and optical communication systems:

- a. Which one has higher frequency ?
- b. Which one has shorter wavelength ?
- c. Write the frequency range of HF.
- d. Write the wavelength range of UHF.

Answer to Homework Question 4

- a. Optical communication systems have higher frequency
- b. Optical communication systems have shorter wavelength
- c. 3 – 30 MHz.
- d. 300 MHz – 3 GHz corresponds to wavelength range of $300000000 \text{ m/sec} / 300000000 \text{ (1/sec)} = 1 \text{ m}$
 $300000000 \text{ m/sec} / 3000000000 \text{ (1/sec)} = 0.1 \text{ m} = 10 \text{ cm}$

Homework Question 5

- a. How many total voice channels are transmitted in a 2.048 Mb/s system ?
- b. How many total video channels can be transmitted in a 139.264 Mb/s system ?

Answer to Homework Question 5

- a. $2.048 \text{ Mb/s} / 64 \text{ Kb/s} = 2048000 \text{ b/s} / 64000 \text{ b/s} = 32$ channels total channels
 $32 - 1$ signalling channel – 1 synchronization channel = 30 voice channels.
- b. One video channel in 1.b 96 Mbps or in 1.c 120 Mbps. In either case only one video channel can be transmitted in a 139.264 Mb/s system ?

Homework Question 6

- a. For the analog signal $v = 3.6 \sin 6280 t$, find the minimum sampling rate needed.
- b. What happens if the sampling rate is 250 Hz ?
- c. What happens if the sampling rate is 5 KHz ?

Answer to Homework Question 6

- a. For the analog signal $v = 3.6 \sin 6280 t$, find the minimum sampling rate needed = 2KHz.
- b. If the sampling rate is 250 Hz, then the signal can not be recovered correctly at the receiver ?
- c. If the sampling rate is 5 KHz, the signal can be recovered correctly, however there is no need to sample over the sampling rate since it will bring unnecessary complication and cost to electronics.

Homework Question 7

An analog signal has time variation $f(t) = 3 + 0.2 \cos (8000\pi t) - 0.3 \sin (4000\pi t)$.

- a. Minimum how many samples should be taken to satisfy Nyquist requirement?
- b. 256 levels is used to represent one sample. How many bits are required to transmit one sample value?
- c. What is the minimum transmission rate of this signal?
- d. Would you allocate a 256 kbps channel to transmit this signal? Why?
- e. Would you allocate a 32 kbps channel to transmit this signal? Why?

Answer to Homework Question 7

An analog signal has time variation $f(t) = 3 + 0.2 \cos (8000\pi t) - 0.3 \sin (4000\pi t)$.

- a. Minimum how many samples should be taken to satisfy Nyquist requirement?

Maximum frequency = 4 KHz, i.e. sampling frequency = 8 KHz

The minimum number of samples per second needed to satisfy Nyquist requirement = **8000**

- b. 256 levels is used to represent one sample. How many bits are required to transmit one sample value?

256 levels mean that each sample is represented by 8 bits since $256 = 2^8$

The number of bits needed to transmit one sample = **8 bits**

- c. What is the minimum transmission rate of this signal?

The minimum rate in Kbps at which this signal is transmitted

= 8000 samples / sec x 8 bits / sample = **64 Kbps**

- d. Would you allocate a 256 kbps channel to transmit this signal? Why?

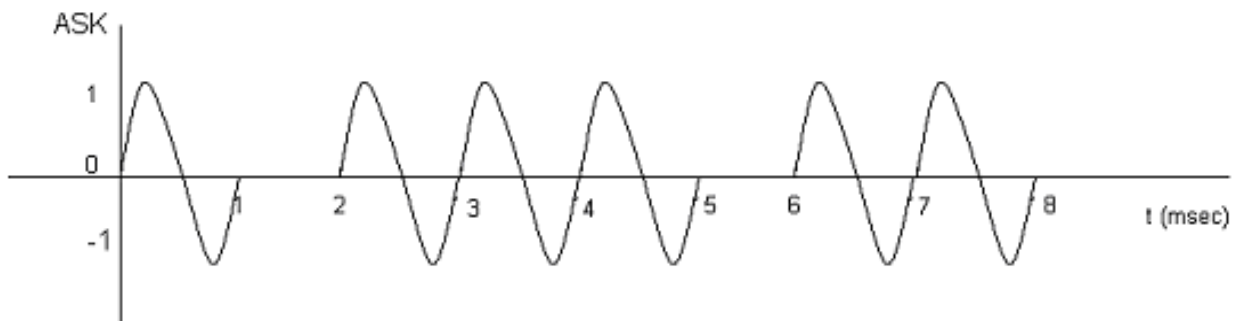
No because more than 64 kbps rate will be unnecessary in the recovery of the original signal.

- e. Would you allocate a 32 kbps channel to transmit this signal? Why?

No because with a rate less than 64 kbps, the original signal will only be recovered with loss of information which is not desired.

Homework Question 8

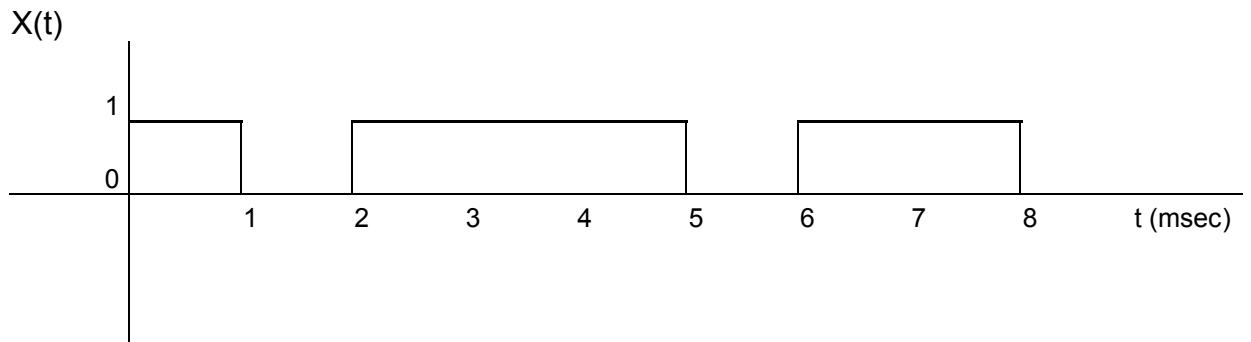
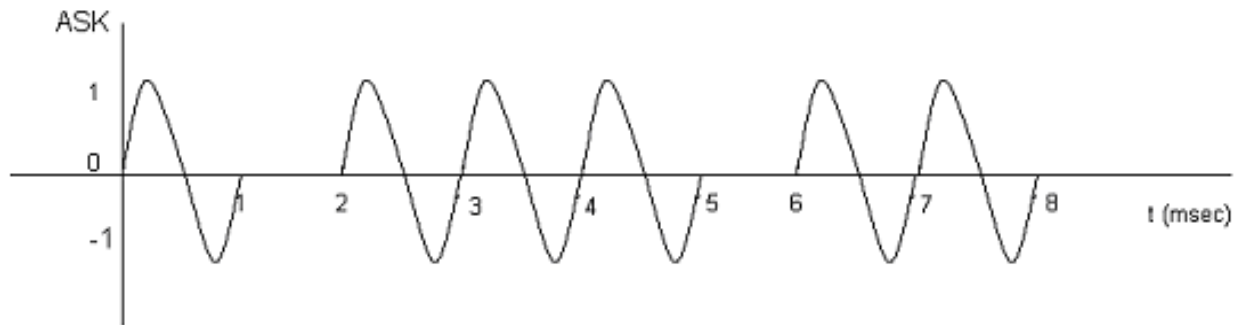
- a. For a carrier of $\sin(2000\pi t)$, the Amplitude Shift Keying (ASK) Modulated signal is given below. Plot the digital information signal $x(t)$.



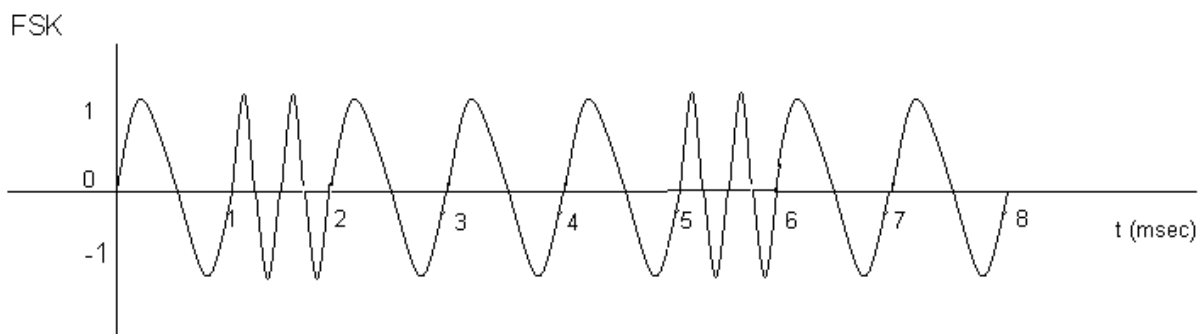
- b. If digital level "1" is represented by $\sin(2000\pi t)$ and digital level "0" is represented by $\sin(4000\pi t)$, plot the Frequency Shift Keying (FSK) Modulated signal for the digital information signal $x(t)$ found in part a.
- c. If digital level "1" is represented by $\sin(2000\pi t)$ and digital level "0" is represented by $\cos(2000\pi t)$, plot the Phase Shift Keying (PSK) Modulated signal for the digital information signal $x(t)$ found in part a.
- d. If the carrier in part a becomes $\sin(4000\pi t)$, re-plot the Amplitude Shift Keying (ASK) Modulated signal given in part a.
- e. Find the rate of the digital information signal $x(t)$ found in part a.

Answer to Homework Question 8

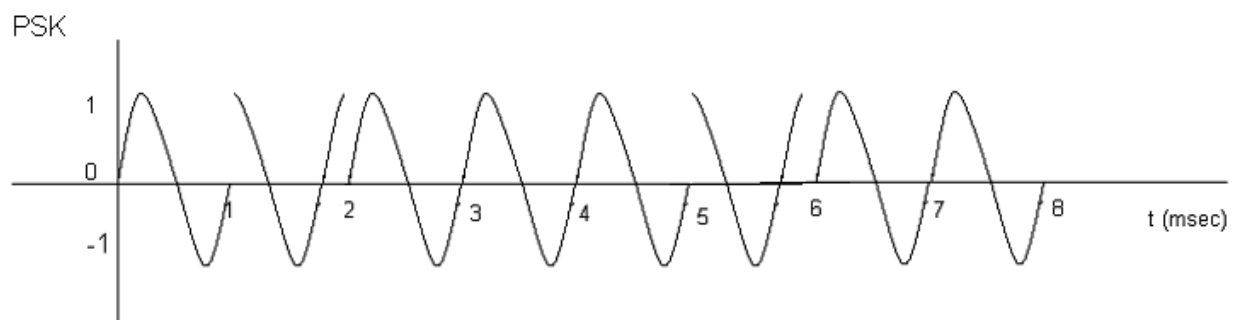
- a. For a carrier of $\sin(2000\pi t)$, the Amplitude Shift Keying (ASK) Modulated signal is given below. Plot the digital information signal $x(t)$.



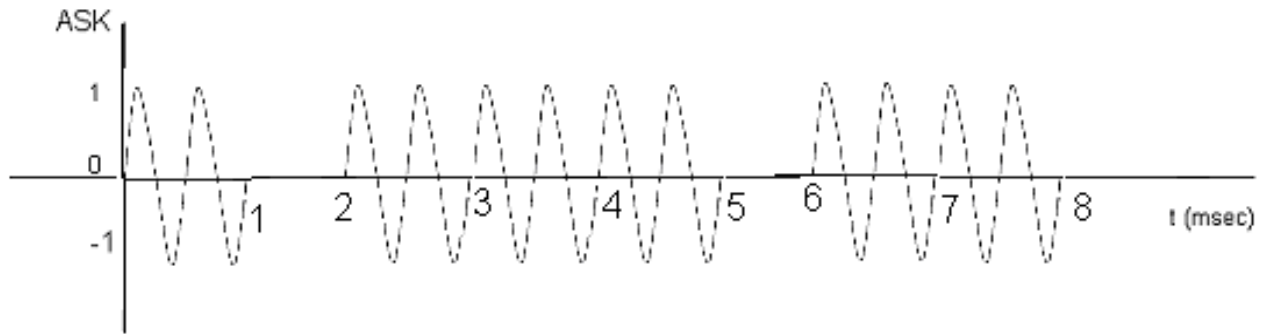
- b. If digital level "1" is represented by $\sin(2000 \pi t)$ and digital level "0" is represented by $\sin(4000 \pi t)$, plot the Frequency Shift Keying (FSK) Modulated signal for the digital information signal $x(t)$ found in part a.



- c. If digital level "1" is represented by $\sin(2000 \pi t)$ and digital level "0" is represented by $\cos(2000 \pi t)$, plot the Phase Shift Keying (PSK) Modulated signal for the digital information signal $x(t)$ found in part a.



- d. If the carrier in part a becomes $\sin(4000 \pi t)$, re-plot the Amplitude Shift Keying (ASK) Modulated signal given in part a.

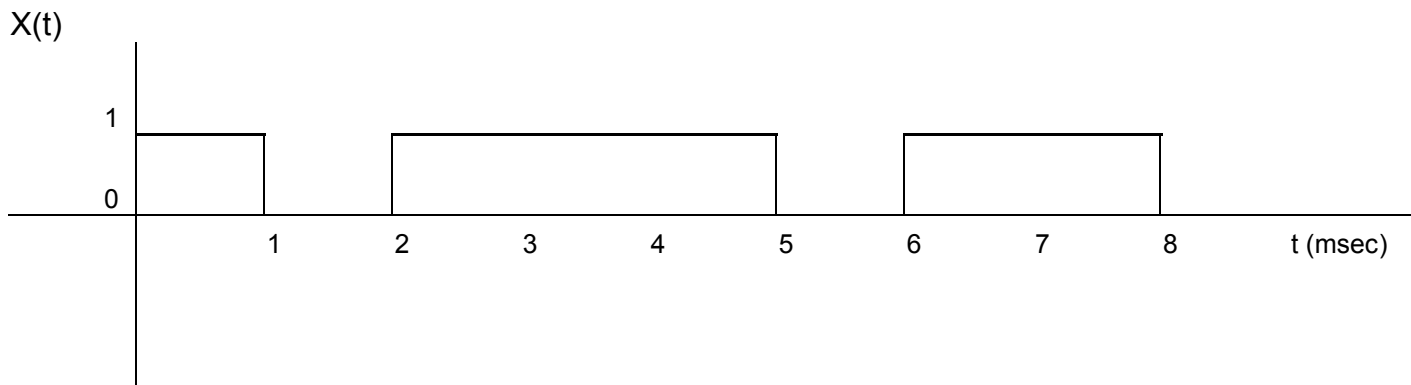


e. Find the rate of the digital information signal $x(t)$ found in part a.

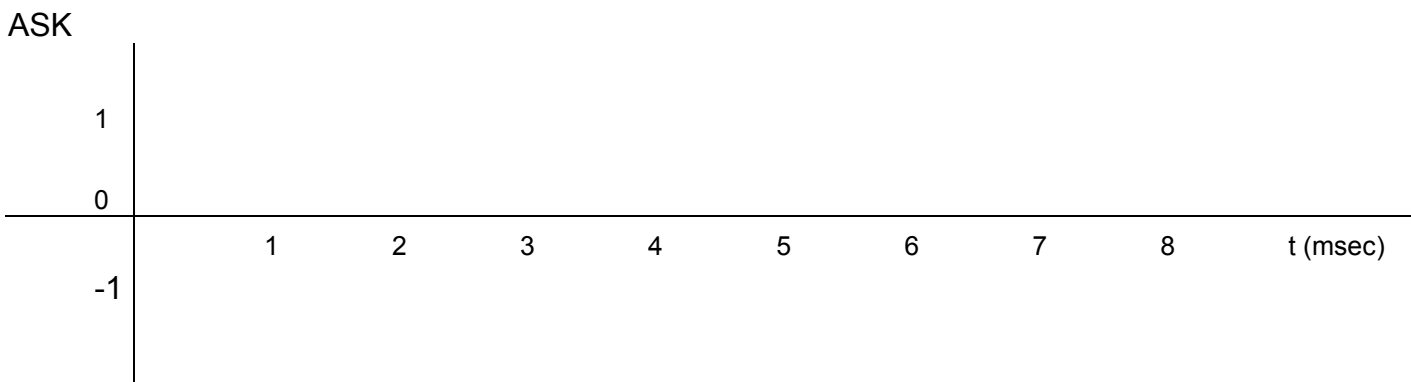
Rate of $x(t)$ found in part a = 1 bit / msec = 1 bit / 10^{-3} sec = 10^3 bits / sec = 1 kbps.

Homework Question 9

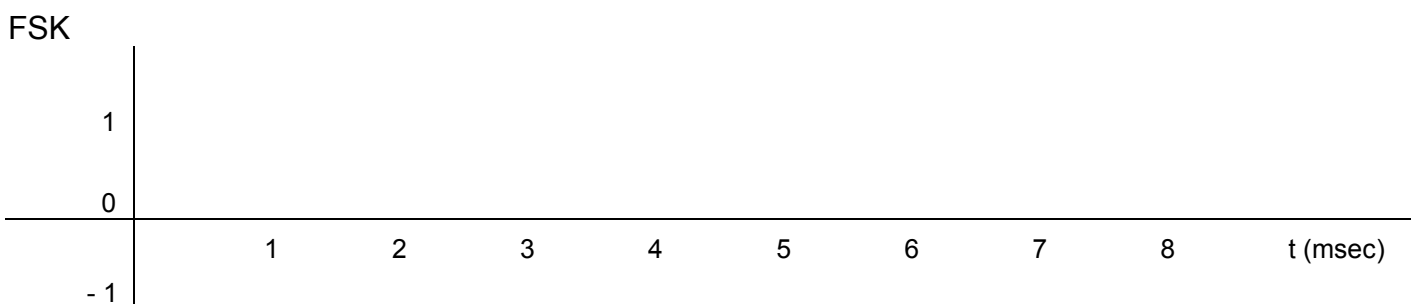
The digital signal $X(t)$ given below.



a. If the carrier is $\sin(2000 \pi t)$, plot Amplitude Shift Keying (ASK) Modulated signal.

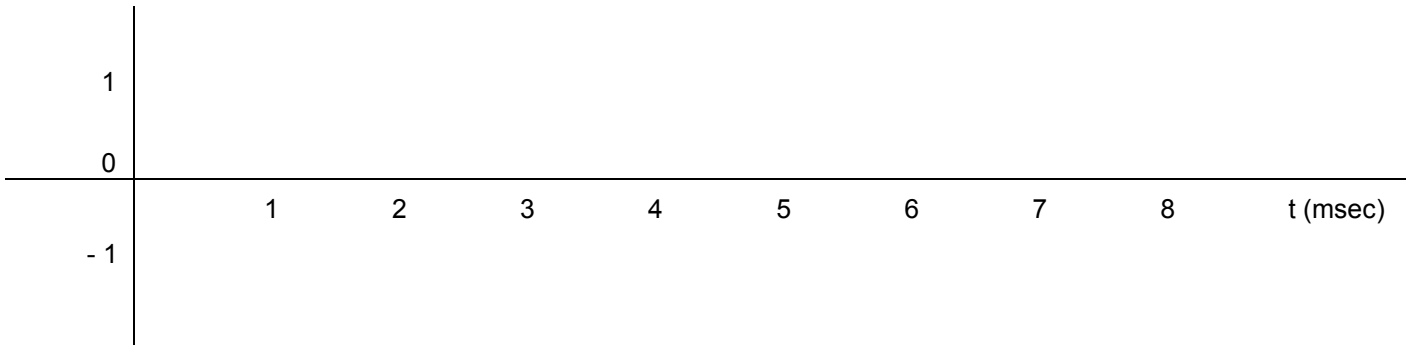


b. If digital level "1" is represented by $\sin(2000 \pi t)$ and digital level "0" is represented by $\sin(4000 \pi t)$, plot Frequency Shift Keying (FSK) Modulated signal.



- c. If digital level "1" is represented by $\sin(2000 \pi t)$ and digital level "0" is represented by $\cos(2000 \pi t)$, plot Phase Shift Keying (PSK) Modulated signal.

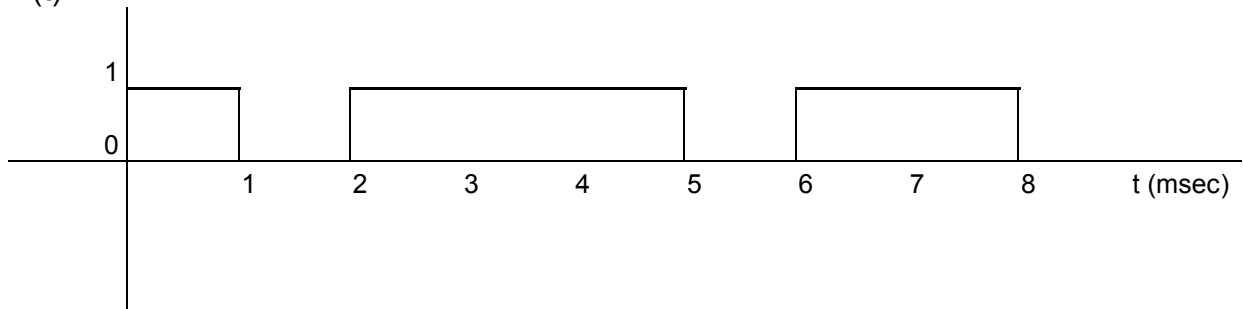
PSK



Answer to Homework Question 9

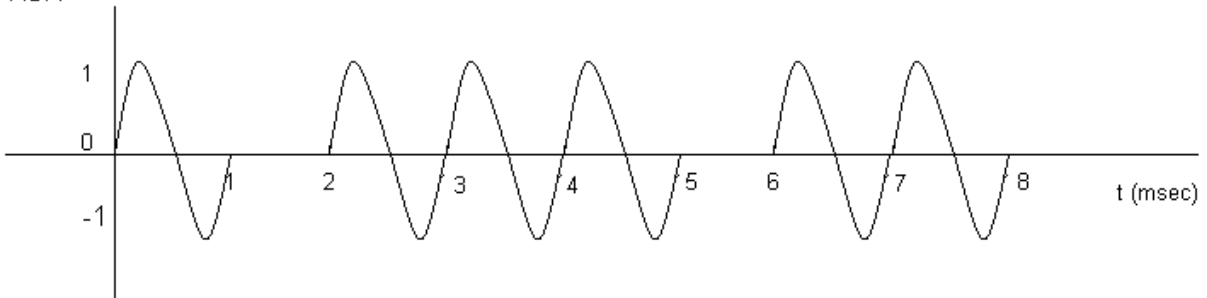
The digital signal X(t) given below.

X(t)



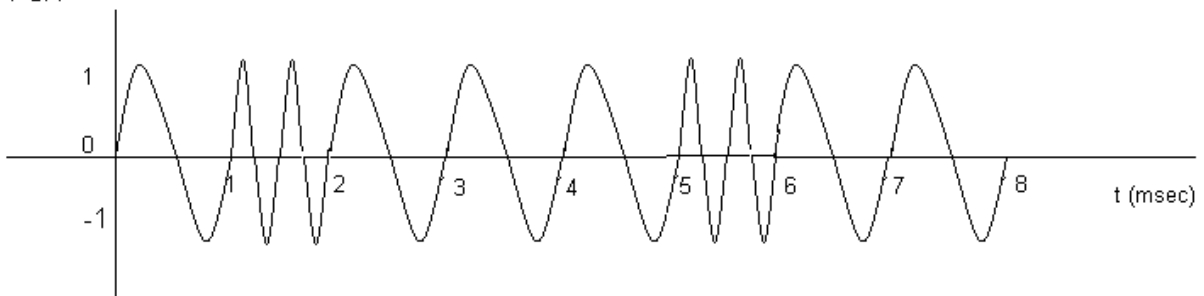
- a. If the carrier is $\sin(2000 \pi t)$, plot Amplitude Shift Keying (ASK) Modulated signal.

ASK

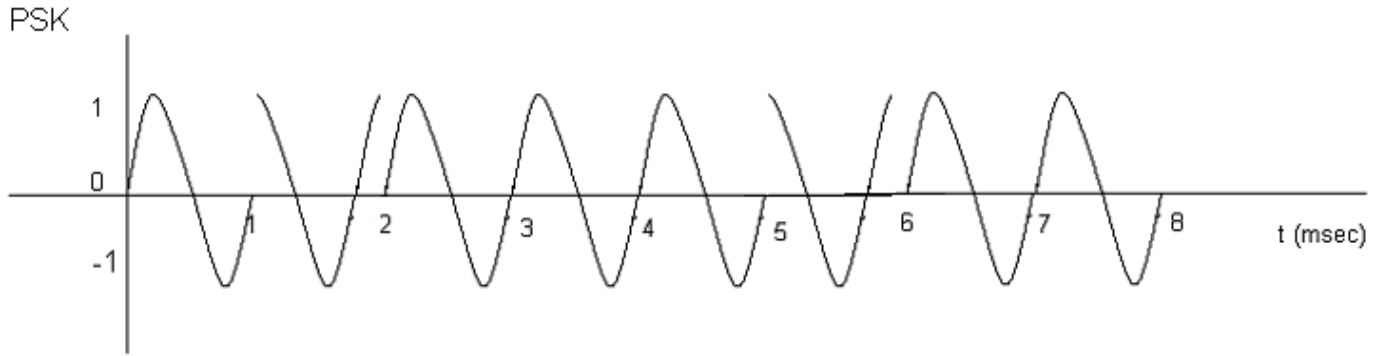


- b. If digital level "1" is represented by $\sin(2000 \pi t)$ and digital level "0" is represented by $\sin(4000 \pi t)$, plot Frequency Shift Keying (FSK) Modulated signal.

FSK

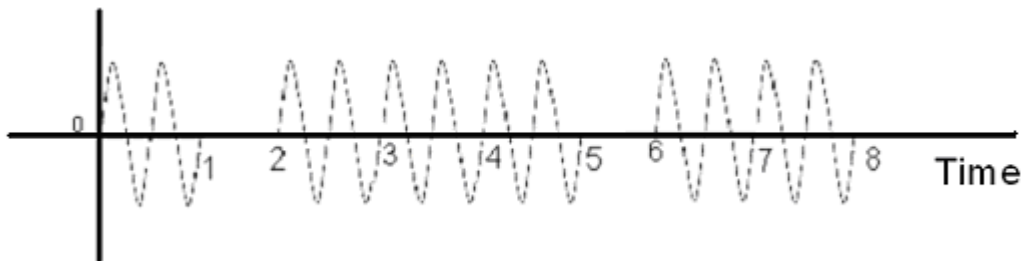


- c. If digital level "1" is represented by $\sin(2000\pi t)$ and digital level "0" is represented by $\cos(2000\pi t)$, plot Phase Shift Keying (PSK) Modulated signal.



Homework Question 10

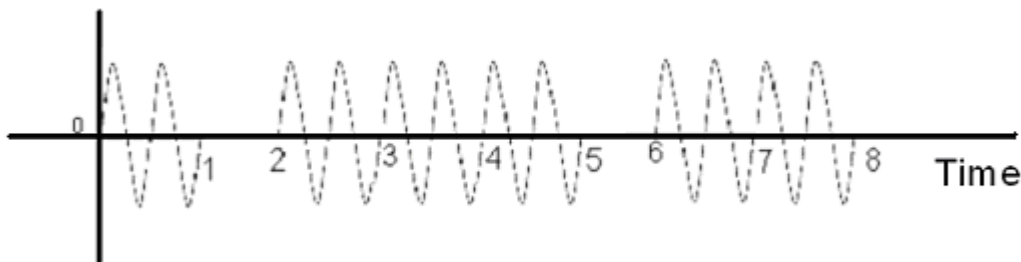
Eight bits of information is sent in the following modulated signal where time axis is in microseconds:



- Write the type of modulation used. Why?
- Find the carrier frequency.
- Find the rate of the information signal.
- Plot the information signal if "1" is represented by no signal, and "0" is represented by 0.5 mV and no carrier.
- Is this information signal convenient to carry 1 digital voice channel? Why?
Is this information signal convenient to carry 1 digital video channel? Why?

Answer to Homework Question 10

Eight bits of information is sent in the following modulated signal where time axis is in microseconds:



- Write the type of modulation used. Why?

Solution: ASK (Amplitude Shift Keying) because digits “1” and “0” are differentiated with different amplitudes.

- b. Find the carrier frequency.

Solution: For one bit, duration is $1 \mu\text{sec}$. and the number of cycles=2

Thus, the carrier frequency = 2 cycle in $1 \mu\text{sec}$., i.e., $2 \times 10^6 \text{ cycles/sec} = 2 \text{ MHz}$.

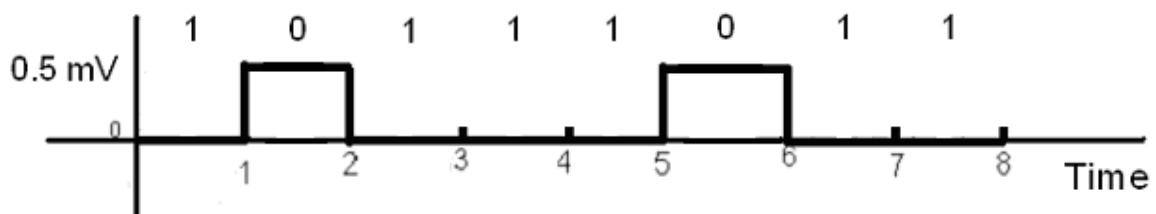
- c. Find the rate of the information signal.

Solution: One bit has duration of $1 \mu\text{sec}$.

Thus, the rate of the signal = $1 \times 10^6 \text{ bits/sec} = 1 \text{ Mbps}$.

- d. Plot the information signal if “1” is represented by no signal, and “0” is represented by 0.5 mV and no carrier.

Solution:



- e. Is this information signal convenient to carry 1 digital voice channel ? Why?
Is this information signal convenient to carry 1 digital video channel ? Why?

Solution: This information signal is convenient to carry 1 digital voice channel because the information signal has a rate of 2 Mbps and 1 digital voice channel needs only 64 kbps.

However, this information signal is not convenient to carry 1 digital video channel because the information signal has a rate of 2 Mbps and 1 digital video channel needs $(6 \times 10^6 \times 2) \text{ samples / sec} \times 8 \text{ bits / sample} = 96 \text{ Mbps}$.

Homework Question 11

Based on E-Carrier European (CEPT) hierarchies, you own 4 different types of multiplexers, E-1, E-2, E-3 and E-4.

- Which of these multiplexers would you prefer to send one digital video channel?
- Which of these multiplexers would you prefer to send 150 digital voice channels?
- How efficient is your choice in part b ? What can happen if you use statistical multiplexer instead ? Explain.

Answer to Homework Question 11

Based on E-Carrier European (CEPT) hierarchies, you own 4 different types of multiplexers, E-1, E-2, E-3 and E-4.

- a. Which of these multiplexers would you prefer to send one digital video channel ?
E-4
- b. Which of these multiplexers would you prefer to send 150 digital voice channels ?
E-3
- d. How efficient is your choice in part b ? What can happen if you use statistical multiplexer instead ? Explain.
It is not efficient because only 150 digital voice channels are used whereas there are 480 digital voice channels available in E-3.

If statistical mux of the right size is used instead, the traffic flow would be more efficient.

Homework Question 12

10000000 = 10^7 books will be downloaded. Each book has average 100 pages, each page has average 100 words, each word has average 4 letters, each letter is encoded by 8 bits. Dense Wavelength Division Multiplexing (DWDM) system with 100 separate wavelengths (channels) is used to download the information. Each wavelength is modulated at 10 Gbps. Assuming no control bits or other bit redundancy is involved in the communication link:

- a. What is the total number of bits that will present the total information content in 10^7 books?
- b. What is the time required to download the total information content in the 10^7 books with the given DWDM system?
- c. What is the number of DWDM channels required so that the same total information content in 10^7 books is downloaded in 32 milliseconds?
- d. Find the number of years required to download the total information content in 10^7 books when a standard 56 Kbps modem is used (assuming full rate is utilized).
- e. xDSL technology is used to download the same total information content in the 10^7 books. If the download takes 17.094 hours, find the rate of the download. Specify the type of xDSL used.

Answer to Homework Question 12

10000000 = 10^7 books will be downloaded. Each book has average 100 pages, each page has average 100 words, each word has average 4 letters, each letter is encoded by 8 bits. Dense Wavelength Division Multiplexing (DWDM) system with 100 separate wavelengths (channels) is used to download the information. Each wavelength is modulated at 10 Gbps. Assuming no control bits or other bit redundancy is involved in the communication link:

- a. What is the total number of bits that will present the total information content in 10^7 books?

The total number of bits that will present the total information content in 10^7 books = $10^7 \times 100 \times 100 \times 4 \times 8 = 3200 \times 10^9$ bits = **3.2 Tbits**

- b. What is the time required to download the total information content in the 10^7 books with the given DWDM system?

The time required to download the total information content in the 10^7 books with the given DWDM system $3.2 \text{ Tbits} / (10 \text{ Gbps} \times 100) = \mathbf{3.2 \text{ sec}}$.

- c. What is the number of DWDM channels required so that the same total information content in 10^7 books is downloaded in 32 milliseconds?

The number of DWDM channels required so that the same total information content in 10^7 books is downloaded in 32 milliseconds

$$\Rightarrow 3.2 \text{ Tbits} / (10 \text{ Gbps} \times (\text{no. of channels})) = 32 \times 10^{-3} \text{ sec}$$

$$\Rightarrow \text{no. of channels} = 3.2 \text{ Tbits} / (10 \text{ Gbps} \times 32 \times 10^{-3} \text{ sec}) = \mathbf{10000 \text{ channels}}$$

- d. Find the number of years required to download the total information content in 10^7 books when a standard 56 Kbps modem is used (assuming full rate is utilized).

The number of years required to download the total information content in 10^7 books when a standard 56 Kbps modem is used (assuming full rate is utilized) = $3.2 \text{ Tbits} / 56 \text{ Kbps} = 57.143.000 \text{ sec} = 57.143.000 \text{ sec} / (365 \text{ days} / \text{year} \times 24 \text{ hrs/day} \times 60 \text{ min./hr} \times 60 \text{ sec} / \text{min}) = 57.143.000 \text{ sec} / (365 \text{ days} / \text{year} \times 86400 \text{ sec} / \text{day}) = \mathbf{1.812 \text{ years}}$

- e. xDSL technology is used to download the same total information content in the 10^7 books. If the download takes 17.094 hours, find the rate of the download. Specify the type of xDSL used.

$$\text{Rate of the download} = 3.2 \text{ Tbits} / (17.094 \text{ hours} \times 60 \text{ min./hr} \times 60 \text{ sec} / \text{min}) = \mathbf{52 \text{ Mbps}}$$

The type of xDSL used is **VDSL**.

Homework Question 13

In a library there exists 448000 books, each book has average 500 pages, each page has average 500 words, each word has average 5 letters, each letter is encoded by 8 bits. Dense Wavelength Division Multiplexing (DWDM) system with 16 separate wavelengths (channels) is used to transmit the information. Each wavelength is modulated at 2.5 Gbps. Assuming no control bits or other bit redundancy is involved in the communication link:

- Find the total number of bits that will present the total information content in the library.
- Find the time needed to transmit the total information content in the library with the given DWDM system.
- Find the number of channels needed if another DWDM is to be used so that the same total information content in the library is transmitted in 112 milliseconds.
- Find the time (in years) needed to transmit the total information content in the library when a standard 56 Kbps modem is used (assume full rate can be utilized).
- xDSL technology is used to download the same total information content in the library. Which of the xDSL technologies would be appropriate to complete the download in less than 1 day? Also specify the maximum transmission distance.

Answer to Homework Question 13

- The total number of bits that will present the total information content in the library = $448000 \times 500 \times 500 \times 5 \times 8 = 4480 \times 10^9 \text{ bits} = 4480 \text{ Gbits} = 4.48 \text{ Tbps}$

- b. The time to transmit the total information content in the library with the given DWDM system = $4480 \text{ Gbits} / (2.5 \text{ Gbps} \times 16) = 112 \text{ sec}$.
- c. The number of channels needed if another DWDM system is to be used so that the same total information content in the library is transmitted in 112 millisecond
 $\Rightarrow 4480 \text{ Gbits} / (2.5 \text{ Gbps} \times (\text{no.of channels})) = 112 \times 10^{-3} \text{ sec}$
 $\Rightarrow \text{no.of channels} = 4480 \text{ Gbits} / (2.5 \text{ Gbps} \times 112 \times 10^{-3} \text{ sec}) = 16000$
- d. The time needed to transmit the total information content in the library when a standard 56 Kbps modem is used (assuming full rate can be utilized) = $4480 \text{ Gbits} / 56 \text{ Kbps} = 80.000.000 \text{ sec} = 2.54 \text{ year}$
- e. $4480 \text{ Gbits} / (\text{Download rate of xDSL}) = 1 \text{ day} \times 24 \text{ hrs/day} \times 60 \text{ min./hr} \times 60 \text{ sec} / \text{min} = 86400 \text{ sec}$
 $\Rightarrow \text{Download rate of xDSL} = 4480 \text{ Gbits} / 86400 \text{ sec} = 51,851,852 \text{ bits/sec}$

This download rate can only be supported by VDSL for maximum transmission distance of 300 meters.

Homework Question 14

For a single TV channel, the bandwidth can be taken as 6 MHz.

- What is the maximum number of analog voice channels that can be transmitted in two TV channels?
- What is the required minimum bit rate to transmit one TV channel digitally, if one sample value is represented by 10 bits?
- What is the required minimum bit rate to transmit one TV channel digitally, if one sample value is represented by 256 levels?
- Maximum how many digital voice channels can be transmitted in one digital TV channel given in part c?
- For the transmission of the bit rate you found in part b, which E-Carrier European (CEPT) level do you need?

Answer to Homework Question 14

For a single TV channel, the bandwidth can be taken as 6 MHz.

- What is the maximum number of analog voice channels that can be transmitted in two TV channels?
 One analog voice channel bandwidth is $4 \text{ KHz} = 4 \times 10^3 \text{ Hz}$.
 In 6 MHz band, there are $(6 \times 10^6 \text{ Hz}) / (4 \times 10^3 \text{ Hz}) = 1500$ times 4 KHz.
 So, maximum number of analog voice channels that can be transmitted in two TV channels = 3000.
- What is the required minimum bit rate to transmit one TV channel digitally, if one sample value is represented by 10 bits?
 Sampling by twice the maximum frequency $\Rightarrow 6 \text{ MHz} \times 2 = 12 \text{ M samples per second}$
 To represent the sample with 10 bits means 10 bits / sample

Minimum Bit Rate= 12 M samples per second x 10 bits / sample = 120 Mbps

- c. What is the required minimum bit rate to transmit one TV channel digitally, if one sample value is represented by 256 levels?

Sampling by twice the maximum frequency $\Rightarrow 6 \text{ MHz} \times 2 = 12 \text{ M samples per second}$
To represent the sample with 256 levels means 8 bits / sample

Minimum Bit Rate= 12 M samples per second x 8 bits / sample = 96 Mbps

- d. Maximum how many digital voice channels can be transmitted in one digital TV channel given in part c?

One digital voice channel at the same number of bits representing one sample is 64 Kbps

In 96 Mbps, there are $96 \text{ M} / 64 \text{ K} = 1500$.

So, the maximum number of digital voice channels that can be transmitted in one digital channel is 1500.

- e. For the transmission of the bit rate you found in part b, which E-Carrier European (CEPT) level do you need?

Fourth level (E-4) 139.264 Mb/s (1920 Ch.)

Homework Question 15

- a. Assuming that there are 2 billion telephone subscribers in the world and each subscriber is connected to the telephone exchange with twisted pair cable at an average distance of 4 km. If the cost of the twisted pair cable is 0.5 YTL /meter, find the total value (in YTL) of the twisted pair cable installed in such infrastructure.
- b. Based on the result obtained in part a, what can you comment on the feasibility of fiber optics and DSL technology applications used in the local loop part of the telecommunication network? Explain.

Answer to Homework Question 15

- a. Assuming that there are 2 billion telephone subscribers in the world and each subscriber is connected to the telephone exchange with twisted pair cable at an average distance of 4 km. If the cost of the twisted pair cable is 0.5 YTL /meter, find the total value (in YTL) of the twisted pair cable installed in such infrastructure.

Solution: The total value (in YTL) of the twisted pair cable installed in such infrastructure is

(2 billion telephone subscribers) x (3 km / subscriber) x (1000 m / km) x (0.1 YTL /meter)

$= 2 \times 10^9 \times 4000 \times 0.5 \text{ YTL} = 4 \times 10^{12} \text{ YTL} = 4000 \times 10^9 \text{ YTL} \approx 3000 \text{ bilion } \$$

- b. Based on the result obtained in part a, what can you comment on the feasibility of fiber optics and DSL technology applications used in the local loop part of the telecommunication network? Explain.

Solution: Currently, fiber optics connection to all the local loop subscribers is not feasible since very big investment will be needed to replace the existing twisted pair installations. Under the present conditions, DSL technologies that utilize the existing twisted pair infrastructure seem much more feasible.

Homework Question 16

A 10 mile link operates at 10 GHz . Both transmitting and receiving antenna gains are 28.3 dBi each and cabling loss both at the transmitter and at the receiver are 5 dB each. Output power of the transmitter is 10 dBm.

- Find the Unfaded Received Signal Level.
- If a Fade Margin of 20 dB is used in the design, find the Receiver Sensitivity Threshold required.
- Changing the operating frequency of the link to 1 GHz and keeping all the other link parameters the same, find the Unfaded Received Signal Level.
- If for the 1 GHz link, the same receiver is used as in part b, find the Fade Margin.
- Which is a better design, part b or part d ? Explain.

Answer to Homework Question 16

A 10 mile link operates at 10 GHz . Both transmitting and receiving antenna gains are 28.3 dBi each and cabling loss both at the transmitter and at the receiver are 5 dB each. Output power of the transmitter is 10 dBm.

- Find the Unfaded Received Signal Level.

$$FSL = 96.6 + 20 \log D + 20 \log F = 96.6 + 20 \log 10 + 20 \log 10 = 96.6 + 20 + 20 = 136.6 \text{ dB}$$

$$P_o - L_{ctx} + G_{atx} - L_{crx} + G_{arx} - FSL = RSL$$

$$RSL = 10 \text{ dBm} - 5 \text{ dB} + 28.3 \text{ dBi} - 5 \text{ dB} + 28.3 \text{ dBi} - 136.6 \text{ dB} = -80 \text{ dBm}$$

- If a Fade Margin of 20 dB is used in the design, find the Receiver Sensitivity Threshold required.

$$\text{Fade Margin} = \text{Unfaded Receive Signal Level} - \text{Receiver Sensitivity Threshold}$$

$$\text{Receiver Sensitivity Threshold} = -80 \text{ dBm} - 20 \text{ dB} = -100 \text{ dBm}$$

- Changing the operating frequency of the link to 1 GHz and keeping all the other link parameters the same, find the Unfaded Received Signal Level.

$$FSL = 96.6 + 20 \log D + 20 \log F = 96.6 + 20 \log 10 + 20 \log 1 = 96.6 + 20 + 0 = 116.6 \text{ dB}$$

$$P_o - L_{ctx} + G_{atx} - L_{crx} + G_{arx} - FSL = RSL$$

$$RSL = 10 \text{ dBm} - 5 \text{ dB} + 28.3 \text{ dBi} - 5 \text{ dB} + 28.3 \text{ dBi} - 116.6 \text{ dB} = -60 \text{ dBm}$$

- If for the 1 GHz link, the same receiver is used as in part b, find the Fade Margin.

$$\text{Fade Margin} = \text{Unfaded Receive Signal Level} - \text{Receiver Sensitivity Threshold}$$

$$= -60 \text{ dBm} - (-100 \text{ dBm}) = 40 \text{ dB}$$

- Which is a better design, part b or part d ? Explain.

If the fade margin of 40 dB is needed due to atmospheric conditions of the microwave link in part d, then part d is a better design. If the atmospheric conditions of the microwave link in part d do not require 40 dB fade margin, but can still perform with 20 dB fade margin, then part b is a better design.

Homework Question 17

Given 3 microwave systems; M1 operating at L-Band, M2 operating at C-Band and M3 operating at millimeter wave. Assuming all the other system parameters (such as transmitter power, atmospheric conditions, receiver sensitivity, ...etc) are the same for all these 3 systems.

- Which one of these 3 would you prefer if you want to design a longest possible link?
- Which one of these 3 would you prefer if you want to design a link able to transmit the highest information bandwidth?
- Considering no fade margin, what should be the receiver sensitivity threshold in dBm if 1 mile microwave link operating at 1 GHz is used whose output power is 1 dBm, both transmitting and receiving antenna gains are 25 dBi each and cabling loss both at the transmitter and at the receiver is of 2.2 dB each.
- Find the fade margin if the receiver sensitivity threshold of the system given in part c is -70 dBm.
- Which one of the links designed in part c and part d will be available with higher probability? Why?

Answer to Homework Question 17

- Longest possible link is achieved by the lowest frequency link which is M1.
- Highest carrier frequency has the possibility to carry the highest information bandwidth. Thus M3 will transmit the highest information bandwidth.
- Free Space Loss $FSL = 96.6 + 20 \log D + 20 \log F = 96.6 + 20 \log 1 + 20 \log 1 = 96.6$ dB
 $P_o - L_{ctx} + G_{atx} - L_{crx} + G_{atx} - FSL = RSL$
 Received Signal Level, $RSL = 1 \text{ dBm} - 2.2 \text{ dB} + 25 \text{ dBi} - 2.2 \text{ dB} + 25 \text{ dBi} - 96.6 \text{ dB}$
 $= -50 \text{ dBm}$
 Since there is no fade margin, receiver sensitivity threshold = $RSL = -50 \text{ dBm}$
- Fade Margin = Unfaded Receive Signal Level - Receiver Sensitivity Threshold
 $= -50 \text{ dBm} - (-70 \text{ dBm}) = 20 \text{ dBm}$
- Link design in part d will be available with higher probability because it has 20 dBm fade margin whereas the link design in part c has no fade margin.

Homework Question 18

The first microwave link (LINK-1) operating at 10 GHz has a link distance of 1 mile. The second microwave link (LINK-2) operates at 1 GHz. In both of the links, both transmitting and receiving antenna gains are 20 dBi each and cabling loss both at the transmitter and at the receiver are 2 dB each.

- What should be the link distance in the second link (LINK-2) so that both links (LINK-1 and LINK-2) have the same free space loss?
- Find the Received Signal Level in LINK-1 if the output power of the transmitter in LINK-1 is 10.6 dBm.
- Find the output power of the transmitter in LINK-2 if the Received Signal Level in LINK-2 is -72.6 dBm.
- The Receiver Sensitivity Threshold (R_x) for LINK-1 is - 90 dBm and the Receiver Sensitivity Threshold for LINK-2 is - 60 dBm. Can LINK-1 and LINK-2 operate? Why?
- For a given microwave transmitter and receiver system, you have made an unsuccessful link design. What can you do to make this link operate?

Answer to Homework Question 18

The first microwave link (LINK-1) operating at 10 GHz has a link distance of 1 mile. The second microwave link (LINK-2) operates at 1 GHz. In both of the links, both transmitting and receiving antenna gains are 20 dBi each and cabling loss both at the transmitter and at the receiver are 2 dB each.

- What should be the link distance in the second link (LINK-2) so that both links (LINK-1 and LINK-2) have the same free space loss?

$$\text{For LINK-1: } FSL = 96.6 + 20\log 1 + 20\log 10 = 96.6 + 0 + 20 = 116.6 \text{ dB}$$

$$\text{For LINK-2: } FSL = 116.6 \text{ dB} = 96.6 + 20\log D + 20\log 1 = 96.6 + 20\log D + 0$$

$$116.6 \text{ dB} = 96.6 + 20\log D \text{ ,i.e., } \log D = 1 \text{ , } D = \mathbf{10 \text{ miles}}$$

- Find the Received Signal Level in LINK-1 if the output power of the transmitter in LINK-1 is 10.6 dBm.

$$P_o - L_{ctx} + G_{atx} - L_{crx} + G_{atr} - FSL = RSL$$

$$RSL = 10.6 \text{ dBm} - 2 \text{ dB} + 20 \text{ dBi} - 2 \text{ dB} + 20 \text{ dBi} - 116.6 \text{ dB} = \mathbf{- 70 \text{ dBm}}$$

- Find the output power of the transmitter in LINK-2 if the Received Signal Level in LINK-2 is -72.6 dBm.

$$P_o = RSL + L_{ctx} - G_{atx} + L_{crx} - G_{atr} + FSL$$

$$P_o = -72.6 \text{ dBm} + 2 \text{ dB} - 20 \text{ dBi} + 2 \text{ dB} - 20 \text{ dBi} + 116.6 \text{ dB} = \mathbf{8 \text{ dBm}}$$

- The Receiver Sensitivity Threshold (R_x) for LINK-1 is - 90 dBm and the Receiver Sensitivity Threshold for LINK-2 is - 60 dBm. Can LINK-1 and LINK-2 operate? Why?

For LINK-1, $RSL = - 70 \text{ dBm} > R_x = - 90 \text{ dBm}$. i.e., LINK-1 can operate.

For LINK-2, $RSL = -72.6 \text{ dBm} < R_x = - 60 \text{ dBm}$. i.e., LINK-2 can not operate.

- For a given microwave transmitter and receiver system, you have made an unsuccessful link design. What can you do to make this link operate?

For the given microwave transmitter and receiver system, to make the link operate, link distance should be reduced.

Homework Question 19

Write 2 basic similarities and 3 basic differences between LMDS and FSO Systems.

Answer to Homework Question 19

LMDS	FSO
Atmospheric Link	Atmospheric Link
Access System	Access System
Microwave frequencies	Optical (Infrared) frequencies
Up to 622 Mbps	Can be up to 2.5 Gbps or even DWDM
Can cover up to 5 km	Coverage is 1.5-2 km

Homework Question 20

Explain the difference between Time Division Duplexing (TDD) and Frequency Division Duplexing (FDD) in LMDS.

Answer to Homework Question 20

In Time Division Duplexing (TDD), the subscriber and the base station take turns talking to each other. At any time, both parties will use the entire spectrum allocated for that link.

In Frequency Division Duplexing (FDD), the uplink and the downlink use different frequency bands separated by a large guard band.

Homework Question 21

In each of the below items (i, ii, iii, iv, v) 5 systems are named. For each item, write the name of the system which is unrelated to the other 4 systems.

- i. Microwave, Radio Link, MMDS, Optical Fiber, LMDS
- ii. STM-1, E-1, T-3, PDH, 2 Mbps/8 MBps Multiplexer
- iii. FSO, SDH, LMDS, Fiber, STM-16
- iv. PSTN, Circuit Switching, Packet Switching, PBX, E-1
- v. ISDN, ADSL, Twisted Pair Cable, Coaxial Cable, Local Loop

Answer to Homework Question 21

In each of the below items (i, ii, iii, iv, v) 5 systems are named. For each item, write the name of the system which is unrelated to the other 4 systems.

- i. Microwave, Radio Link, MMDS, Optical Fiber, LMDS
Answer: Optical Fiber
- ii. STM-1, E-1, T-3, PDH, 2 Mbps/8 MBps Multiplexer
Answer: STM-1
- iii. FSO, SDH, LMDS, Fiber, STM-16

Answer: LMDS

v. PSTN, Circuit Switching, Packet Switching, PBX, E-1

Answer: Packet Switching

v. ISDN, ADSL, Twisted Pair Cable, Coaxial Cable, Local Loop

Answer: Coaxial Cable

Homework Question 22

Write 1 common feature and 4 differences between Fiber Optic and Satellite Systems.

Answer to Homework Question 22

Fiber Optic Systems	Satellite Systems
Long Distance Communications	Long Distance Communications
Optical frequencies	Microwave frequencies
Cable	Free Space
10 Gbps - 40 Tbps	155 Mbps
Point-to-point or point-multipoint	Broadcast

Homework Question 23

If you have options of Twisted Pair, Coaxial, Microwave, Satellite and Optical Fiber Communication Systems. Using all of these systems, which one would you prefer to use for the following telecommunication applications:

- i. Broadcast of a Turkish TV channel from Türkiye to Germany.
- ii. Telephone traffic from Ankara to İstanbul.
- iii. Low data rate LAN
- iv. Multimedia transmission from Erzurum to Trabzon
- v. Cable TV distribution in Adana

Answer to Homework Question 23

- i. Broadcast of a Turkish TV channel from Türkiye to Germany: Satellite
- ii. Telephone traffic from Ankara to İstanbul: Optical Fiber
- iii. Low data rate LAN: Twisted Pair
- iv. Multimedia transmission from Erzurum to Trabzon: Microwave
- v. Cable TV distribution in Adana: Coaxial

Homework Question 24

What are the advantages and disadvantages of satellite telecommunication systems as compared to terrestrial telecommunication systems.

Answer to Homework Question 24

Advantages of satellite telecommunication systems as compared to terrestrial telecommunication systems:

- Access to remote areas
- Coverage of large geographical areas
- Insensitivity to topology
- Cost is independent of distance

Disadvantages of satellite telecommunication systems as compared to terrestrial telecommunication systems:

- High initial cost
- Propagation delay with GEO systems
- Licencing requirements

Homework Question 25

- What are the wavelengths commonly used in optical fiber communication (OFC) systems?
- Which wavelength would you prefer for very long distance repeaterless OFC? Why?
- Which wavelength would you prefer for very high rate OFC? Why?

Answer to Homework Question 25

- 1310 nm, 1550 nm, 800 nm – 900 nm are the wavelengths commonly used in optical fiber communication (OFC) systems.
- 1550 nm because this wavelength provides the minimum attenuation in the fiber.
- 1310 nm because this wavelength provides the minimum dispersion in the fiber.

Homework Question 26

Compare Twisted Pair, Coaxial, Microwave, Satellite, Fiber and Free Space Optics Communication Systems in terms of:

- Frequency of Operation,
- Maximum Bit Rate which is possible to transmit,
- Distance Between Repeaters.

Answer to Homework Question 26

Medium Type	Frequency of Operation	Maximum Bit Rate	Distance Between Repeaters
Twisted Pair	1MHz - 100MHz - 1GHz	2Mbps-100Mbps-1Gbps	2 km - 100 m
Coaxial	1 GHz	565 Mbps	2-3 km
Microwave	300 MHz - 40 GHz	622 Mbps	30-70 km
Satellite	390 MHz - 30 GHz	155 Mbps	800-1500-36000 km
Fiber	750 -194 THz	2.5 -10 Gbps -150 Tbps	50 -100 -6000 km
Free Space Optics	750 -194 THz	2.5 -10 Gbps -150 Tbps	1.5 -4 km

Homework Question 27

You have a multimode and a single mode fiber.

- a. Write their core diameters, cladding diameters,
- b. Which one is preferred for long distance communication and for LAN applications?
- c. Which one is preferred to be used with an LED and with a laser diode?

Answer to Homework Question 27

- a. For multimode fibers, core diameters are 50, 62.5 and 100 micrometers, corresponding cladding diameters are 125, 125 and 140 micrometers. For singlemode fibers, core diameter is 9 micrometers, cladding diameter is 125 micrometers.
- b. Singlemode fibers are preferred for long distance communication and multimode fibers are preferred for LAN applications.
- c. Multimode fibers are preferred to be used with an LED. Singlemode fibers are preferred to be used with a laser diode?

Homework Question 28

- a. List the disturbances due to the atmosphere which effects Free Space Optical communication systems.
- b. List the disturbances other than atmosphere which effects Free Space Optical communication systems

Answer to Homework Question 28

- a. Disturbances due to the atmosphere effecting Free Space Optical communication systems are:
 - Fog: Major effect to FSO.
 - Rain and Snow: Have relatively little effect.
 - Molecular Absorption
 - Aerosol Absorption
 - Molecular Scattering
 - Aerosol Scattering
 - Scintillation
 - Beam Wander
 - Beam Spreading
- b. Disturbances other than atmosphere which effects Free Space Optical communication systems are:
 - Physical obstructions: Flying birds can temporarily (for a short time) block a single beam
 - Building sway/seismic activity: Movement of buildings can disturb receiver and transmitter alignment.
 - Safety: Human exposure to laser beams

Homework Question 29

Describe the "packet" used in packet switching networks.

Answer to Homework Question 29

A packet (or frame, block, cell or datagram) is a container carrying control and data bits. Control and data bits can each be in various sizes, i.e. can contain different number of bits. Control bits (start, header, destination address, data sequence number, stop, ...etc) are used by the network nodes to route the packet under certain protocol (available bandwidth, existing noise, need for retransmission, latency considerations, ... etc).

Homework Question 30

- a. Explain how the communication is established in circuit switching.
- b. Explain how the communication is established in packet switching

Answer to Homework Question 30

- a. Establishment of communication in circuit switching:
 - When requested by the end user (for example when the user dials up the phone), a circuit is formed between the calling and the called party,
 - A fixed share of the network resources for that connection are reserved for this specific communication during the full duration of conversation. I.e no other call can use those resources until the communication ends. This means that the capacity provisioned on that specific path can only be used by this call, no one else can share or use the capacity available on that path,
 - When the conversation is over, connection is released, i.e the circuit is disconnected.
- b. Establishment of communication in packet switching:
 - A packet (or frame, block, cell or datagram) is generated
 - Packets are stored-and-forwarded by packet switches up to the destination
 - Packets from many different sources are statistically multiplexed and sent to their destinations over virtual circuits
 - Packet switches examine packet header and check destination against a routing table
 - Packets are routed to the specified nodes.

Homework Question 31

Write 2 basic similarities and 3 basic differences between Fiber Optic and FSO Systems.

Answer to Homework Question 31

Write 2 basic similarities and 3 basic differences between Fiber Optic and FSO Systems.

Basic similarities:

- Both operate at optical carrier wavelengths,
- Both can handle very high information rates

Basic differences:

- Fiber Optics is used both in backbone and access networks, FSO is used mainly in the access networks,

- Repeaterless link distance in Fiber Optics can be hundred (or even thousand) kilometers where in FSO repeaterless link distance is maximum 4 – 5 km,
- Fiber Optics uses transmission medium of optical fiber cable whereas FSO uses atmospheric transmission.

Homework Question 32

Write 2 basic similarities and 3 basic differences between Microwave and Satellite Systems.

Answer to Homework Question 32

Write 2 basic similarities and 3 basic differences between Microwave and Satellite Systems.

Basic similarities:

- Both operate at microwave frequencies,
- Both are wireless systems

Basic differences:

- Repeaterless transmission distance in Microwave Systems is much shorter,
- Satellites can transmit to, and receive from, a large area (foot print or coverage), thus advantageous in point-to-multipoint and broadcast applications,
- Propagation delay is quite important in satellite communications, not so important in microwave.

Homework Question 33

Write 1 basic similarity and 4 basic differences between the Twisted Pair and the Coaxial Systems.

Answer to Homework Question 33

Write 1 basic similarity and 4 basic differences between the Twisted Pair and the Coaxial Systems.

Basic similarity:

- Both use cable transmission,

Basic differences:

- Twisted Pair is not secure, coaxial is relatively more secure,
- Twisted Pair is usually for slow rate transmission and very high rate transmission can be realized for very short distances. Coaxial is higher bandwidth for longer distances.
- Coaxial Systems are usually used mainly in CATV networks whereas Twisted Pairs are employed in the classical analog local loop, xDSL and LAN applications,
- Twisted Pair is usually less expensive than coax and easier to install and reconfigure.

Homework Question 34

Among the Twisted Pair, FSO, Microwave, Satellite and Optical Fiber Communication Systems, which one will fit the best for the following telecommunication applications:

- Heavy telephone traffic from İstanbul to İzmir.
- ADSL.
- Broadcast of Turkish TV channels to Germany.
- Multimedia transmission from Mersin to Konya.
- 1 Gbps access network in Ulus, Ankara.

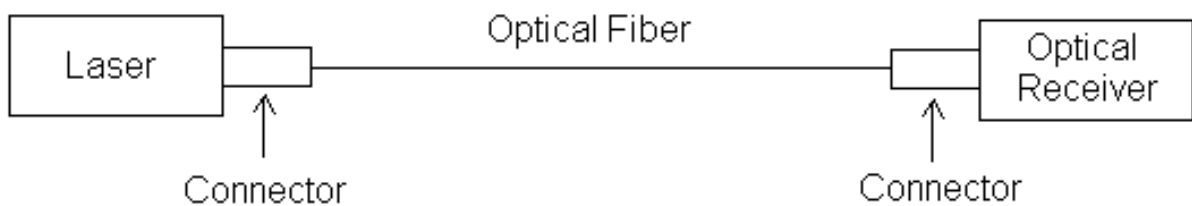
Answer to Homework Question 34

Among the Twisted Pair, FSO, Microwave, Satellite and Optical Fiber Communication Systems, which one will fit the best for the following telecommunication applications:

- Heavy telephone traffic from İstanbul to İzmir.
Answer: Optical Fiber Communication
- ADSL.
Answer: Twisted Pair
- Broadcast of Turkish TV channels to Germany.
Answer: Satellite
- Multimedia transmission from Mersin to Konya.
Answer: Microwave
- 1 Gbps access network in Ulus, Ankara.
Answer: FSO

Homework Question 35

A basic block diagram of a fiber optics communication system is given below:



Link values are given in the below table:

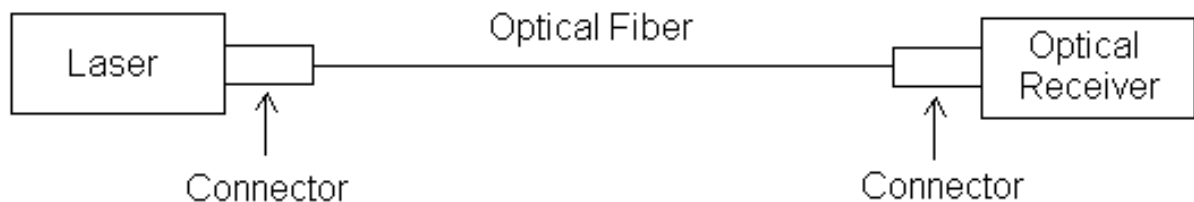
LINK ELEMENT	VALUE
Laser output power	10 dBm
Laser to optical fiber connector loss	1 dB
Optical fiber attenuation	0.3 dB / km
Optical fiber to receiver connector loss	1 dB
Receiver Sensitivity	-60 dBm

Length of the optical fiber	100 km
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- Find the optical power delivered at the optical receiver.
- Find the power margin in the link design of part a.
- We have the same link values as given by the above table, except the length of the optical fiber is changed. Assuming that a power margin of 14 dBm is reasonable in the link design, find the maximum length of the optical fiber that can be used in the link design.
- What happens if the optical fiber used in part c is 300 km?
- What happens if the optical fiber used in part c is 50 km?

Answer to Homework Question 35

A basic block diagram of a fiber optics communication system is given below:



Link values are given in the below table:

LINK ELEMENT	VALUE
Laser output power	10 dBm
Laser to optical fiber connector loss	1 dB
Optical fiber attenuation	0.3 dB / km
Optical fiber to receiver connector loss	1 dB
Receiver Sensitivity	-60 dBm
Length of the optical fiber	100 km

- Find the optical power delivered at the optical receiver.

Optical power delivered at the optical receiver

$$= 10 \text{ dBm} - 1 \text{ dB} - (0.3 \text{ dB / km}) \times 100 \text{ km} - 1 \text{ dB} = \mathbf{-22 \text{ dBm}}$$

- Find the power margin in the link design of part a.

$$\text{Power margin} = -22 \text{ dBm} - (-60 \text{ dBm}) = \mathbf{38 \text{ dB}}$$

- We have the same link values as given by the above table, except the length of the optical fiber is changed. Assuming that a power margin of 14 dBm is reasonable in the link design, find the maximum length of the optical fiber that can be used in the link design.

$$\text{Power margin} = 14 \text{ dBm} = \text{Optical power delivered at the optical receiver} - (-60 \text{ dBm})$$

i.e., Optical power delivered at the optical receiver = 14 dBm - 60 dBm = -46 dBm

-46 dBm = 10 dBm - 1 dB - (0.3 dB / km) x (the maximum length of the optical fiber that can be used) - 1 dB

(0.3 dB / km) x (the maximum length of the optical fiber that can be used) = 8 - (-46) = 54 dB

The maximum length of the optical fiber that can be used = 54 dB / 0.3 dB / km = **180 km**

d. What happens if the optical fiber used in part c is 300 km?

The link will not function

e. What happens if the optical fiber used in part c is 50 km?

The link will function, however the laser and / or the optical fiber and / or the receiver chosen will have unnecessarily better specifications than required. Thus the link design will be unnecessarily expensive.

Homework Question 36

In SDH system, mapping of data packets on an STM-1 frame is done by placing the data packets in the STM-1 payload area where three columns of bytes is secured as Path Overhead (POH) in the STM-1 payload area. RSOH, AU Pointer and MSOH occupy their known columns of bytes. Data packets to be transported are composed of 53 bytes each where 5 bytes are overhead and 48 bytes are data. Assuming that the packets can be split between the two consecutive rows in the STM-1 payload area:

- Find the maximum integer number of packets that an STM-1 frame can carry.
- If each of the packets in part a has 47 bytes data, find the number of data bits (carrying information) in one STM-1 frame.
- What percent of the total STM-1 capacity is used by the information found in part b.
- Find the rate of the information found in part b.
- Find the rate (in bits / sec) of transport of the packets (overhead+data) found in part a.

Answer to Homework Question 36

In SDH system, mapping of data packets on an STM-1 frame is done by placing the data packets in the STM-1 payload area where three columns of bytes is secured as Path Overhead (POH) in the STM-1 payload area. RSOH, AU Pointer and MSOH occupy their known columns of bytes. Data packets to be transported are composed of 53 bytes each where 5 bytes are overhead and 48 bytes are data. Assuming that the packets can be split between the two consecutive rows in the STM-1 payload area:

- Find the maximum integer number of packets that an STM-1 frame can carry.

In the STM-1 frame, first 9 columns of bytes are reserved for RSOH, AU Pointer and MSOH, leaving $270-9 = 261$ columns of bytes for the payload area.

Three column of bytes are secured for the path overhead (POH) in the payload area leaving $261 - 3 = 258$ columns of bytes for the payload area.

One column is 9 bytes. Thus there are total space for $258 \times 9 = 2322$ bytes in the payload area.

Packet size is fixed and 53 bytes

Since packets can be split between the two consecutive rows in the payload area, the maximum integer number of ATM cells that an STM-1 frame can carry = $2322 / 53 = 43$ packets.

- b. If each of the packets in part a has 47 bytes data, find the number of data bits (carrying information) in one STM-1 frame.

In one packet, there are 47 bytes of data, i.e., 47 payload bytes.

Thus, in one packet, there are $47 \text{ bytes} \times 8 \text{ bits / byte} = 376$ bits of data in one packet, i.e. 376 payload bits.

In part a, 43 packets are found in one STM-1 frame.

i.e., there are $376 \times 43 = 16,168$ bits of data (carrying information) in one STM-1 frame

- c. What percent of the total STM-1 capacity is used by the information found in part b.

STM-1 frame carries a total of (headers + information) $9 \text{ rows} \times 270 \text{ columns} = 2,430$ bytes = $2,430 \text{ bytes} \times 8 \text{ bits / byte} = 19,440$ bits

Thus $16,168 \text{ bits} / 19,440 \text{ bits} \times 100 = 83.17 \%$ of the total STM-1 capacity is used by the actual information as found in part b.

- d. Find the rate of the information found in part b.

One STM-1 frame is transmitted every 0.000125 seconds (1/8000th of a second)

In part b, it is found that the information in one STM-1 frame is 16,168 bits

Thus rate of the information found in part b is 16,168 bits in 0.000125 seconds. i.e $16,168 \text{ bits} \times (1/0.000125 \text{ sec}) = 129.344 \text{ Mbps}$

- e. Find the rate (in bits / sec) of transport of the packets (overhead+data) found in part a.

In one STM-1 frame, 43 packets are found in part a.

43 packets are $43 \text{ packets} \times 53 \text{ bytes/packet} \times 8 \text{ bits / byte} = 18,232$ bits in one STM-1 frame.

Thus rate of packets found in 1.a above is 18,232 bits in 0.000125 seconds, i.e., $18,232 \text{ bits} \times (1/0.000125 \text{ sec}) = 145.856 \text{ Mbps}$

Homework Question 37

In the STM-1 frame of an SDH system, RSOH, AU Pointer and MSOH occupy their known columns of bytes and the Path Overhead (POH) occupies 3 columns from column 10 to column 12. Data packets of 576 bytes each are loaded in the remaining part (i.e., the payload area) of the STM-1 frame. 24 bytes of the data packets are overhead and the remaining 552 bytes contain the actual data. Assuming that the packets can be split between the two consecutive rows in the STM-1 payload area,

- Maximum how many data packets can be transported in one STM-1 frame ? Note: Your answer should be an integer number)
- How many actual data bits exist within the total number of data packets found in part a ?
- What is the actual data rate ?
- Find the percentage of the total STM-1 capacity which is occupied by **none** actual data.
- Assuming that the packets can be split between the 2 consecutive frames in the STM-1 payload area, how many frames do you need to load 80 data packets of 53 bytes each.

Answer to Homework Question 37

In the STM-1 frame of an SDH system, RSOH, AU Pointer and MSOH occupy their known columns of bytes and the Path Overhead (POH) occupies 3 columns from column 10 to column 12. Data packets of 576 bytes each are loaded in the remaining part (i.e., the payload area) of the STM-1 frame. 24 bytes of the data packets are overhead and the remaining 552 bytes contain the actual data. Assuming that the packets can be split between the two consecutive rows in the STM-1 payload area,

- Maximum how many data packets can be transported in one STM-1 frame ? Note: Your answer should be an integer number)

In the STM-1 frame, first 9 columns of bytes are reserved for RSOH, AU Pointer and MSOH, leaving $270 - 9 = 261$ columns of bytes

Three column of bytes are secured for the path overhead (POH) leaving $261 - 3 = 258$ columns of bytes for the payload area.

One column is 9 bytes. Thus there are total space for $258 \times 9 = 2322$ bytes in the payload area.

Packet size is fixed and 576 bytes

Since packets can be split between the two consecutive rows in the payload area, the maximum number of data packets that can be transported in one STM-1 frame = $2322 / 576 = 4$ data packets.

- How many actual data bits exist within the total number of data packets found in part a ?

In one packet, there are 552 bytes of actual data, i.e., 552 payload bytes.

Thus, in one packet, there are $552 \text{ bytes} \times 8 \text{ bits / byte} = 4416$ bits of actual data in one packet, i.e. 4416 payload bits.

In part a, 4 packets are found in one STM-1 frame.

i.e., there are total of $4416 \times 4 = 17,664$ bits of actual data (carrying information) in one STM-1 frame

c. What is the actual data rate ?

One STM-1 frame is transmitted every 0.000125 seconds (1/8000th of a second)

In part b, it is found that the actual data in one STM-1 frame is 17,664 bits

Thus the rate of the actual data found in part b, is 17,664 bits in 0.000125 seconds. i.e $17,664 \text{ bits} \times (1/0.000125 \text{ sec}) = 141.312 \text{ Mbps}$

d. Find the percentage of the total STM-1 capacity which is occupied by **none** actual data.

Total STM-1 capacity is 9 rows X 270 columns = 2,430 bytes = 2,430 bytes x 8 bits / byte) = 19,440 bits

In part c, it is found that the actual data in one STM-1 frame is 17,664 bits,

So, **none** actual data in one STM-1 frame is $19,440 \text{ bits} - 17,664 \text{ bits} = 1,776 \text{ bits}$

Thus $1,776 \text{ bits} / 19,440 \text{ bits} \times 100 = 9.13 \%$ of the total STM-1 capacity is occupied by **none** actual data.

e. Assuming that the packets can be split between the 2 consecutive frames in the STM-1 payload area, how many frames do you need to load 80 data packets of 53 bytes each.

To load 80 data packets of 53 bytes each, we need $80 \times 53 \text{ bytes} = 4,240 \text{ bytes}$ in the payload area

There are total space for $258 \times 9 = 2,322 \text{ bytes}$ in the payload area in one STM-1 frame.

In two STM-1 frames, we have total of $2,322 \text{ bytes} \times 2 = 4,644 \text{ bytes}$ of payload area which is more than 4,240 bytes (which is needed to load 80 data packets of 53 bytes each).

Thus we need 2 frames.

Homework Question 38

- a. Write the basic structure of all IP packets.
- b. Draw the IPv4 packet structure and briefly explain all the fields if the header is 28 bytes with 7 bytes options field and the total packet size is 576 bytes.

Answer to Homework Question 38

- a. Write the basic structure of all IP packets.
 - All IP packets are structured the same way:
 - An IP header and
 - Followed by a variable-length data field

- b. Draw the IPv4 packet structure and briefly explain all the fields if the header is 28 bytes with 7 bytes options field and the total packet size is 576 bytes.

Bits	0	4	8	16	19	24	31
	Version	IHL	Type of Service		Total Length		
	Identification				Flags	Fragment Offset	
	Time To Live		Protocol		Header Checksum		
	Source IP Address						
	Destination IP Address						
	Options						
	Options					Padding	
	Data (576 - 28 bytes = 548 bytes i.e., 548 / 4 = 137 rows)						

Version (4 bits): Indicates the format of the internet header.

IHL (Internet Header Length) (4 bits): Is the length of the internet header in 32 bit words.

Type of Service (8 bits): Provides an indication of the abstract parameters of the quality of service desired.

Total Length (16 bits): Is the length of the datagram, measured in bytes, including internet header and data.

Identification (16 bits): An identifying value assigned by the sender to aid in assembling the fragments of a datagram.

Flags (3 bits): Various Control Flags.

Bit 0: reserved, must be zero

Bit 1: (DF) 0 = May Fragment, 1 = Don't Fragment.

Bit 2: (MF) 0 = Last Fragment, 1 = More Fragments.

Fragment Offset (13 bits): Indicates where in the datagram this fragment belongs. The fragment offset is measured in units of 8 bytes (64 bits). The first fragment has offset zero.

Time to Live (TTL) (8 bits): Indicates the maximum time the datagram is allowed to remain in the internet system. If this field contains the value zero, then the datagram must be destroyed. This field is modified in internet header processing.

Protocol (8 bits): Indicates the next level protocol used in the data portion of the internet datagram.

Header Checksum (16 bits): A checksum on the header only. Since some header fields change (e.g., time to live), this is recomputed and verified at each point that the internet header is processed.

Source Address (32 bits)

Destination Address (32 bits)

Options (56 bits):

Padding (8 bits): The internet header padding is used to ensure that the internet header ends on a 32 bit boundary. The padding is zero.

Data: (548 bytes = 137 rows)

Homework Question 39

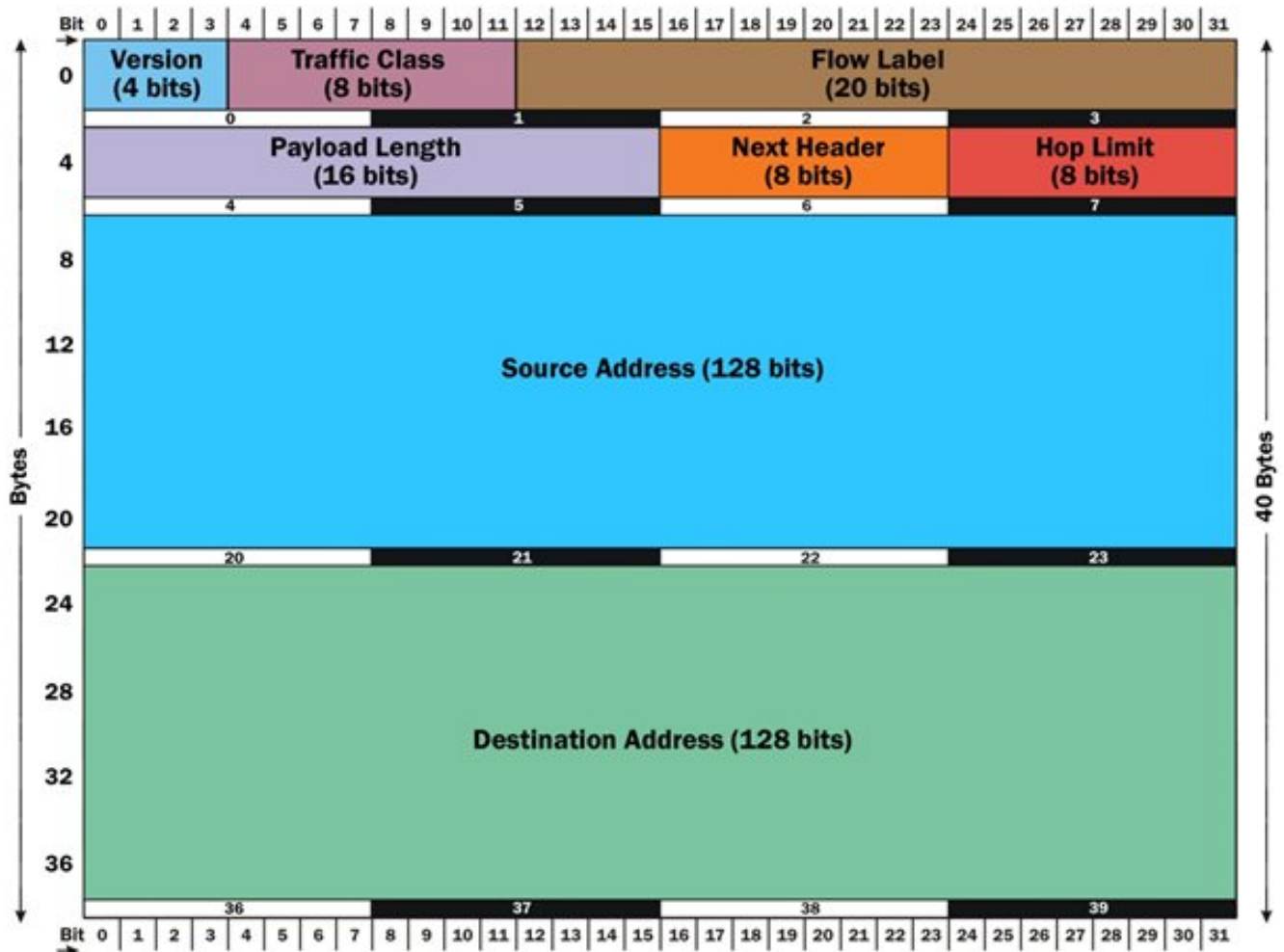
Show the IPv6 packet structure write the functions of all the boxes.

Homework Question 39

Show the IPv6 packet structure write the functions of all the boxes.

IPv6 PACKET HEADER

The IPv6 Packet Header is found at the start of every IPv6 Packet. It is always 40 bytes in length, Every bit of it is accounted for. It is twice the size of the (which results in 20 bytes of additional overhead in every IPv6 packet, compared to IPv4), yet has fewer fields. This is due to the far larger (4X) Source Address and Destination Address fields. It not only has fewer fields, it is actually much simpler. The complexity is moved off into Packet Header Extensions.



The **Version** field (4 bits) contains the value 6 in all IPv6 packets (imagine that!). In comparison, the Version field in all IPv4 packets contains the value 4. This field allows IPv4 and IPv6 traffic to be mixed in a single network.

The **Traffic Class** field (8 bits) is available for use by originating nodes and/or forwarding routers to identify and distinguish between different classes or priorities of IPv6 traffic, in a manner identical to that of IPv4 "Type of Service".

The **Flow Label** field (20 bits) is something new in IPv6. It can be used to tag up to 2^{20} (1,048,576) distinct traffic flows, for purposes such as fine grained bandwidth management (QoS). Its use is still experimental. Hosts or routers that do not support this function should set it to zero when originating a packet, or ignore it when receiving a packet. A specific traffic flow is identified by a 3-tuple which includes the Source Address, Destination Address and a Flow Control number. As with Differentiated Service, the Flow Label field is just a request for prioritization - the actual prioritization is done in routers in the path. Unfortunately most current routers do not process the Flow Label field, so at this time, QoS in IPv6 is identical to that in IPv4. Once routers process the Flow Label information, IPv6 QoS will be significantly better than that in IPv4.

The **Payload Length** field (16 bits) is the length of the IPv6 packet payload (data field) in bytes, not counting the standard packet header (as it is in IPv4 Total Length). However, the Payload Length DOES include the size of any extension headers, which don't even exist in IPv4. You can think of packet extension headers as being the first part of the data field (payload) of the IPv6 packet. Since the Payload Length field is 16 bits, the data field can be up to 65,535 bytes long. A new Hop-by-Hop extension header is defined in [RFC 2675, "IP Jumbograms"](#), August 1999. If this extension header is present, it overrides the Payload Length field with a 32 bit value. This allows the payload length to be up to 4 gigabytes.

The **Next Header** field (8 bits) indicates the type of header immediately following the basic IPv6 packet header. It uses some of the same values as the IPv4 Protocol field but there are some new values possible in IPv6 Packet Headers.

If the Next Header field in the basic packet header contains the code for TCP (6), UDP (17) or SCTP (132), then the transport layer header (TCP, UDP or SCTP) begins immediately after the basic packet header, followed by the data. If the Next Header field contains the value for ICMPv6 (58), then the ICMPv6 header begins immediately after the basic packet header, and may be followed with data. Otherwise one or more IPv6 extension headers will be found between the basic packet header and the transport or ICMPv6 header, which may be followed by data. Since each extension header has another Next Header field (and a Header Length field), this constitutes a linked list of headers before the transport or ICMPv6 header, which is followed by the data.

The **Hop Limit** field (8 bits) serves the same purpose as the Time To Live field in the IPv4 Packet Header. It is used to prevent packets from being circling around indefinitely on a network. Every time a packet crosses a switch or router, the hop count is decremented by one. If the hop count reaches zero, the packet is dropped, and the node that drops the packet sends an ICMPv6 "time exceeded" message to the packet sender. This mechanism is used to implement the traceroute command.

The **Source Address** field (128 bits) contains the IPv6 address of the packet sender. This can be any unicast IPv6 address (link local, global or ULA). It cannot be a multicast address. In some cases (if the node does not yet have any unicast address), the unspecified address (::) may be used.

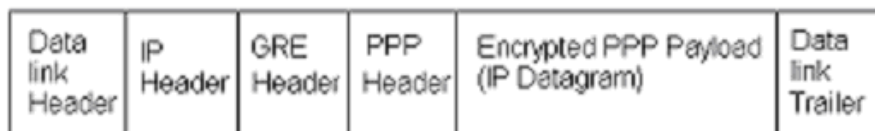
The **Destination Address** field (128 bits) contains the IPv6 address of the packet recipient. This can be a unicast IPv6 address (link local, global or ULA). It can also be a multicast IPv6 address of any scope. It cannot be the unspecified address.

Homework Question 40

- What can be achieved by using Virtual Private Network (VPN)?
- Write the three basic security features included in VPN.
- Write the function of Point-to-Point Tunneling Protocol (PPTP).
- Draw the packet structure of PPTP tunnelling.
- Write two common VPN types.
- Write the Advantages of VPN.

Answer to Homework Question 40

- What can be achieved by using Virtual Private Network (VPN)?
Connection of remote sites or users together in the same private network through the use of a public network (usually the Internet) can be achieved by using Virtual Private Network (VPN).
- Write the three basic security features included in VPN.
Encryption, authentication and tunneling.
- Write the function of Point-to-Point Tunneling Protocol (PPTP).
PPTP encapsulates Point-to-Point Protocol (PPP) frames into IP datagrams for transmission over an IP-based internetwork, such as the Internet or a private intranet.
- Draw the packet structure of PPTP tunnelling.



- Write two common VPN types.
 - Remote-Access VPN (or Virtual Private Dial-up Network (VPDN))
 - Site-to-site VPN
- Write the Advantages of VPN.
 - Extends geographic connectivity
 - Improves security
 - Reduces operational costs versus traditional WAN
 - Reduces transit time and transportation costs for remote users
 - Provides global networking opportunities
 - Provides broadband networking compatibility

Homework Question 41

- Why is QoS (Quality of Service) needed?
- What are the QoS parameters?
- Give two examples of application QoS.
- Give three examples of network QoS.

Answer to Homework Question 41

- Why is QoS (Quality of Service) needed?

QoS is needed to provide service differentiation and performance assurance for Internet applications, i.e., QoS provides a specification of how good the offered network services are.

b. What are the QoS parameters?

- End-to-end delay,
- jitter,
- packet rate,
- burst,
- throughput,
- packet loss.

c. Give two examples of application QoS.

- Sample size 8-bit telephone voice quality. Sample rate 8 KHz, intermediate delay 125 μ s
- 16-bit CD audio. 44.1 KHz, intermediate delay 22.7 μ s.

d. Give three examples of network QoS.

- End-to-end delay:
 - 0 to 150 ms, acceptable for most applications
 - 150 to 400 ms, may impact some applications.
 - > 400 ms, unacceptable
- Round-trip delay up to 800 ms, acceptable for conversation
- Packet loss $\leq 10^{-2}$ Telephone quality