Chapter-1

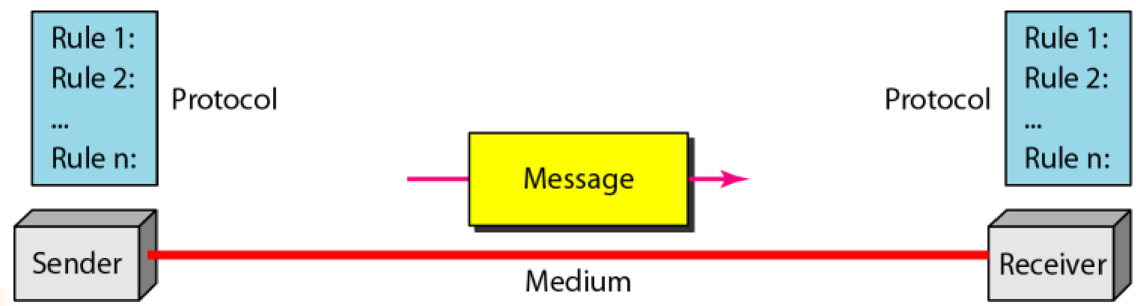
Data refers to information presented in whatever form

Data communications are the exchange of data between two or more devices

Characters of Data Communication System

1. **Delivery: -** Deliver data to the correct destination
2. **Accuracy:-** System must deliver data accurately without modification.
3. **Timeliness:-** System must deliver data in a timely manner
4. **Jitter:-** Variation in packet arrival time.

Components of a data communication system



1. **Message:-** Information to be communicated.
2. **Sender:-** Device that sends data.
3. **Receiver:-** Device that receives the message.
4. **Medium:-** Physical path by which a message travels
5. **Protocol:-** is a set of rules that controls the communication.

Data Representation

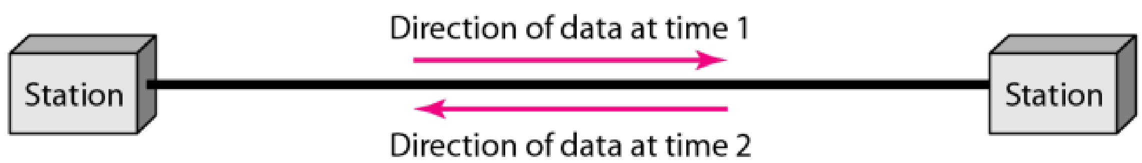
1. **Text**
2. **Numbers**
3. **Images**
4. **Audio**
5. **Video**

Data flow

1-Simplex

Only one direction

2-Half-duplex



In both directions but one at a time

3-Full-duplex

In both directions all the time

Network is a set of devices connected by communication links

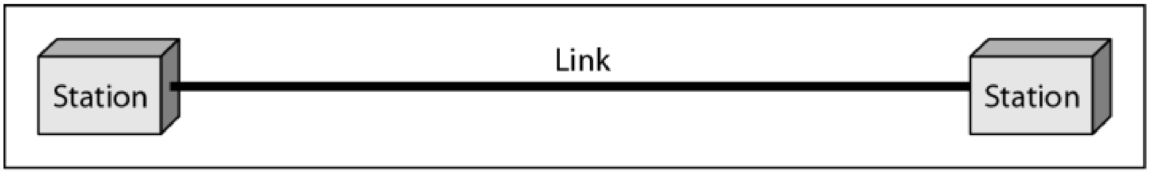
Note// network devices often referred to as nodes

Network Criteria

- **Performance**
  Measured in terms of Delay and Throughput
- **Reliability**
  Failure rate of network components
- **Security**
  Data protection against corruption/loss of data

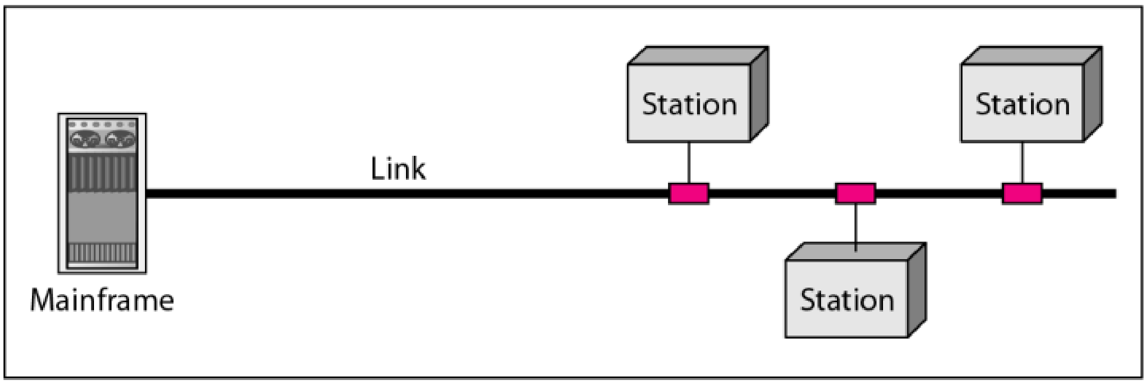
Type of Connection

- **Point to Point** - single transmitter and receiver



a. Point-to-point

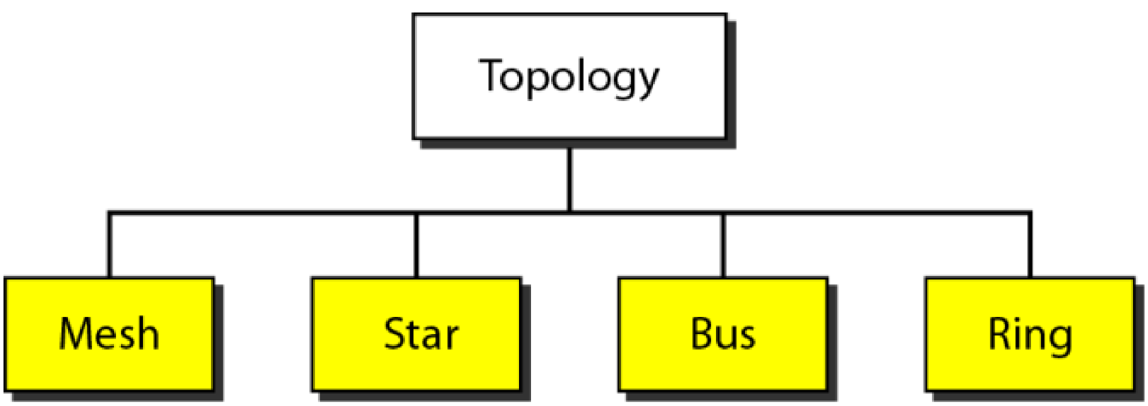
- **Multipoint** - multiple recipients of single transmission



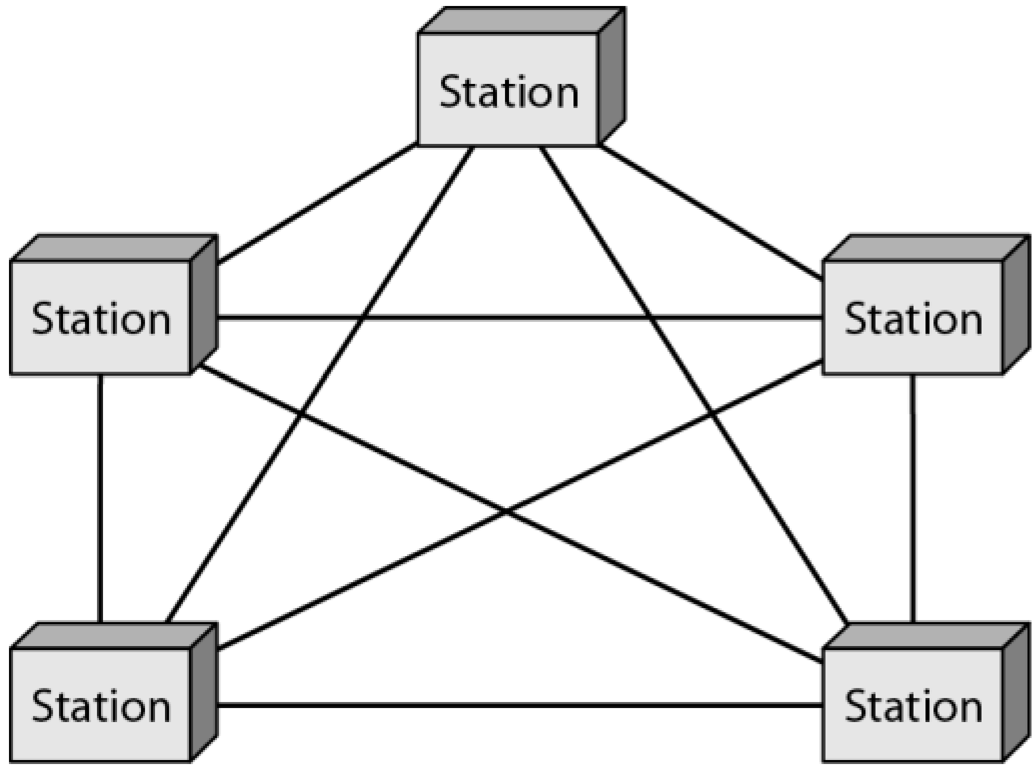
b. Multipoint

Physical Topology

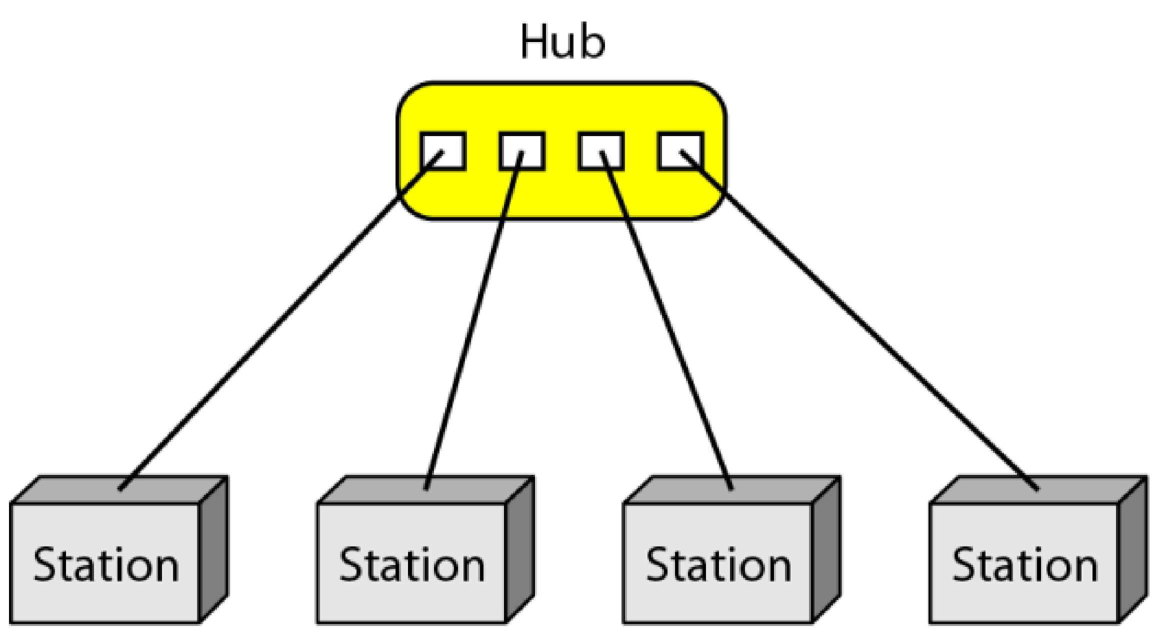
- **Connection of devices**
- **Type of transmission** - unicast, mulitcast, broadcast.



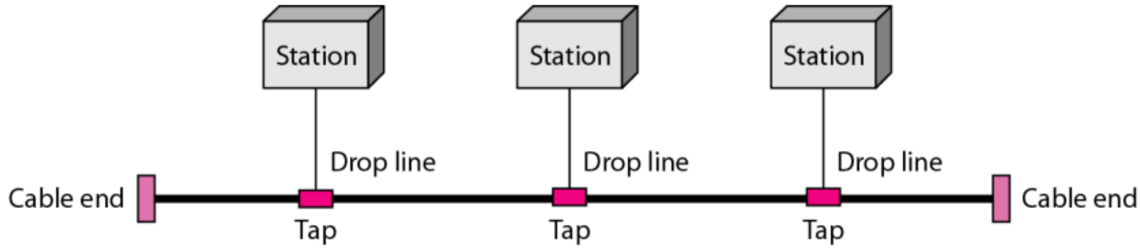
Mesh topology



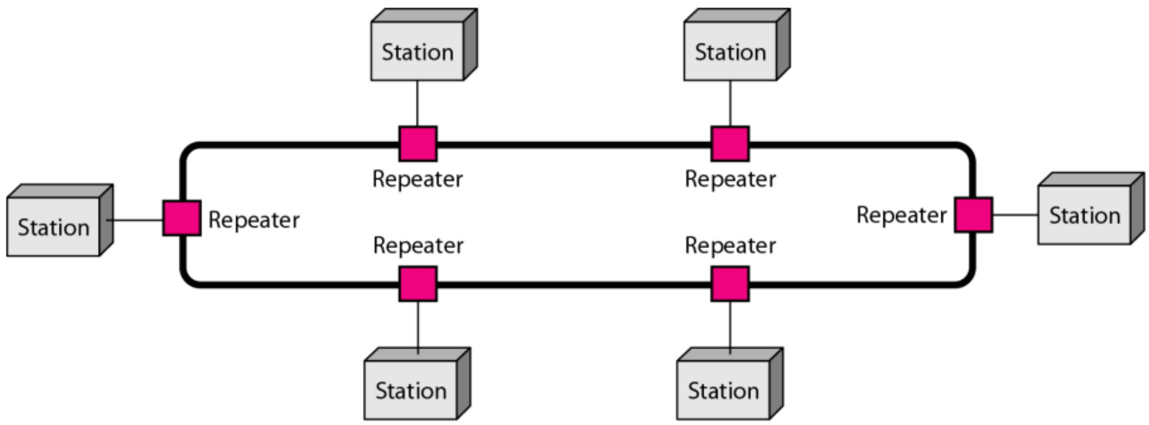
Star topology



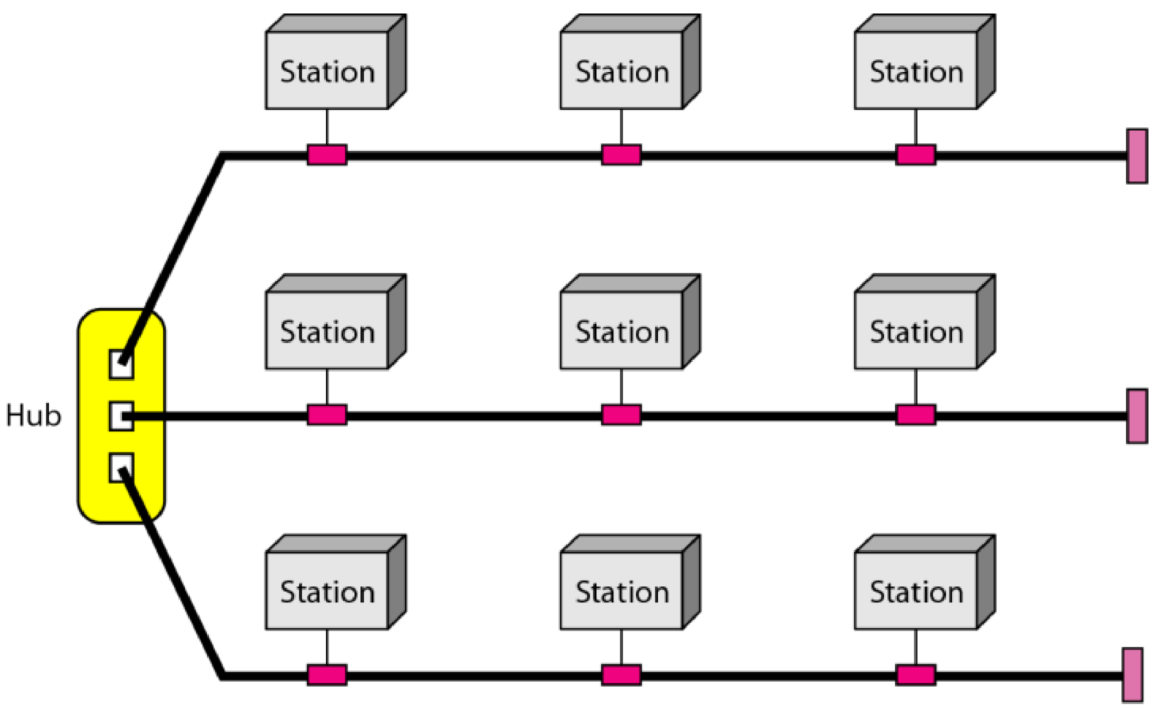
Bus topology



Ring topology



Hybrid topology (star + 3 buses)



Local Area Networks (LANs)

- Short distances
- Designed to provide local interconnectivity

Metropolitan Area Networks (MANs)

- Provide connectivity over areas such as a city, a campus

Wide Area Networks (WANs)

- Long distances
- Provide connectivity over large areas

Internet: network of networks that are provided by ISP.

Protocol is a set of rules that controls the communication.

Elements of a Protocol

1. **Syntax**: how it's written
    - Structure or format of the data
    - Indicates how to read the bits - field delineation
2. **Semantics**: what is the meaning of the syntax
    - Interprets the meaning of the bits
    - Knows which fields define what action
3. **Timing**
    - When data should be sent
    - And what Speed at which data should be sent or speed at which it is being received.

Chapter-2

Note// To be transmitted, data must be transformed to electromagnetic signals.

Data can be analog or digital

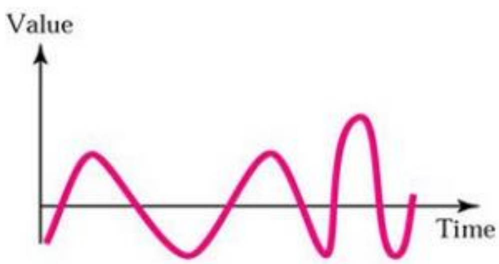
Analog data refers to information that is continuous and take continuous values.

Digital data refers to information that has discrete states and take discrete values.

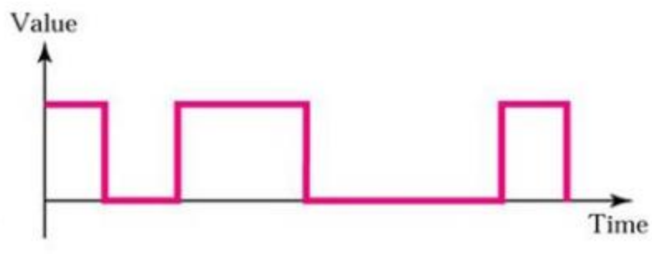
Signals can be analog or digital.

Analog signals can have an infinite number of values in a range.

Digital signals can have only a limited number of values.



Analog signal



Digital signal

In **data communications**, we commonly use **periodic analog signals** and **nonperiodic digital signals**.

Periodic analog signals can be classified as **simple** or **composite.**

Simple periodic analog signal has only one sine wave.

Composite periodic analog signal is composed of multiple sine waves.

Note// Frequency and period are the inverse of each other.

$$f = \frac{1}{T} \qquad \text{and} \qquad T = \frac{1}{f}$$

Frequency is the rate of change with respect to time. //number of cycles per unit of time

- Change in a short span of time means high frequency.
- Change over a long span of time means low frequency.

Note// If a signal does not change at all, its frequency is zero. If a signal changes instantaneously, its frequency is infinite.

Phase describes the position of the waveform relative to time 0.

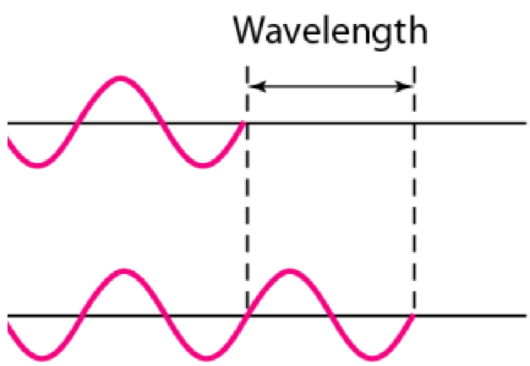
A sine wave is offset 1/6 cycle with respect to time 0. What is its phase in degrees and radians?

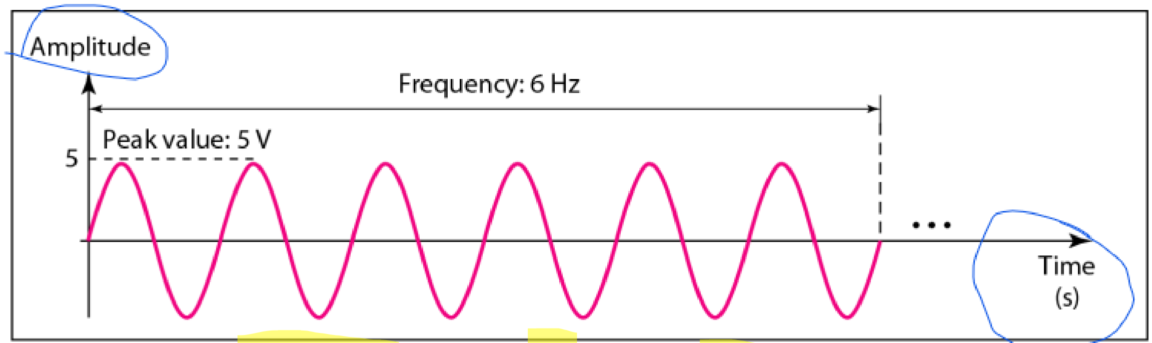
Solution

We know that 1 complete cycle is 360° . Therefore, 1/6 cycle is

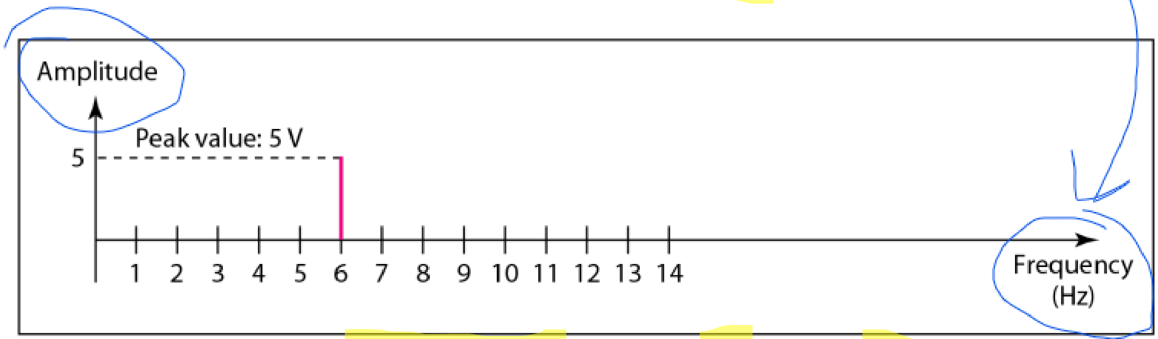
$$\frac{1}{6} \times 360 = 60° = 60 \times \frac{2\pi}{360} \text{ rad} = \frac{\pi}{3} \text{ rad} = 1.046 \text{ rad}$$

Wavelength is the length of one cycle





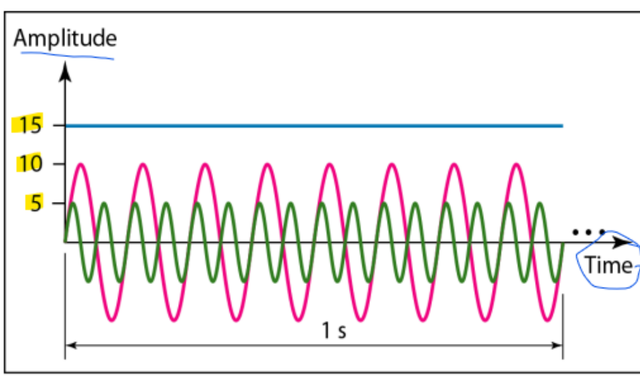
a. A sine wave in the time domain (peak value: 5 V, frequency: 6 Hz)



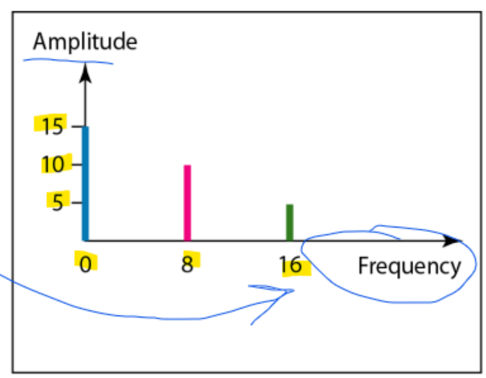
b. The same sine wave in the frequency domain (peak value: 5 V, frequency: 6 Hz)

Note// A complete sine wave in the time domain can be represented by one single spike in the frequency domain.

Note// The frequency domain is more compact and useful when we are dealing with more than one sine wave



a. Time-domain representation of three sine waves with frequencies 0, 8, and 16



b. Frequency-domain representation of the same three signals

A single-frequency sine wave is not useful in data communications

We need to send a composite signal, a signal made of many simple sine waves.

If the **composite signal is periodic**, the **decomposition** gives a series of signals with **discrete frequencies**.

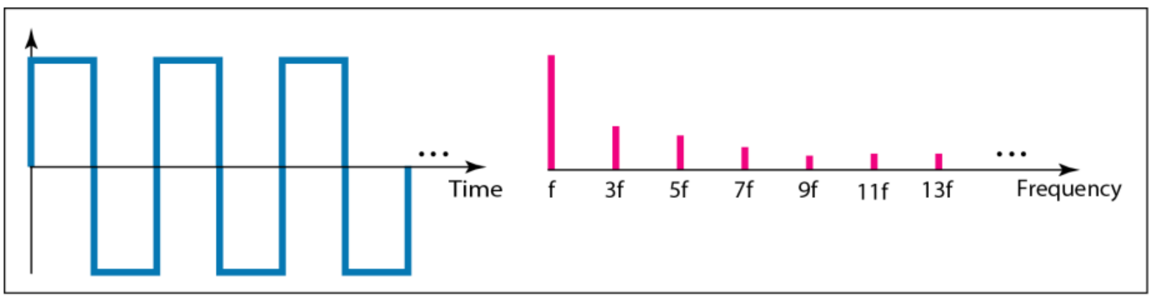
If the **composite signal is nonperiodic**, the **decomposition** gives a combination of sine waves with **continuous frequencies**.

Assume we need to download text documents at the rate of 100 pages per sec. What is the required bit rate of the channel?

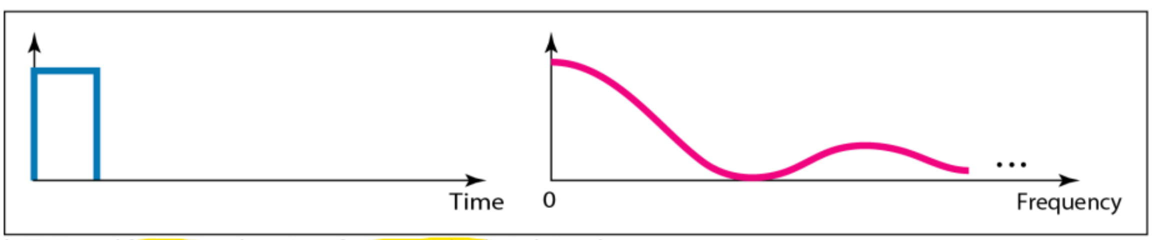
Solution

A page is an average of 24 lines with 80 characters in each line. If we assume that one character requires 8 bits (ascii), the bit rate is

$$100 \times 24 \times 80 \times 8 = 1{,}636{,}000 \text{ bps} = 1.636 \text{ Mbps}$$



a. Time and frequency domains of periodic digital signal



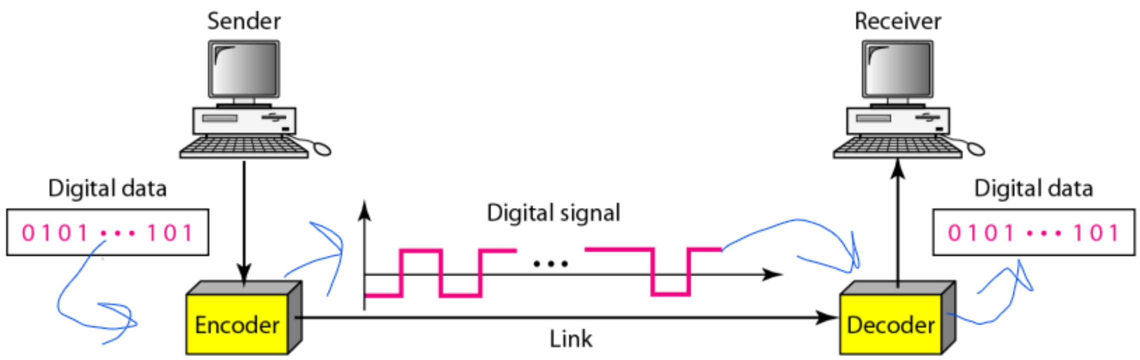
b. Time and frequency domains of nonperiodic digital signal

Chapter-3

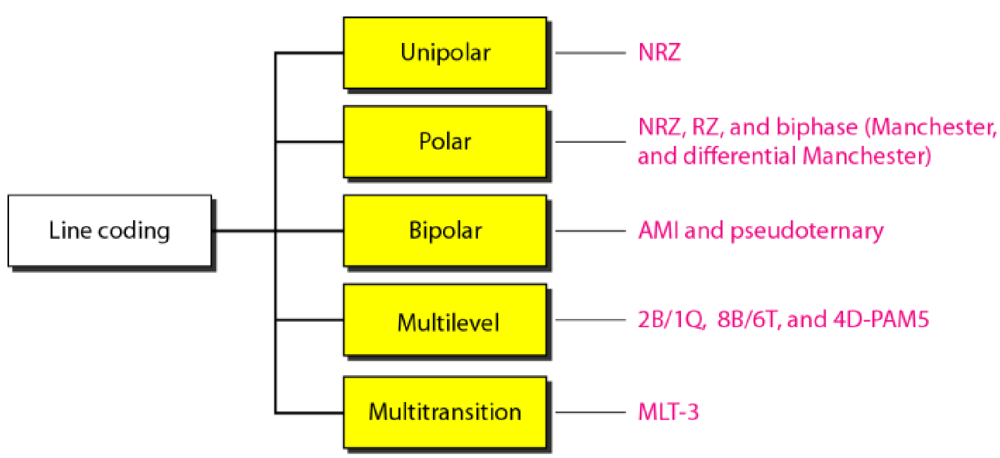
DIGITAL CONVERSION techniques

1. **line coding**
   Converting a string of 1's and 0's (digital data) into a sequence of signals that denote the 1's and 0's.

   For example a high voltage level (+V) could represent a "1" and a low voltage level (0 or -V) could represent a "0"
2. **block coding**
3. **scrambling**

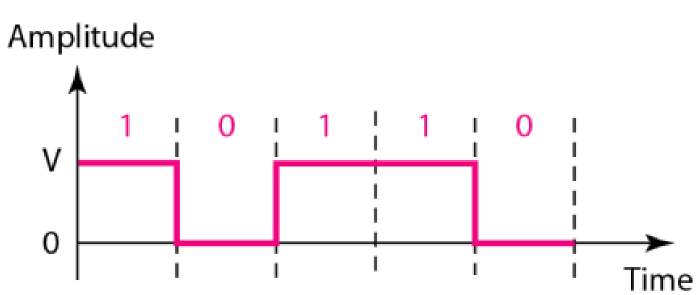


Line coding schemes



Unipolar

All signal levels are on one side of the time axis - either above or below



$$\frac{1}{2}V^2 + \frac{1}{2}(0)^2 = \frac{1}{2}V^2$$

Normalized power

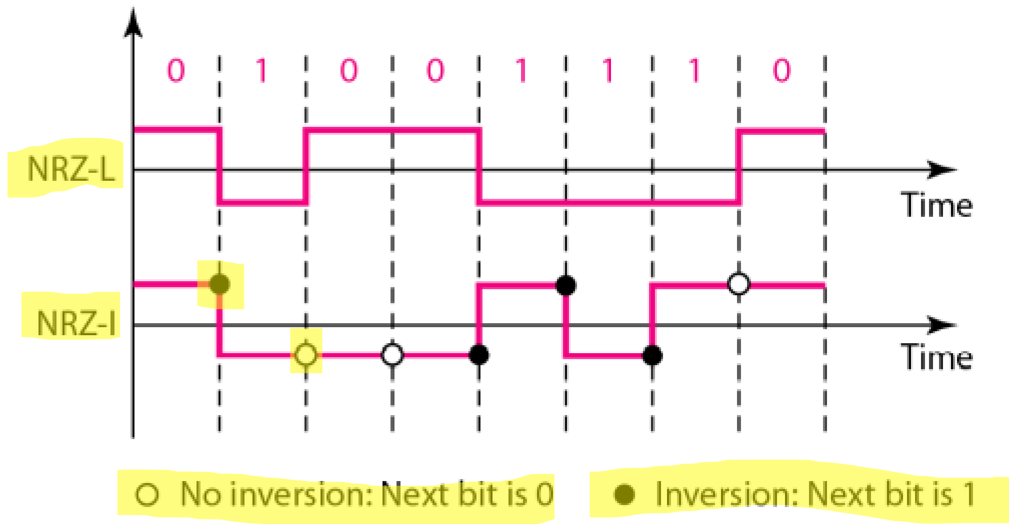
Polar – NRZ

The voltages are on both sides of the time axis.

There are two versions:

1. NRZ - Level (NRZ-L) - positive voltage for one symbol and negative for the other
2. NRZ - Inversion (NRZ-I) - the change or lack of change in polarity determines the value of a symbol. E.g. a “1” symbol inverts the polarity a “0” does not.

r = 1 S_{ave} = N/2



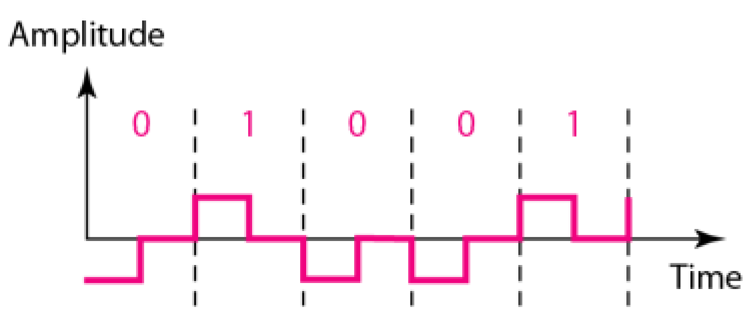
Note// In **NRZ-L** the level of the **voltage determines the value of the bit.**

In **NRZ-I** the inversion or the lack of **inversion determines the value of the bit.**

Polar – RZ

The Return to Zero (RZ) scheme uses three voltage values. +, 0, -.

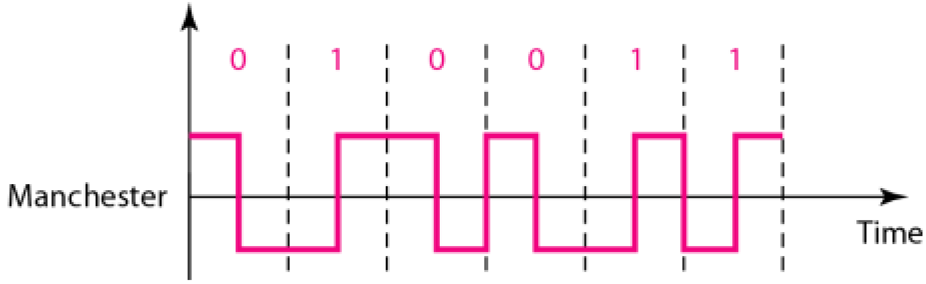
When the voltage is positive the signal equals 1 when it's negative the signal equals 0 but between each bit the signal has to go back to zero



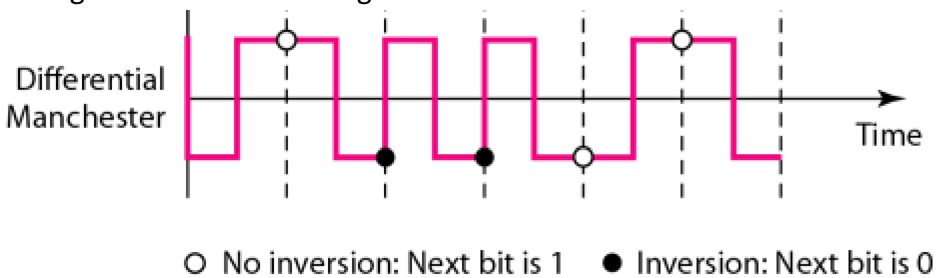
r = 1/2 S_{ave} = N

Polar - Biphase

1. **Manchester**
   coding consists of combining the **NRZ-L and RZ** schemes.



2. **Differential Manchester**
   coding consists of combining the **NRZ-I and RZ** schemes.

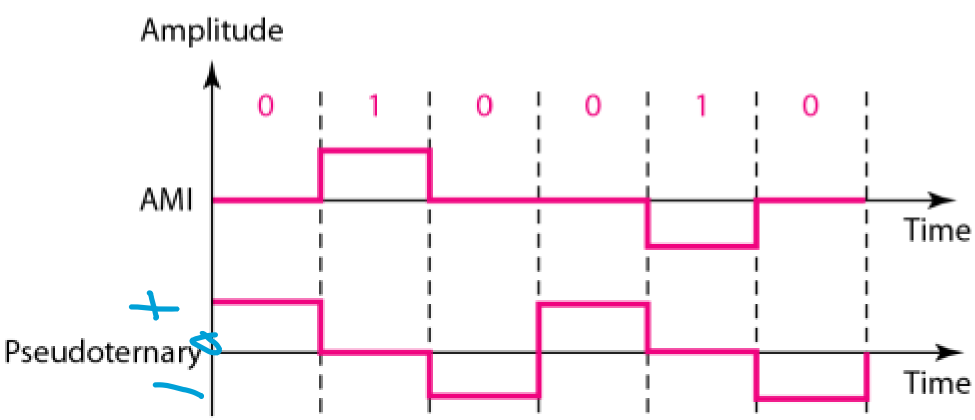


r = 1/2 S_{ave} = N

Note// In Manchester and differential Manchester encoding, the transition at the middle of the bit is used for synchronization.

Bipolar

1. **AMI**
2. **Pseudoternary**



In **Pseudoternary** if the **bit is 1** then the **voltage will be 0** and if the **bit is 0** then at first time the **voltage will be positive and with the 2nd 0 the voltage will be negative** up and down

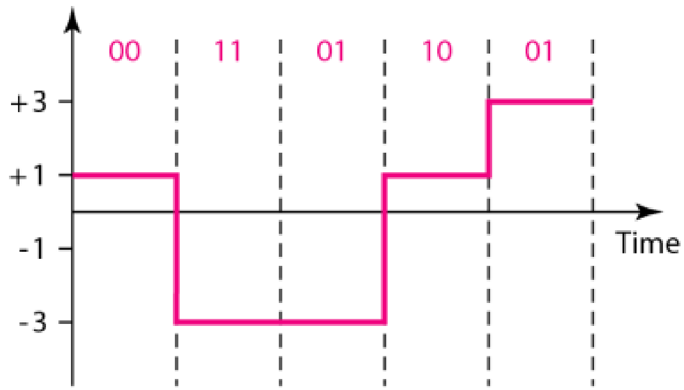
Multilevel Schemes

In these schemes we increase the number of data bits per symbol thereby increasing the bit rate.

2B1Q scheme

	Previous level: positive	Previous level: negative
Next bits	Next level	Next level
00	+1	-1
01	+3	-3
10	-1	+1
11	-3	+3

Transition table

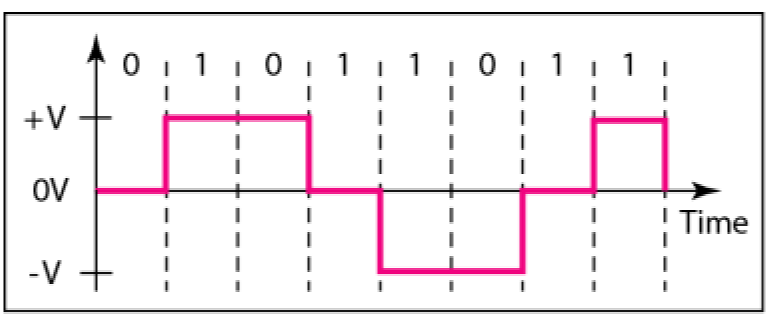


Assuming positive original level

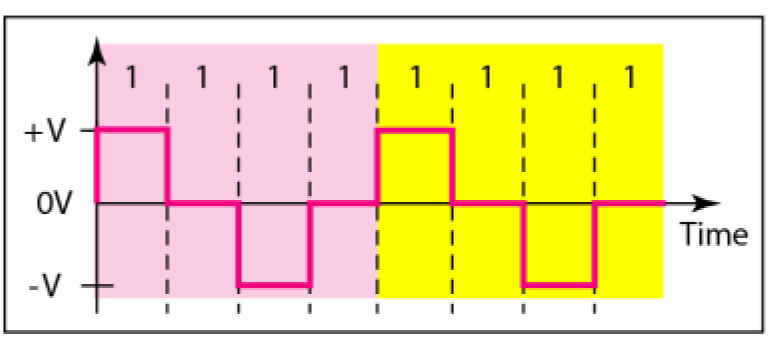
Multitransition Coding

MLT-3 scheme

is a line code (a signaling method used in a telecommunication system for transmission purposes) **0 no change. 1 change between 3 levels +, 0, -**



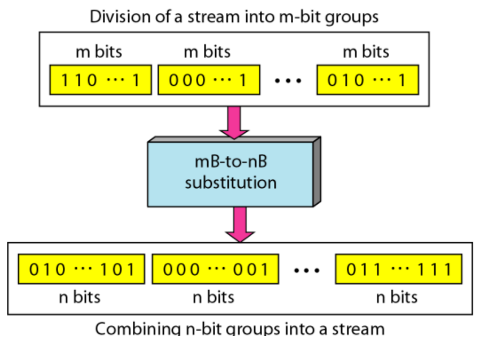
a. Typical case

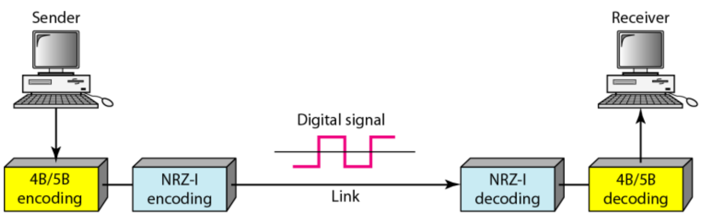


b. Worse case

Block Coding

Block coding is normally referred to as mB/nB coding; it replaces each m-bit group with an n-bit group.



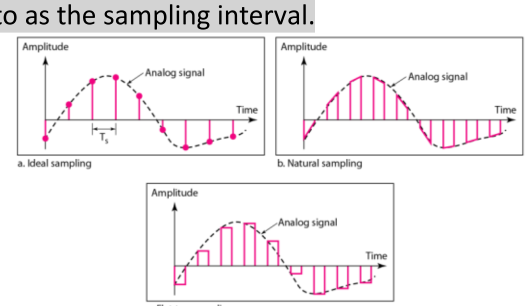


ANALOG-TO-DIGITAL CONVERSION

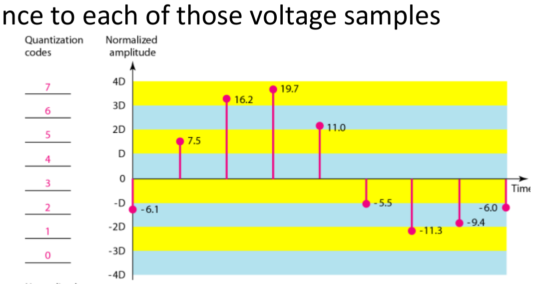
PCM or Pulse Code Modulation

consists of three steps to digitize an analog signal:

1. **Sampling**
   Analog signal is sampled every TS secs.
   Note// Ts is referred to as the sampling interval.



2. **Quantization**
   assign a binary sequence to each of those voltage samples



3. **Binary encoding**

Encoded words	010	101	111	111	110	010	001	010	010
Quantization code	2	5	7	7	6	2	1	2	2
Normalized error	-0.38	0	+0.26	-0.44	+0.30	-0.40	-0.24	+0.38	-0.30
Normalized quantized values	-1.50	1.50	3.50	3.50	2.50	-1.50	-2.50	-1.50	-1.50
Normalized PAM values	-1.22	1.50	3.24	3.94	2.20	-1.10	-2.26	-1.88	-1.20

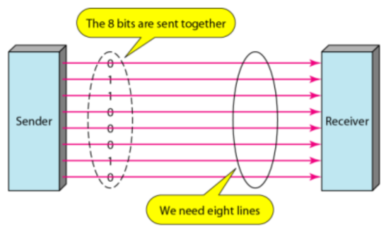
PCM Decoder

recover an analog signal from a digitized signal.

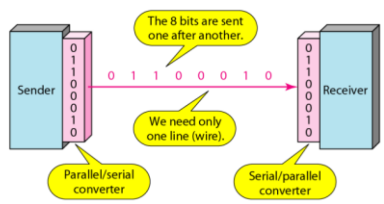
TRANSMISSION MODES

The transmission of binary data across a link can be accomplished in either parallel or serial mode.

In **parallel mode**, multiple bits are sent with each clock tick.

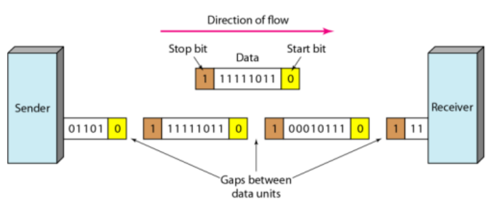


In **serial mode**, 1 bit is sent with each clock tick.

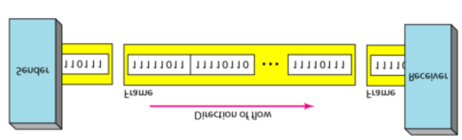


serial transmission:

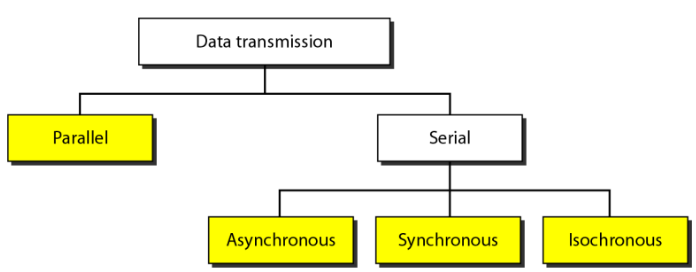
1. **Asynchronous** In asynchronous transmission, we send 1 start bit (0) at the beginning and 1 or more stop bits (1s) at the end of each byte. There may be a gap between each byte.



2. **Synchronous** we send bits one after another without start or stop bits or gaps.



3. **Isochronous** we cannot have uneven gaps between frames.
   Note//Transmission of bits is fixed with equal gaps.

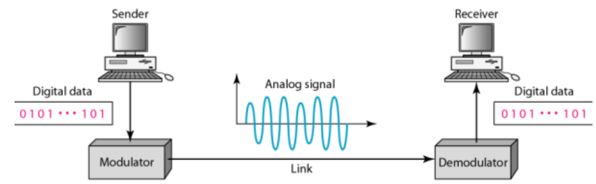


Chapter-4

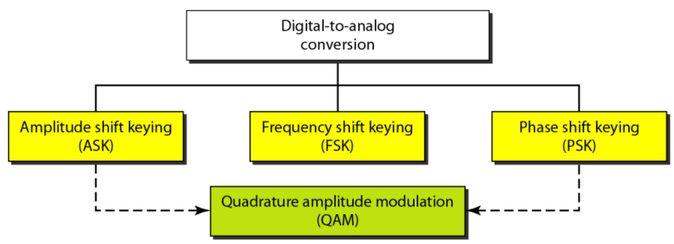
DIGITAL-TO-ANALOG CONVERSION

is the process of changing one of the characteristics of an analog signal based on the information in digital data.

carrier signal (frequency fc) performs the function of transporting the digital data in an analog waveform.



Types of digital-to-analog conversion



Bit rate, N, is the number of bits per second (bps).

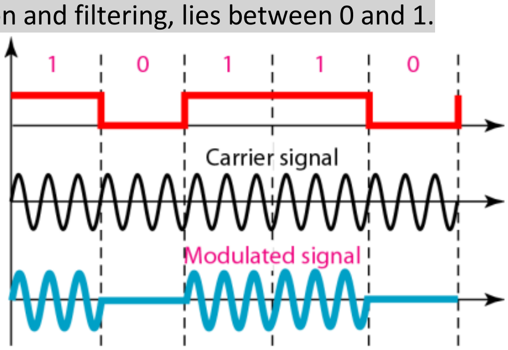
Baud rate is the number of signal elements per second (bauds).

Note// In the analog transmission of **digital data**, the signal or **baud rate** is less than or equal to the **bit rate**.

S=Nx1/r bauds Where r is the number of **data bits per signal element**.

1. Amplitude Shift Keying (ASK)

Changing the amplitude of carrier signal according to the digital data.
Note// The bandwidth B of ASK is proportional to the signal rate S. B = (1+d)S.
"d" is due to modulation and filtering, lies between 0 and 1.



We have an available bandwidth of 100 kHz which spans from 200 to 300 kHz. What are the carrier frequency and the bit rate if we modulated our data by using ASK with d = 1?

Solution

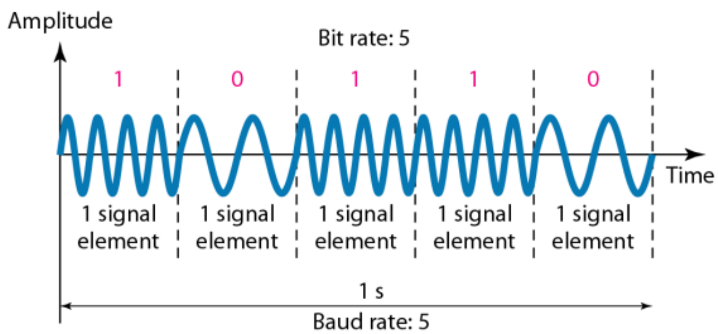
The middle of the bandwidth is located at 250 kHz. This means that our carrier frequency can be at f_c = 250 kHz. We can use the formula for bandwidth to find the bit rate (with d = 1 and r = 1).

$$B = (1 + d) \times S = 2 \times N \times \frac{1}{r} = 2 \times N = 100 \text{ kHz} \rightarrow N = 50 \text{ kbps}$$

2. Frequency Shift Keying (FSK)

Changing the frequency of carrier signal according to the digital data.

Note// If the difference between the two frequencies (f1 and f2) is 2f, then the required BW B will be: B = (1+d)xS +2f



We have an available bandwidth of 100 kHz which spans from 200 to 300 kHz. What should be the carrier frequency and the bit rate if we modulated our data by using FSK with d = 1?

Solution

This problem is similar to Example 5.3, but we are modulating by using FSK. The midpoint of the band is at 250 kHz. We choose 2Δf to be 50 kHz; this means

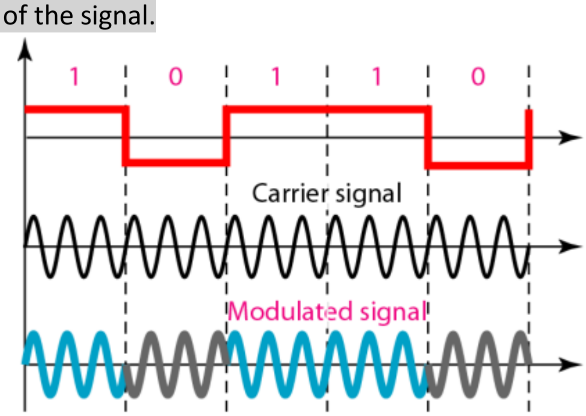
$$B = (1 + d) \times S + 2\Delta f = 100 \rightarrow 2S = 50 \text{ kHz} \quad S = 25 \text{ kbaud} \quad N = 25 \text{ kbps}$$

3. Phase Shift Keying (PSK)

Changing the phase of carrier signal according to the digital data.

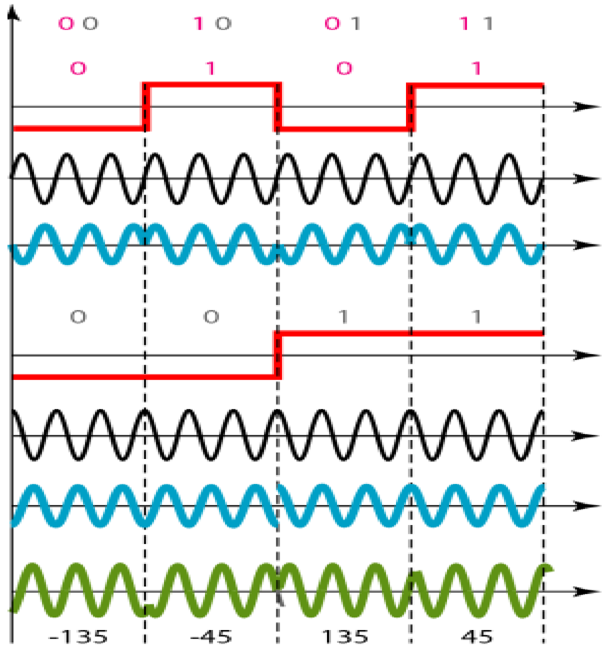
Note// The bandwidth requirement, B is: B = (1+d)xS.

Note// PSK is much more robust than ASK as it is not that vulnerable to noise, which changes amplitude of the signal.



Quadrature PSK (QPSK)

Used to increase the bit rate, in which it code 2 or more bits onto one signal element.



Find the bandwidth for a signal transmitting at 12 Mbps for QPSK. The value of d = 0.

Solution

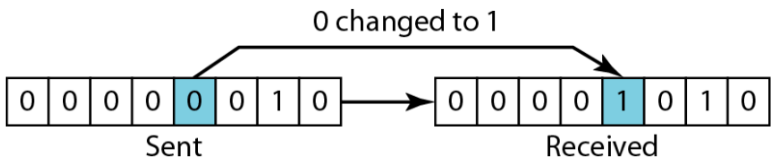
For QPSK, 2 bits is carried by one signal element. This means that r = 2. So the signal rate (baud rate) is S = N × (1/r) = 6 Mbaud. With a value of d = 0, we have B = S = 6 MHz.

Note// **Quadrature amplitude modulation** is a combination of ASK and PSK.

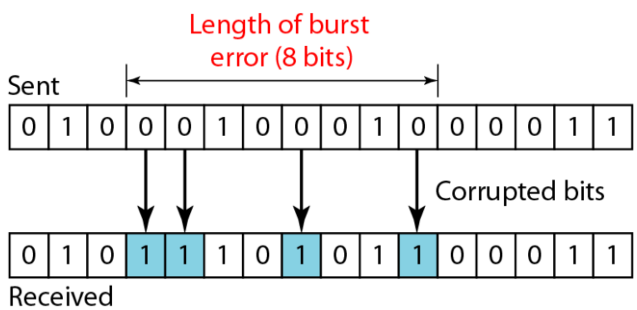
Chapter-5

Note// Data can be corrupted during transmission. Some applications require that errors be detected and corrected.

In a **single-bit error**, only 1 bit in the data unit has changed.



A **burst error** means that 2 or more bits in the data unit have changed.



Note// To detect or correct errors, we need to send extra (redundant) bits with data.

Error Detection

Enough redundancy is added to detect an error. The receiver knows an error occurred but does not know which bit(s) is(are) in error.

Process of error detection in block coding

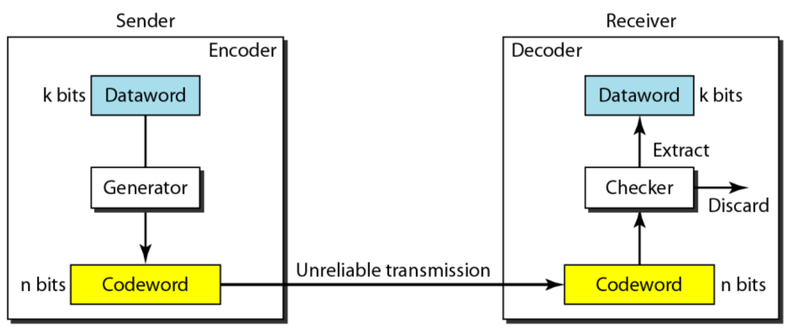


Table 10.1 *A code for error detection (Example 10.2)*

Datawords	*Codewords*
00	000
01	011
10	101
11	110

Structure of encoder and decoder in error correction

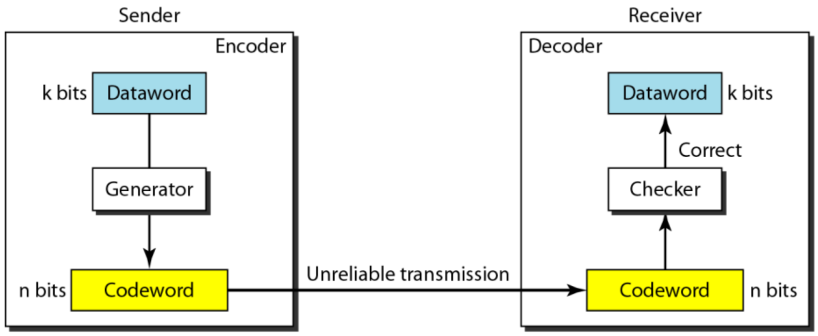


Table 10.2 *A code for error correction (Example 10.3)*

Dataword	*Codeword*
00	00000
01	01011
10	10101
11	11110

Note// The Hamming distance between two words is the number of differences between corresponding bits.

Note// The minimum Hamming distance is the smallest Hamming distance between all possible pairs in a set of words.

To guarantee the detection of up to s errors in all cases, the minimum Hamming distance in a block code must be dmin = s + 1.

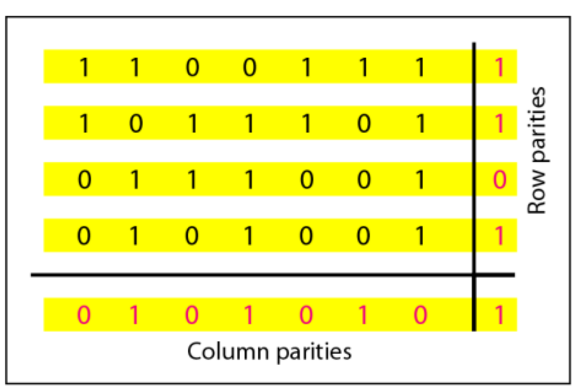
A **simple parity-check** code can detect an odd number of errors.

Table 10.3 *Simple parity-check code C(5, 4)*

Datawords	*Codewords*	*Datawords*	*Codewords*
0000	00000	1000	10001
0001	00011	1001	10010
0010	00101	1010	10100
0011	00110	1011	10111
0100	01001	1100	11000
0101	01010	1101	11011
0110	01100	1110	11101
0111	01111	1111	11110

Note// All Hamming codes discussed in this book have dmin = 3 (2 bit error detection and single bit error correction). A codeword consists of n bits of which k are data bits and r are check bits. Let m = r, then we have: n = 2m -1 and k = n-m

Two-dimensional parity-check code

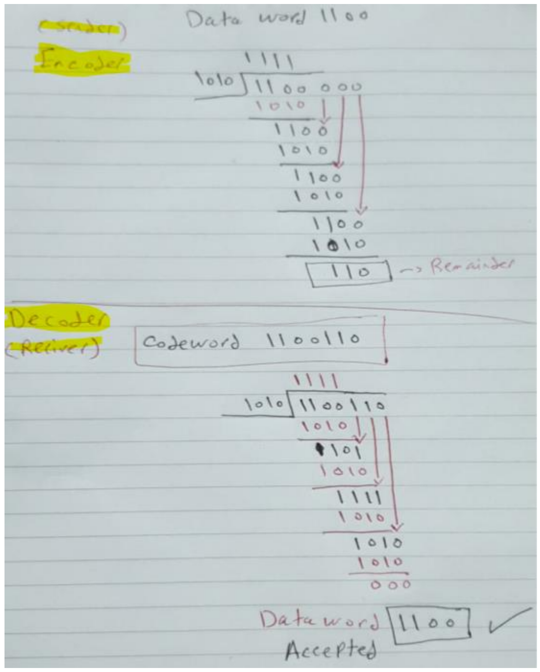


a. Design of row and column parities

Cyclic codes are special linear block codes with one extra property.

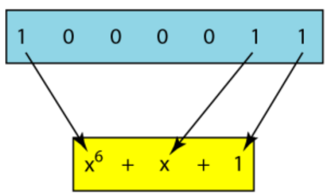
Note// In a cyclic code, if a codeword is cyclically shifted (rotated), the result is another codeword.

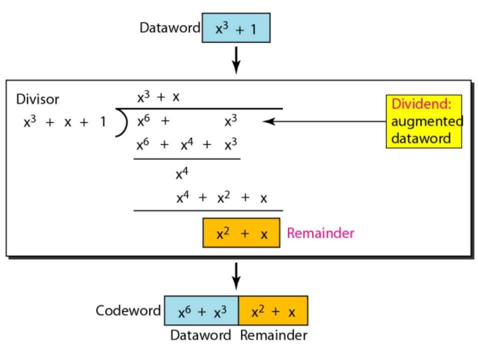
Cyclic Redundancy Check (CRC)



Polynomials

We can use a polynomial to represent a binary word.





Note// The divisor in a cyclic code is normally called the generator polynomial or simply the generator.

Table 10.7 *Standard polynomials*

Name	*Polynomial*	*Application*
CRC-8	$x^8 + x^2 + x + 1$	ATM header
CRC-10	$x^{10} + x^9 + x^5 + x^4 + x^2 + 1$	ATM AAL
CRC-16	$x^{16} + x^{12} + x^5 + 1$	HDLC
CRC-32	$x^{32} + x^{26} + x^{23} + x^{22} + x^{16} + x^{12} + x^{11} + x^{10} + x^8 + x^7 + x^5 + x^4 + x^2 + x + 1$	LANs

CHECKSUM

Is an error detection method.

if the set of numbers is (7, 11, 12, 0, 6), we send (7, 11, 12, 0, 6, 36), where 36 is the sum of the original numbers.

We can make the job of the receiver easier if we send the negative (complement) of the sum, called the checksum. In this case, we send (7, 11, 12, 0, 6, −36). The receiver can add all the numbers received (including the checksum). If the result is 0, it assumes no error; otherwise, there is an error.

How can we represent the number 21 in one's complement arithmetic using only four bits?

Solution

The number 21 in binary is 10101 (it needs five bits). We can wrap the leftmost bit and add it to the four rightmost bits. We have (0101 + 1) = 0110 or 6.

How can we represent the number −6 in one's complement arithmetic using only four bits?

Solution

In one's complement arithmetic, the negative or complement of a number is found by inverting all bits. Positive 6 is 0110; negative 6 is 1001. If we consider only unsigned numbers, this is 9. In other words, the complement of 6 is 9. Another way to find the complement of a number in one's complement arithmetic is to subtract the number from $2^n - 1$ (16 − 1 in this case).

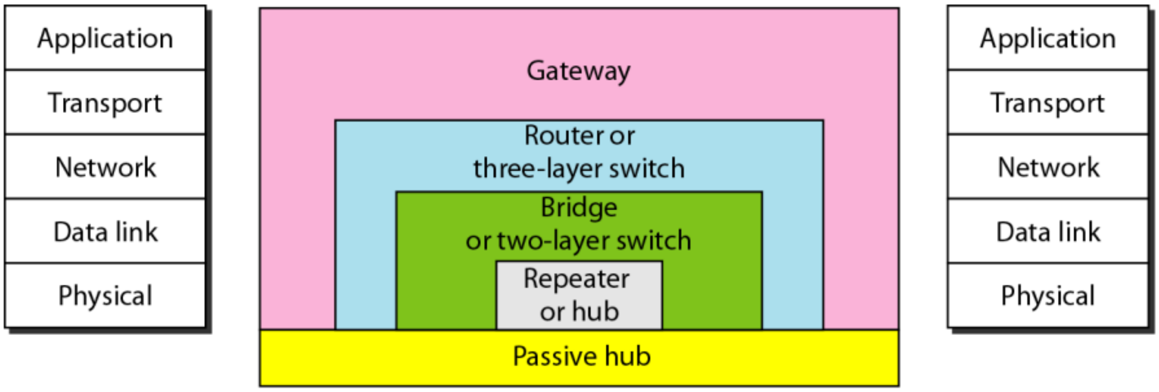
Sender site:

1. The message is divided into 16-bit words.
2. The value of the checksum word is set to 0.
3. All words including the checksum are added using one's complement addition.
4. The sum is complemented and becomes the checksum.
5. The checksum is sent with the data.

Receiver site:

1. The message (including checksum) is divided into 16-bit words.
2. All words are added using one's complement addition.
3. The sum is complemented and becomes the new checksum.
4. If the value of checksum is 0, the message is accepted; otherwise, it is rejected.

Chapter-6

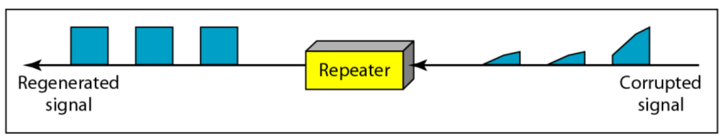


Repeater

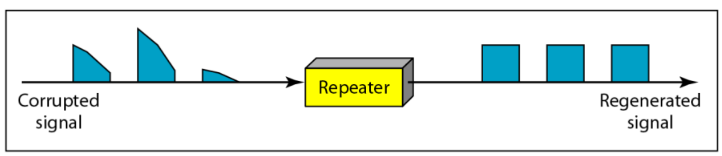
A repeater connects segments of a LAN and increase the level and/or power of the signal.

Note// A repeater forwards every frame; it has no filtering capability.

Note// A repeater is a regenerator, not an amplifier.



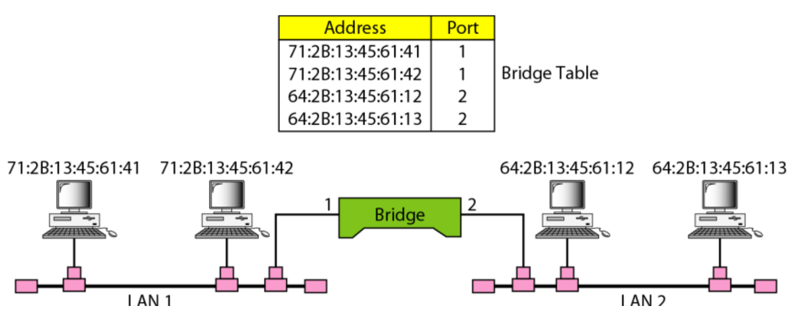
a. Right-to-left transmission.



b. Left-to-right transmission.

Bridge

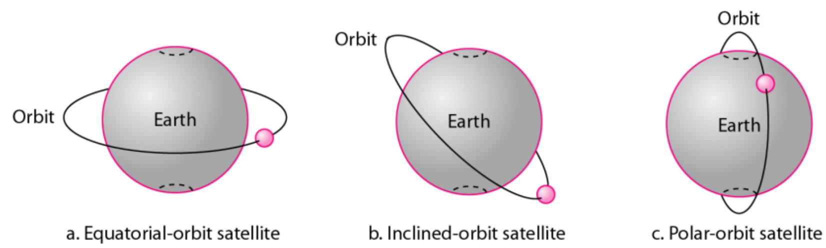
A bridge has a table used in filtering decisions and it does not change the physical (MAC) addresses in a frame.

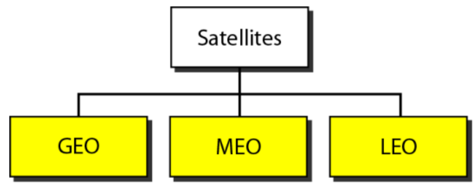


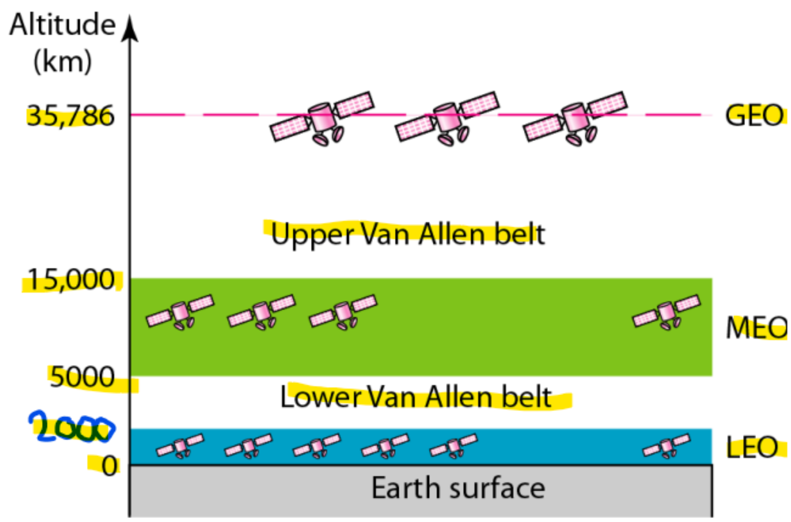
SATELLITE NETWORKS

A satellite network is a combination of nodes(network), some of which are satellites, that provides communication from one point on the Earth to another.

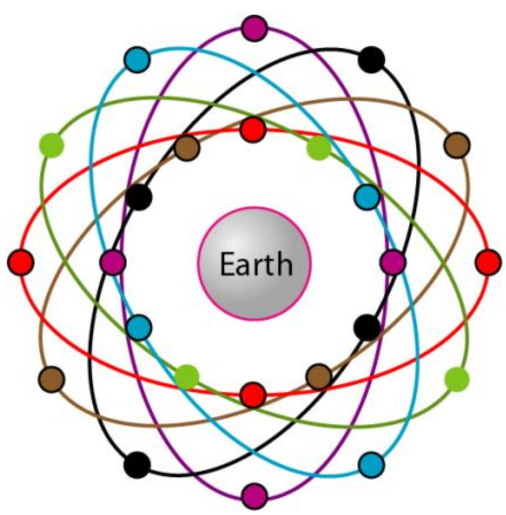
Satellite Orbits



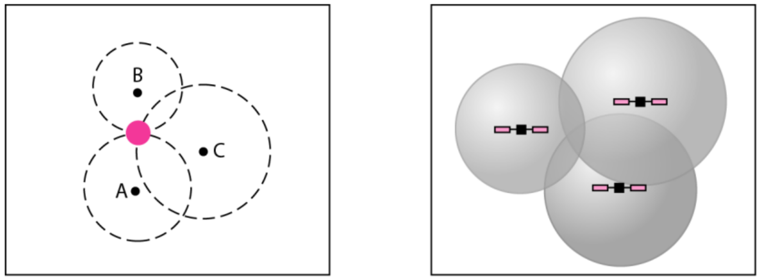




Orbits for **global positioning system (GPS)** satellites

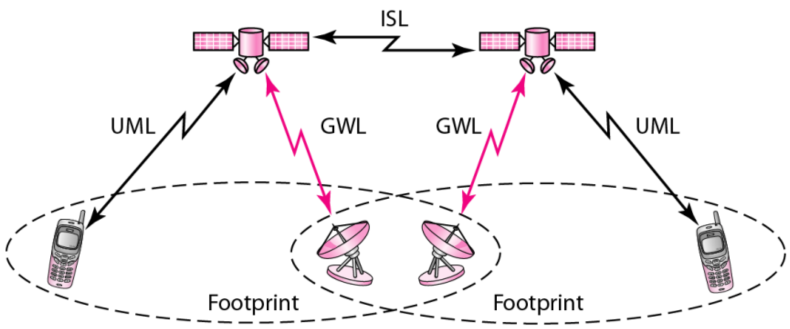


Trilateration



a. Two-dimensional trilateration b. Three-dimensional trilateration

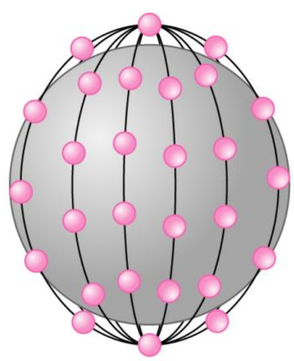
LEO satellite system



Iridium constellation

The Iridium system has 66 satellites in six LEO orbits, each at an altitude of 750 km.

Iridium is designed to provide direct worldwide voice and data communication using handheld terminals, a service similar to cellular telephony but on a global scale.



Teledesic

Teledesic has 288 satellites in 12 LEO orbits, each at an altitude of 1350 km.