UNIT III
SIGNAL ENCODING TECHNIQUES

Encoding is the process of converting the data or a given sequence of characters, symbols, alphabets etc., into a specified format, for the secured transmission of data. **Decoding** is the reverse process of encoding which is to extract the information from the converted format.

Data Encoding

Encoding is the process of using various patterns of voltage or current levels to represent **1s** and **0s** of the digital signals on the transmission link.
The common types of line encoding are Unipolar, Polar, Bipolar, and Manchester.

Encoding Techniques

The data encoding technique is divided into the following types, depending upon the type of data conversion.

- **Analog data to Analog signals** − The modulation techniques such as Amplitude Modulation, Frequency Modulation and Phase Modulation of analog signals, fall under this category.
- **Analog data to Digital signals** − This process can be termed as digitization, which is done by Pulse Code Modulation [Math Processing Error]Hence, it is nothing but digital modulation. As we have already discussed, sampling and quantization are the important factors in this. Delta Modulation gives a better output than PCM.

Digital data to Analog signals − The modulation techniques such as Amplitude Shift Keying [Math Processing Error]
, Frequency Shift Keying [Math Processing Error], Phase Shift Keying [Math Processing Error]
, etc., fall under this category. These will be discussed in subsequent chapters.

- **Digital data to Digital signals** − These are in this section. There are several ways to map digital data to digital signals. Some of them are –

ANALOG TO ANALOG CONVERSION (MODULATION)

Analog Signal: An analog signal is any continuous signal for which the time varying feature of the signal is a representation of some other time varying quantity i.e., analogous to another time varying Signal.

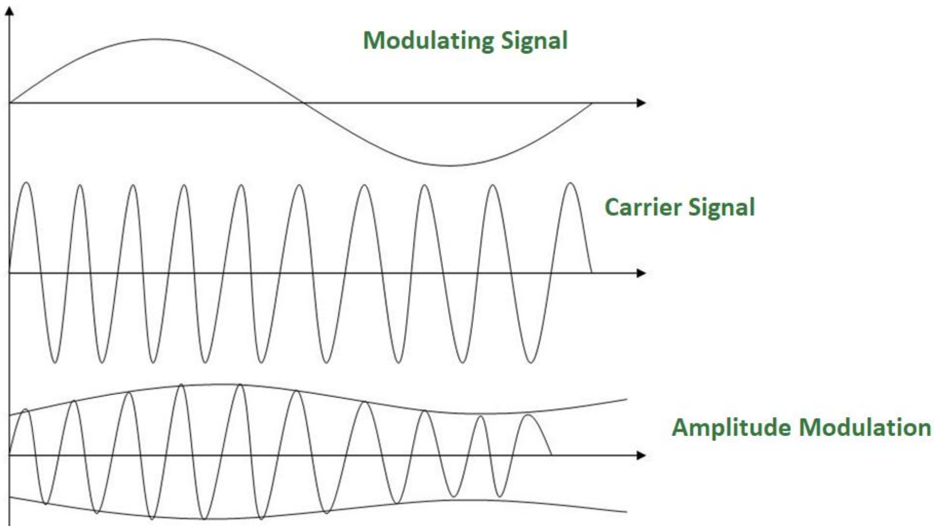
Analog to Analog Conversion –

Analog-to-analog conversion, or modulation, is the representation of analog information by an analog signal. It is a process by virtue of which a characteristic of carrier wave is varied according to the instantaneous amplitude of the modulating signal. This modulation is generally needed when a **bandpass channel** is required. Bandpass is a range of frequencies which are transmitted through a bandpass filter which is a filter allowing specific frequencies to pass preventing signals at unwanted frequencies.
Analog to Analog conversion can be done in three ways:

1. Amplitude Modulation
2. Frequency Modulation
3. Phase Modulation

1. AMPLITUDE MODULATION:

The modulation in which the amplitude of the carrier wave is varied according to the instantaneous amplitude of the modulating signal keeping phase and frequency as constant. The figure below shows the concept of amplitude modulation:



AM is normally implemented by using a simple multiplier because the amplitude of the carrier signal needs to be changed according to the amplitude of the modulating signal.

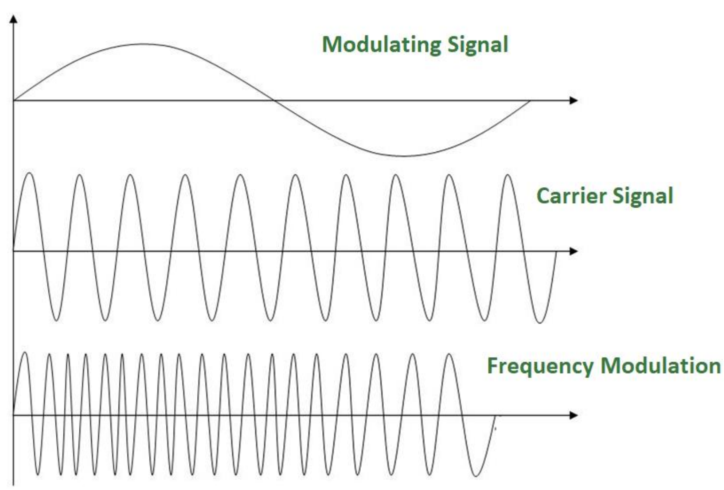
AM bandwidth:

The modulation creates a bandwidth that is twice the bandwidth of the modulating signal and covers a range centered on the carrier frequency.

Bandwidth= 2fm

2. FREQUENCY MODULATION –

The modulation in which the frequency of the carrier wave is varied according to the instantaneous amplitude of the modulating signal keeping phase and amplitude as constant. The figure below shows the concept of frequency modulation:



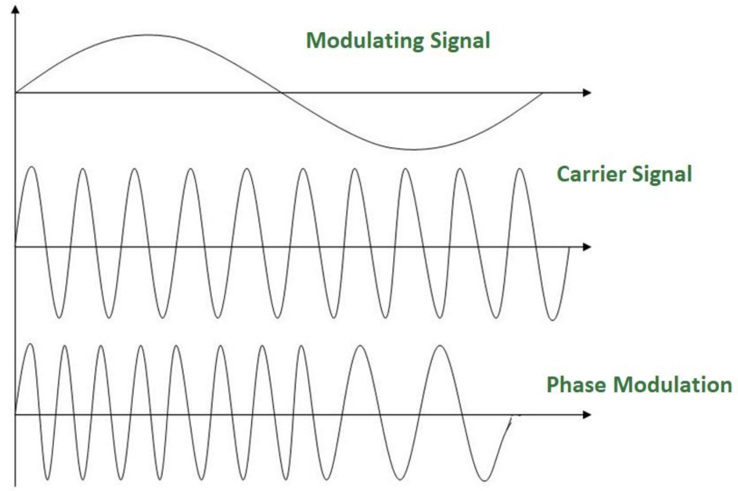
FM is normally implemented by using a voltage-controlled oscillator as with FSK. The frequency of the oscillator changes according to the input voltage which is the amplitude of the modulating signal.

FM bandwidth:

1. The bandwidth of a frequency modulated signal varies with both deviation and modulating frequency.
   If modulating frequency (Mf) 0.5, wide band Fm signal.
2. For a narrow band Fm signal, bandwidth required is twice the maximum frequency of the modulation, however for a wide band Fm signal the required bandwidth can be very much larger, with detectable sidebands spreading out over large amounts of the frequency spectrum.

3. PHASE MODULATION:

The modulation in which the phase of the carrier wave is varied according to the instantaneous amplitude of the modulating signal keeping amplitude and frequency as constant. The figure below shows the concept of frequency modulation:



Phase modulation is practically similar to Frequency Modulation, but in Phase modulation frequency of the carrier signal is not increased. It is normally implemented by using a voltage-controlled oscillator along with a derivative. The frequency of the oscillator changes according to the derivative of the input voltage which is the amplitude of the modulating signal.

PM bandwidth:

1. For small amplitude signals, PM is similar to amplitude modulation (AM) and exhibits its unfortunate doubling of baseband bandwidth and poor efficiency.
2. For a single large sinusoidal signal, PM is similar to FM, and its bandwidth is approximately, **2 (h+1) Fm** where h= modulation index.

Thus, Modulation allows us to send a signal over a bandpass frequency range. If every signal gets its own frequency range, then we can transmit multiple signals simultaneously over a single channel, all using different frequency ranges.

ANALOG TO DIGITAL CONVERSION

Digital Signal: A digital signal is a signal that represents data as a sequence of discrete values; at any given time it can only take on one of a finite number of values. **Analog Signal:** An analog signal is any continuous signal for which the time varying feature of the signal is a representation of some other time varying quantity i.e., analogous to another time varying signal. The following techniques can be used for Analog to Digital Conversion:

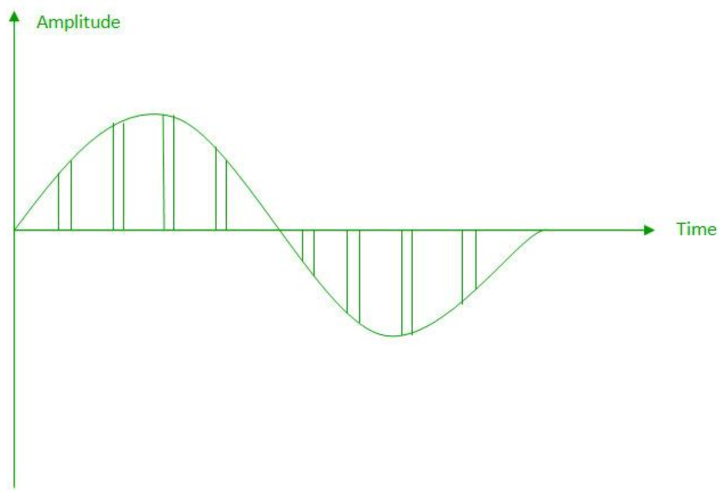
a. PULSE CODE MODULATION:

The most common technique to change an analog signal to digital data is called pulse code modulation (PCM). A PCM encoder has the following three processes:

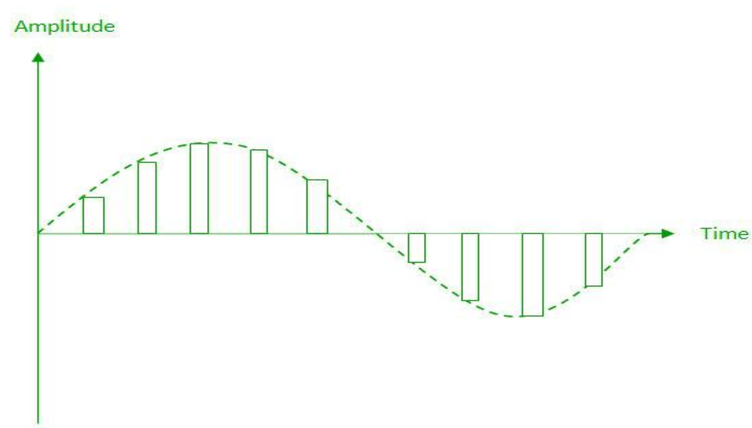
1. Sampling
2. Quantization
3. Encoding

Low pass filter : The low pass filter eliminates the high frequency components present in the input analog signal to ensure that the input signal to sampler is free from the unwanted frequency components.This is done to avoid aliasing of the message signal.

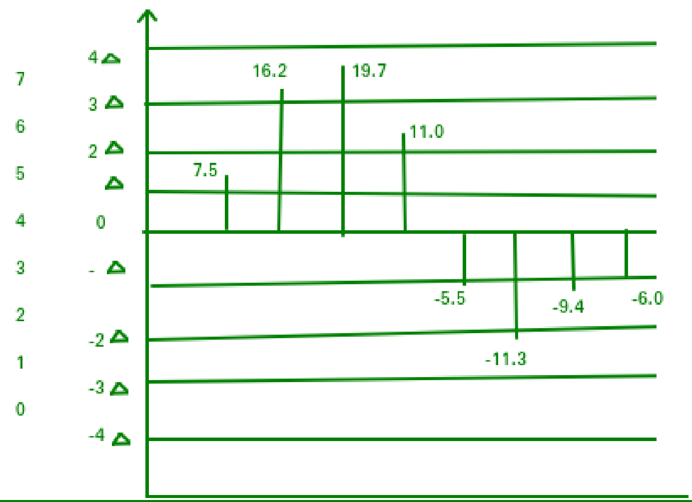
1. **Sampling –** The first step in PCM is sampling. Sampling is a process of measuring the amplitude of a continuous-time signal at discrete instants, converting the continuous signal into a discrete signal. There are three sampling methods: **(i) Ideal Sampling:** In ideal Sampling also known as Instantaneous sampling pulses from the analog signal are sampled. This is an ideal sampling method and cannot be easily implemented. **(ii) Natural Sampling:** Natural Sampling is a practical method of sampling in which pulse have finite width equal to T.The result is a sequence of samples that retain the shape of



the analog signal. **(iii) Flat top sampling:** In comparison to natural sampling flat top sampling can be easily obtained. In this sampling technique, the top of the samples remains constant by using a circuit. This is the most common sampling method used.



2. **Nyquist Theorem:** One important consideration is the sampling rate or frequency. According to the Nyquist theorem, the sampling rate must be at least 2 times the highest frequency contained in the signal. It is also known as the minimum sampling rate and given by: Fs =2*fh
3. **Quantization** – The result of sampling is a series of pulses with amplitude values between the maximum and minimum amplitudes of the signal. The set of amplitudes can be infinite with non-integral values between two limits. The following are the steps in Quantization:
    1. We assume that the signal has amplitudes between Vmax and Vmin
    2. We divide it into L zones each of height d where, d= (Vmax- Vmin)/ L

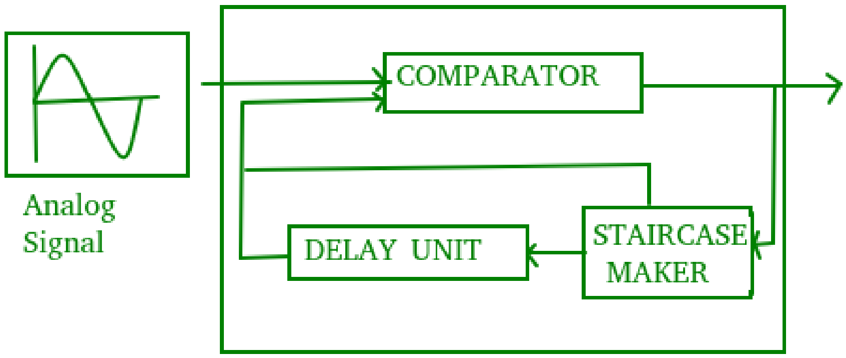


Normalised PAM value :	1.50	3.24	3.94	2.20	-1.10	2.26	-1.88	-1.20
Quantized Value :	1.50	3.50	3.50	2.50	-1.50	-2.50	-1.50	-1.50
Normalized Error :	0	0.26	-0.44	0.30	-0.40	-0.24	0.38	-0.30
Quantization Code :	5	7	7	6	2	1	2	2
Encoded Words :	101	111	111	110	010	001	010	010

    3. The value at the top of each sample in the graph shows the actual amplitude.
    4. The normalized pulse amplitude modulation(PAM) value is calculated using the formula amplitude/d.
    5. After this we calculate the quantized value which the process selects from the middle of each zone.
    6. The Quantized error is given by the difference between quantized value and normalised PAM value.
    7. The Quantization code for each sample based on quantization levels at the left of the graph.
4. **Encoding** – The digitization of the analog signal is done by the encoder. After each sample is quantized and the number of bits per sample is decided, each sample can be changed to an n bit code. Encoding also minimizes the bandwidth used. Note that the number of bits for each sample is determined from the number of quantization levels. If the number of quantization levels is L, the number of bits is n bit = log 2 L.

b. DELTA MODULATION :

Since PCM is a very complex technique, other techniques have been developed to reduce the complexity of PCM. The simplest is delta Modulation. Delta Modulation finds the change from the previous value. **Modulator** – The modulator is used at the sender site to create a stream of bits from an analog signal. The process records a small positive change called delta. If the delta is positive, the process records a 1 else the process records a 0. The modulator builds a second signal that resembles a staircase. The input signal is then compared with this gradually made



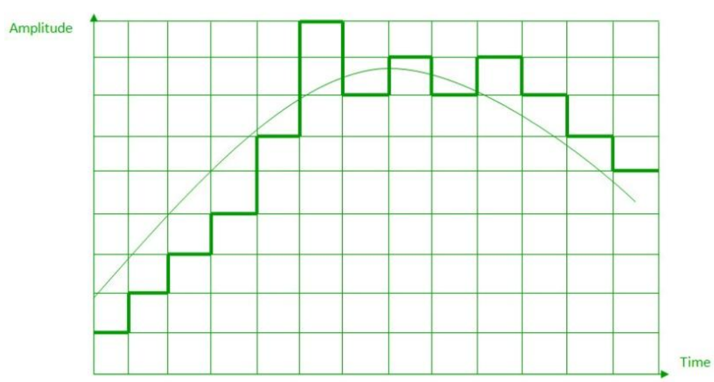
staircase signal. We have the following rules for output:

1. If the input analog signal is higher than the last value of the staircase signal, increase delta by 1, and the bit in the digital data is 1.
2. If the input analog signal is lower than the last value of the staircase signal, decrease delta by 1, and the bit in the digital data is 0.

Demodulator – The demodulator takes the digital data and, using the staircase maker and the delay unit, creates the analog signal. The created analog signal, however, needs to pass through a low-pass filter for smoothing.

c. ADAPTIVE DELTA MODULATION:

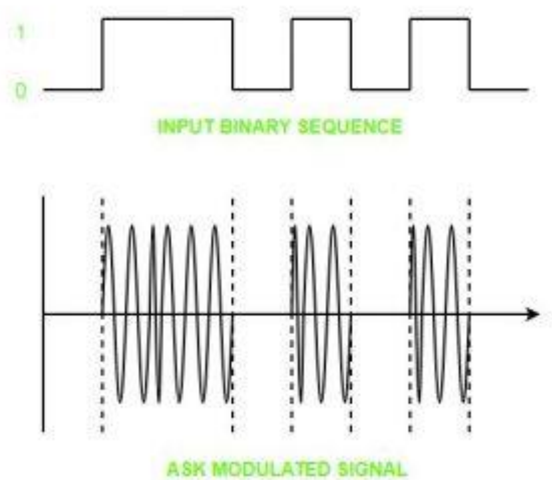
The performance of a delta modulator can be improved significantly by making the step size of the modulator assume a time-varying form. A larger step-size is needed where the message has a steep slope of modulating signal and a smaller step-size is needed where the message has a small slope. The size is adapted according to the level of the input signal. This method is known as



adaptive delta modulation (ADM).

DIGITAL TO ANALOG CONVERSION

Digital Signal – A digital signal is a signal that represents data as a sequence of discrete values; at any given time it can only take on one of a finite number of values.
Analog Signal – An analog signal is any continuous signal for which the time varying feature of the signal is a representation of some other time varying quantity i.e., analogous to another time varying signal.
The following techniques can be used for Digital to Analog Conversion:
1. Amplitude Shift keying – Amplitude Shift Keying is a technique in which carrier signal is analog and data to be modulated is digital. The amplitude of analog carrier signal is modified to reflect binary data.
The binary signal when modulated gives a zero value when the binary data represents 0 while gives the carrier output when data is 1. The frequency and phase of the carrier signal remain constant.

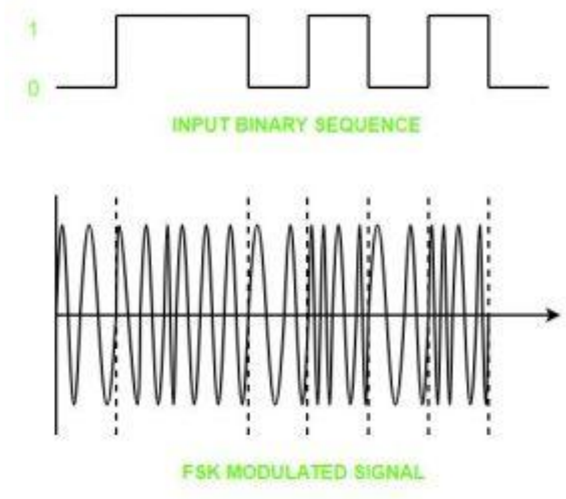


Advantages of amplitude shift Keying –
- It can be used to transmit digital data over optical fiber.
- The receiver and transmitter have a simple design which also makes it comparatively inexpensive.
- It uses lesser bandwidth as compared to FSK thus it offers high bandwidth efficiency.

Disadvantages of amplitude shift Keying –
- It is susceptible to noise interference and entire transmissions could be lost due to this.
- It has lower power efficiency.

2. Frequency Shift keying – In this modulation the frequency of analog carrier signal is modified to reflect binary data.
The output of a frequency shift keying modulated wave is high in frequency for a binary high input and is low in frequency for a binary low input. The amplitude and phase of the carrier

signal remain constant.



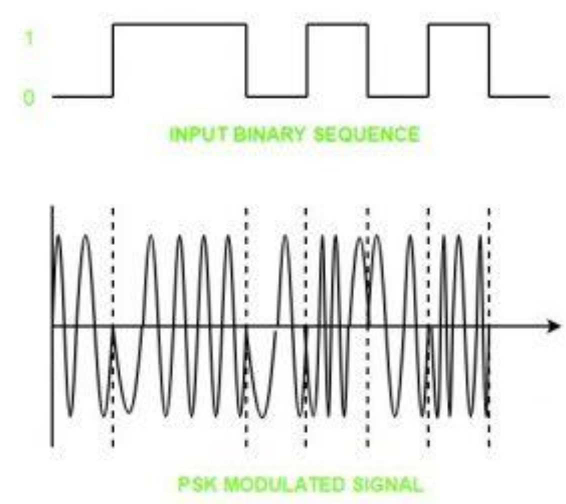
Advantages of frequency shift Keying –

- Frequency shift keying modulated signal can help avoid the noise problems beset by ASK.
- It has lower chances of an error.
- It provides high signal to noise ratio.
- The transmitter and receiver implementations are simple for low data rate application.

Disadvantages of frequency shift Keying –

- It uses larger bandwidth as compared to ASK thus it offers less bandwidth efficiency.
- It has lower power efficiency.

3. Phase Shift keying – In this modulation the phase of the analog carrier signal is modified to reflect binary data.The amplitude and frequency of the carrier signal remains constant.



It is further categorized as follows:

1. **Binary Phase Shift Keying (BPSK):**
   BPSK also known as phase reversal keying or 2PSK is the simplest form of phase shift keying. The Phase of the carrier wave is changed according to the two binary inputs. In Binary Phase shift keying, difference of 180 phase shift is used between binary 1 and binary 0.
   This is regarded as the most robust digital modulation technique and is used for long distance wireless communication.
2. **Quadrature phase shift keying:**
   This technique is used to increase the bit rate i.e we can code two bits onto one single element. It uses four phases to encode two bits per symbol. QPSK uses phase shifts of multiples of 90 degrees.
   It has double data rate carrying capacity compare to BPSK as two bits are mapped on each constellation points.

Advantages of phase shift Keying –

- It is a more power efficient modulation technique as compared to ASK and FSK.
- It has lower chances of an error.
- It allows data to be carried along a communication signal much more efficiently as compared to FSK.

Disadvantages of phase shift Keying –

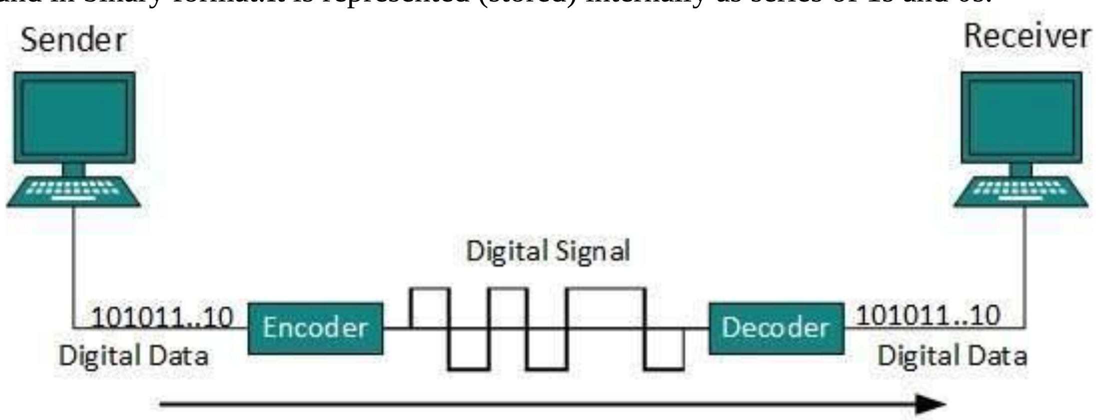
- It offers low bandwidth efficiency.
- The detection and recovery algorithms of binary data is very complex.
- It is a non coherent reference signal

DIGITAL-TO-DIGITAL CONVERSION

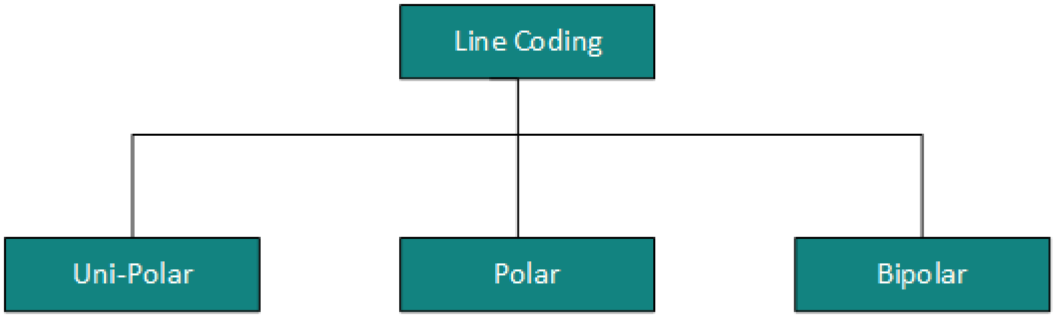
This section explains how to convert digital data into digital signals. It can be done in two ways, line coding and block coding. For all communications, line coding is necessary whereas block coding is optional.

Line Coding

The process for converting digital data into digital signal is said to be Line Coding. Digital data is found in binary format.It is represented (stored) internally as series of 1s and 0s.

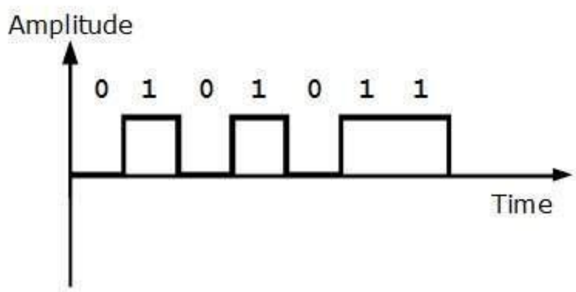


Digital signal is denoted by discreet signal, which represents digital data.There are three types of line coding schemes available:



Uni-polar Encoding

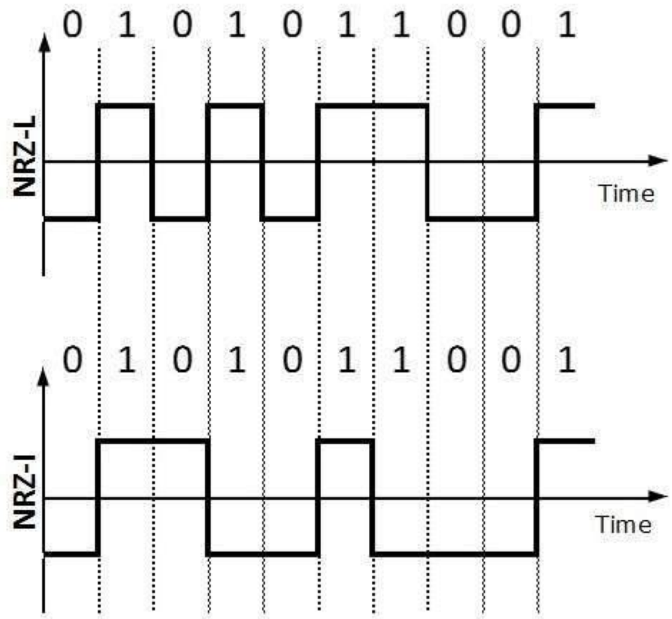
Unipolar encoding schemes use single voltage level to represent data. In this case, to represent binary 1, high voltage is transmitted and to represent 0, no voltage is transmitted. It is also called Unipolar-Non-return-to-zero, because there is no rest condition i.e. it either represents 1 or 0.



Polar Encoding

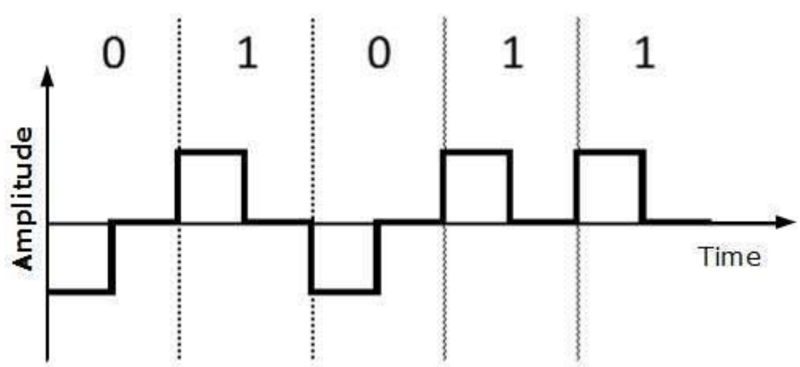
Polar encoding scheme uses multiple voltage levels to represent binary values. Polar encodings is available in four types:

- Polar Non-Return to Zero (Polar NRZ)
  It uses two different voltage levels to represent binary values. Generally, positive voltage represents 1 and negative value represents 0. It is also NRZ because there is no rest condition.
  NRZ scheme has two variants: NRZ-L and NRZ-I.



NRZ-L changes voltage level at when a different bit is encountered whereas NRZ-I changes voltage when a 1 is encountered.

- **Return to Zero (RZ)**
  Problem with NRZ is that the receiver cannot conclude when a bit ended and when the next bit is started, in case when sender and receiver's clock are not synchronized.

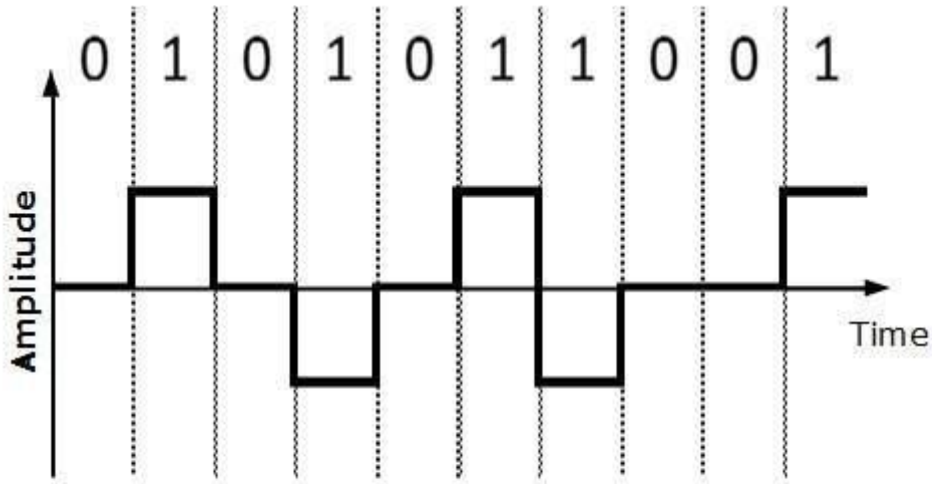


RZ uses three voltage levels, positive voltage to represent 1, negative voltage to represent 0 and zero voltage for none. Signals change during bits not between bits.

- **Manchester**
  This encoding scheme is a combination of RZ and NRZ-L. Bit time is divided into two halves. It transits in the middle of the bit and changes phase when a different bit is encountered.
- **Differential Manchester**
  This encoding scheme is a combination of RZ and NRZ-I. It also transit at the middle of the bit but changes phase only when 1 is encountered.

Bipolar Encoding

Bipolar encoding uses three voltage levels, positive, negative and zero. Zero voltage represents binary 0 and bit 1 is represented by altering positive and negative voltages.



Block Coding

To ensure accuracy of the received data frame redundant bits are used. For example, in even-parity, one parity bit is added to make the count of 1s in the frame even. This way the original number of bits is increased. It is called Block Coding.

Block coding is represented by slash notation, mB/nB.Means, m-bit block is substituted with n-bit block where n > m. Block coding involves three steps:

- Division,
- Substitution
- Combination.

After block coding is done, it is line coded for transmission.

ANALOG-TO-DIGITAL CONVERSION

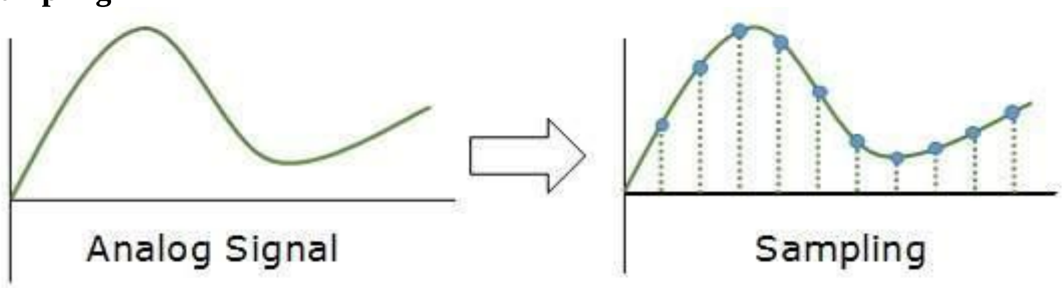
Microphones create analog voice and camera creates analog videos, which are treated is analog data. To transmit this analog data over digital signals, we need analog to digital conversion.

Analog data is a continuous stream of data in the wave form whereas digital data is discrete. To convert analog wave into digital data, we use Pulse Code Modulation (PCM).

PCM is one of the most commonly used method to convert analog data into digital form. It involves three steps:

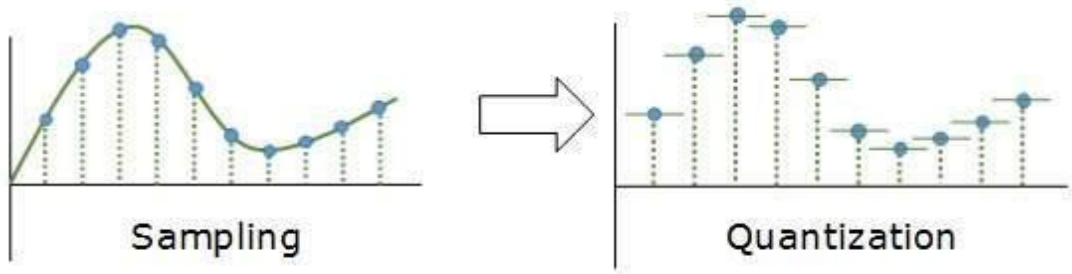
- Sampling
- Quantization
- Encoding.

Sampling



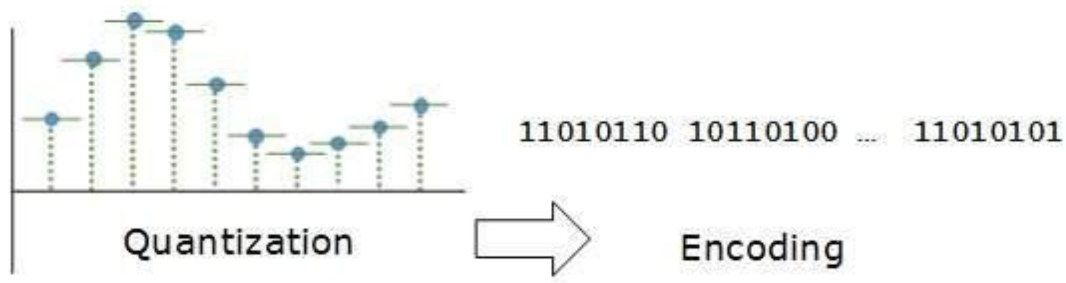
The analog signal is sampled every T interval. Most important factor in sampling is the rate at which analog signal is sampled. According to Nyquist Theorem, the sampling rate must be at least two times of the highest frequency of the signal.

Quantization



Sampling yields discrete form of continuous analog signal. Every discrete pattern shows the amplitude of the analog signal at that instance. The quantization is done between the maximum amplitude value and the minimum amplitude value. Quantization is approximation of the instantaneous analog value.

Encoding

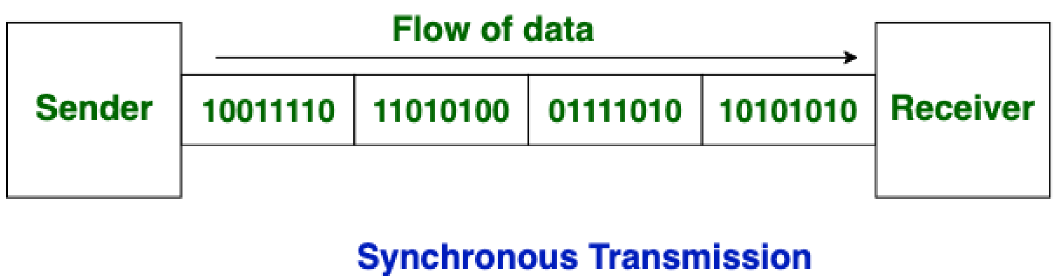


In encoding, each approximated value is then converted into binary format.

Synchronous Transmission: In Synchronous Transmission, data is sent in form of blocks or frames. This transmission is the full-duplex type. Between sender and receiver, synchronization is compulsory. In Synchronous transmission, There is no gap present between data. It is more efficient and more reliable than asynchronous transmission to transfer a large amount of data.

Example:

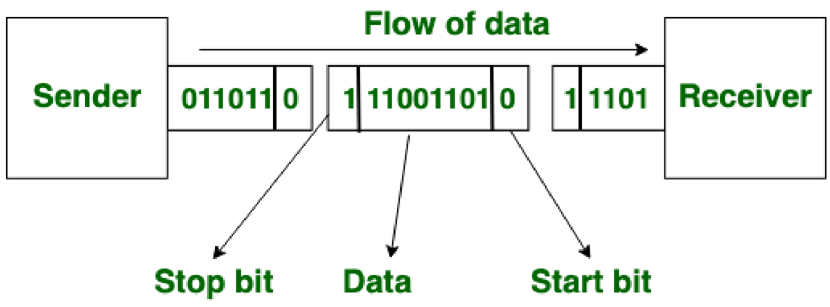
- Chat Rooms
- Telephonic Conversations
- Video Conferencing



Asynchronous Transmission: In Asynchronous Transmission, data is sent in form of byte or character. This transmission is the half-duplex type transmission. In this transmission start bits and stop bits are added with data. It does not require synchronization.

Example:

- Email
- Forums
- Letters



Asynchronous Transmission

Now, let's see the difference between Synchronous Transmission and Asynchronous Transmission:

S. No.	Synchronous Transmission	Asynchronous Transmission
1.	In Synchronous transmission, data is sent in form of blocks or frames.	In Asynchronous transmission, data is sent in form of bytes or characters.
2.	Synchronous transmission is fast.	Asynchronous transmission is slow.
3.	Synchronous transmission is costly.	Asynchronous transmission is economical.
4.	In Synchronous transmission, the time interval of transmission is constant.	In Asynchronous transmission, the time interval of transmission is not constant, it is random.
5.	In this transmission, users have to wait till the transmission is complete before getting a response back from the server.	Here, users do not have to wait for the completion of transmission in order to get a response from the server.
6.	In Synchronous transmission, there is no gap present between data.	In Asynchronous transmission, there is a gap present between data.
7.	Efficient use of transmission lines is done in synchronous transmission.	While in Asynchronous transmission, the transmission line remains empty during a gap in character transmission.
8.	The start and stop bits are not used in transmitting data.	The start and stop bits are used in transmitting data that imposes extra overhead.
9.	Synchronous transmission needs precisely synchronized clocks for the information of new bytes.	Asynchronous transmission does not need synchronized clocks as parity bit is used in this transmission for information of new bytes.
10.	Errors are detected and corrected in real	Errors are detected and corrected when the

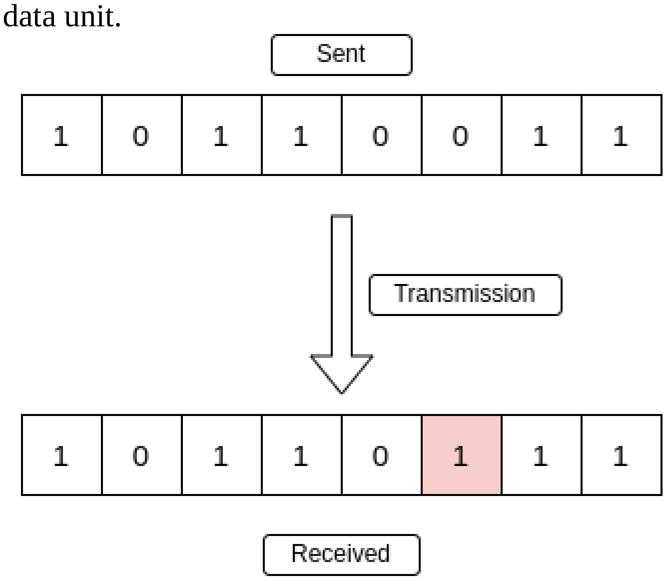
S. No.	Synchronous Transmission	Asynchronous Transmission
	time.	data is received.
11.	Low latency due to real-time communication.	High latency due to processing time and waiting for data to become available.
12.	Examples: Telephonic conversations, Video conferencing, Online gaming.	Examples: Email, File transfer,Online forms.

Error is a condition when the receiver's information does not match the sender's information. During transmission, digital signals suffer from noise that can introduce errors in the binary bits traveling from sender to receiver. That means a 0 bit may change to 1 or a 1 bit may change to 0. Data (Implemented either at the Data link layer or Transport Layer of the OSI Model) may get scrambled by noise or get corrupted whenever a message is transmitted. To prevent such errors, error-detection codes are added as extra data to digital messages. This helps in detecting any errors that may have occurred during message transmission.

TYPES OF ERRORS

Single-Bit Error

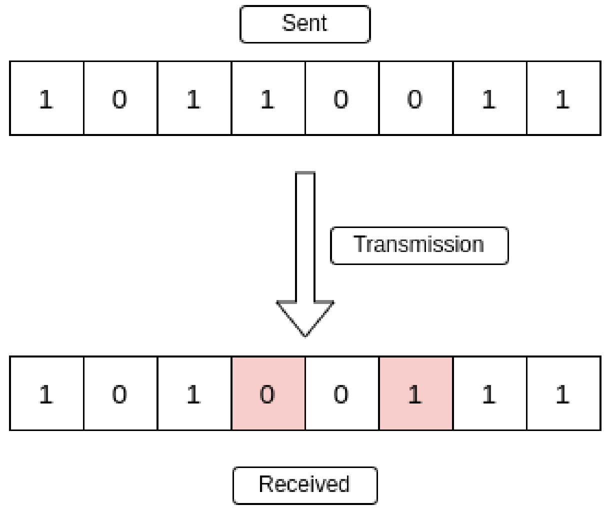
A single-bit error refers to a type of data transmission error that occurs when one bit (i.e., a single binary digit) of a transmitted data unit is altered during transmission, resulting in an incorrect or corrupted data unit.



Single-Bit Error

Multiple-Bit Error

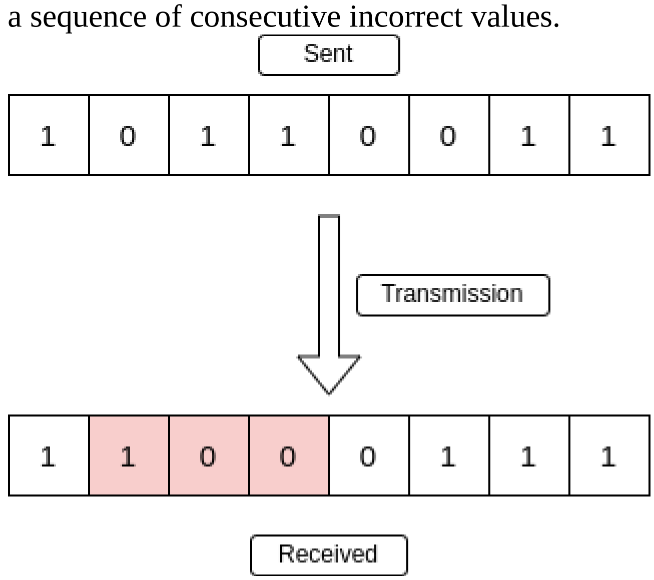
A multiple-bit error is an error type that arises when more than one bit in a data transmission is affected. Although multiple-bit errors are relatively rare when compared to single-bit errors, they can still occur, particularly in high-noise or high-interference digital environments.



Multiple-Bit Error

Burst Error

When several consecutive bits are flipped mistakenly in digital transmission, it creates a burst error. This error causes a sequence of consecutive incorrect values.



Burst Error

To detect errors, a common technique is to introduce redundancy bits that provide additional information. Various techniques for error detection include::

1. Simple Parity Check
2. Two-dimensional Parity Check
3. Checksum
4. Cyclic Redundancy Check (CRC)

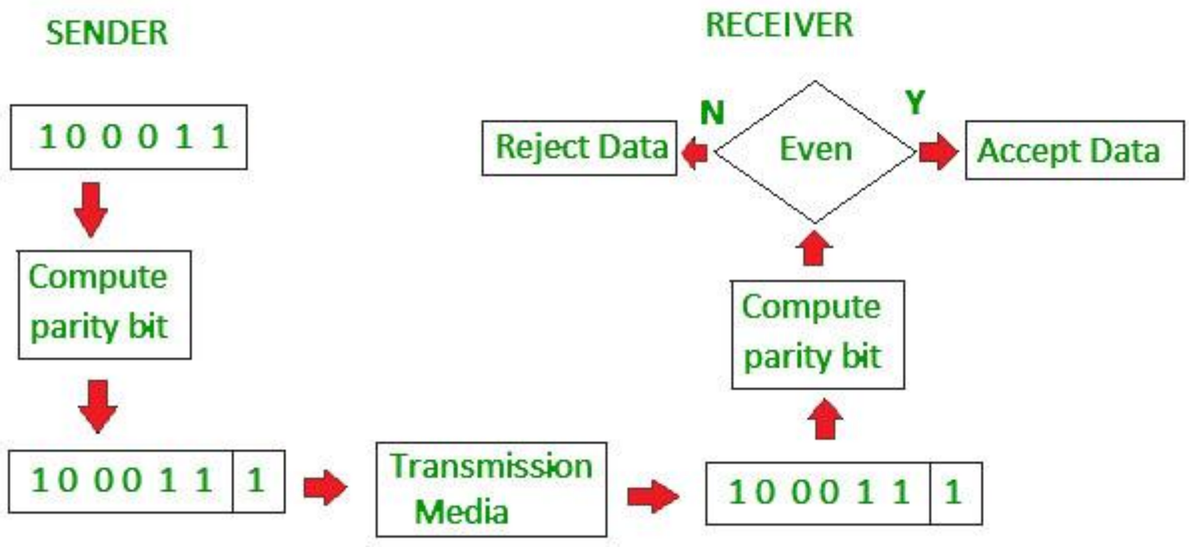
ERROR DETECTION METHODS

Simple Parity Check

Simple-bit parity is a simple error detection method that involves adding an extra bit to a data transmission. It works as:

- 1 is added to the block if it contains an odd number of 1's, and
- 0 is added if it contains an even number of 1's

This scheme makes the total number of 1's even, that is why it is called even parity checking.

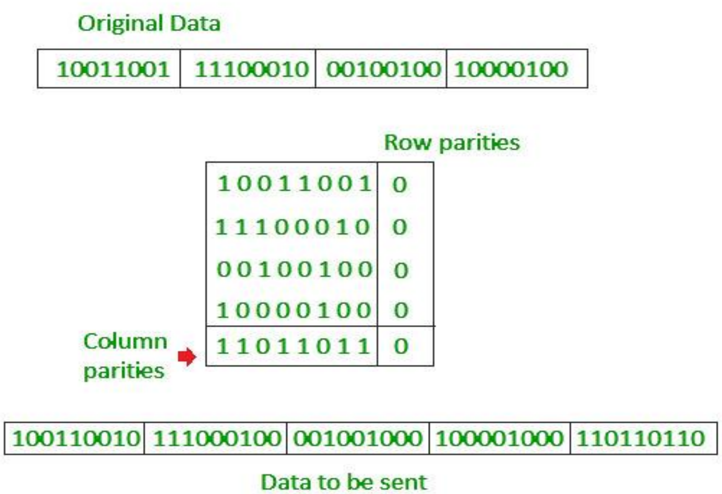


Disadvantages

- Single Parity check is not able to detect even no. of bit error.
- **For example,** the Data to be transmitted is **101010**. Codeword transmitted to the receiver is 1010101 (we have used even parity). Let's assume that during transmission, two of the bits of code word flipped to 1111101. On receiving the code word, the receiver finds the no. of ones to be even and hence **no error,** *which is a wrong assumption.*

Two-dimensional Parity Check

Two-dimensional Parity check bits are calculated for each row, which is equivalent to a simple parity check bit. Parity check bits are also calculated for all columns, then both are sent along with the data. At the receiving end, these are compared with the parity bits calculated on the received data.



Checksum

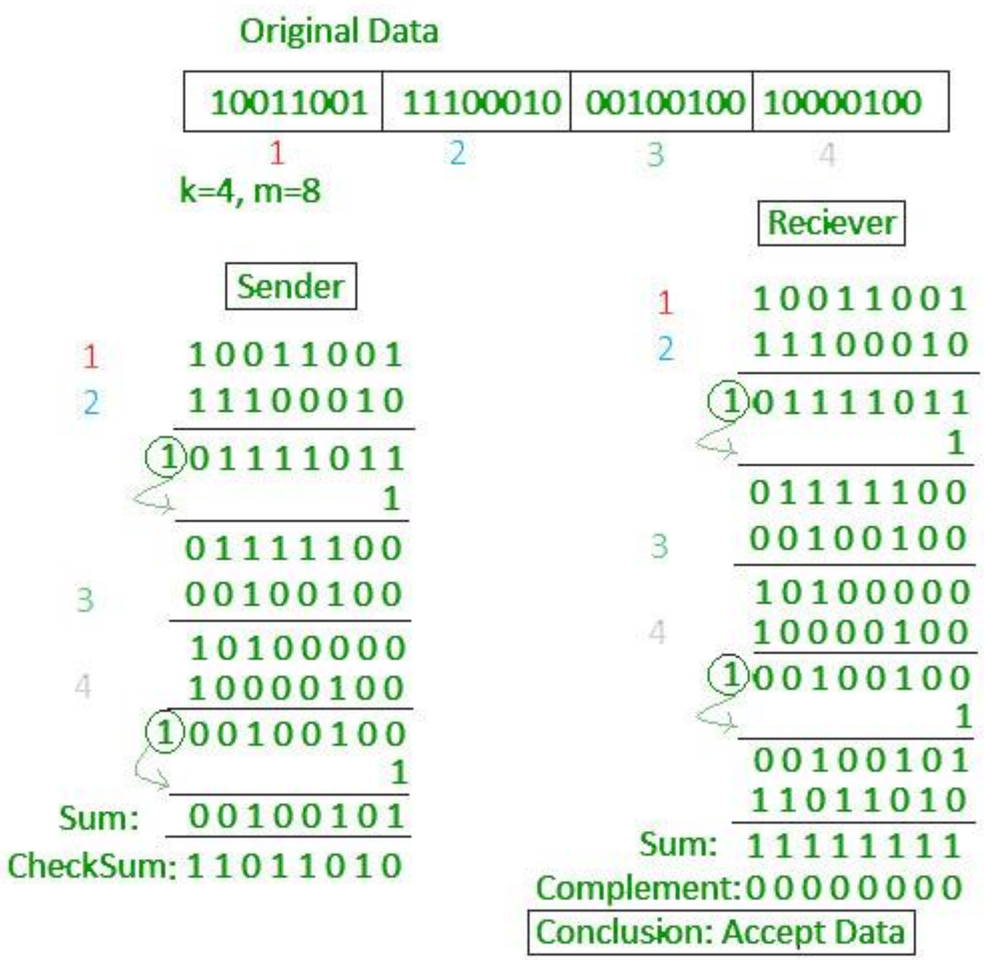
Checksum error detection is a method used to identify errors in transmitted data. The process involves dividing the data into equally sized segments and using a 1's complement to calculate the sum of these segments. The calculated sum is then sent along with the data to the receiver. At the receiver's end, the same process is repeated and if all zeroes are obtained in the sum, it means that the data is correct.

Checksum – Operation at Sender's Side

- Firstly, the data is divided into k segments each of m bits.
- On the sender's end, the segments are added using 1's complement arithmetic to get the sum. The sum is complemented to get the checksum.
- The checksum segment is sent along with the data segments.

Checksum – Operation at Receiver's Side

- At the receiver's end, all received segments are added using 1's complement arithmetic to get the sum. The sum is complemented.
- If the result is zero, the received data is accepted; otherwise discarded.

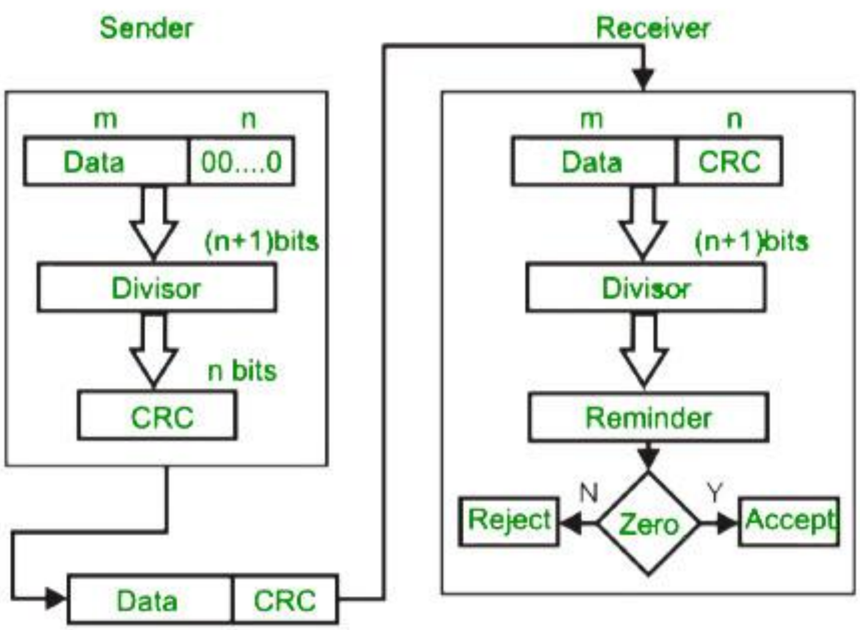


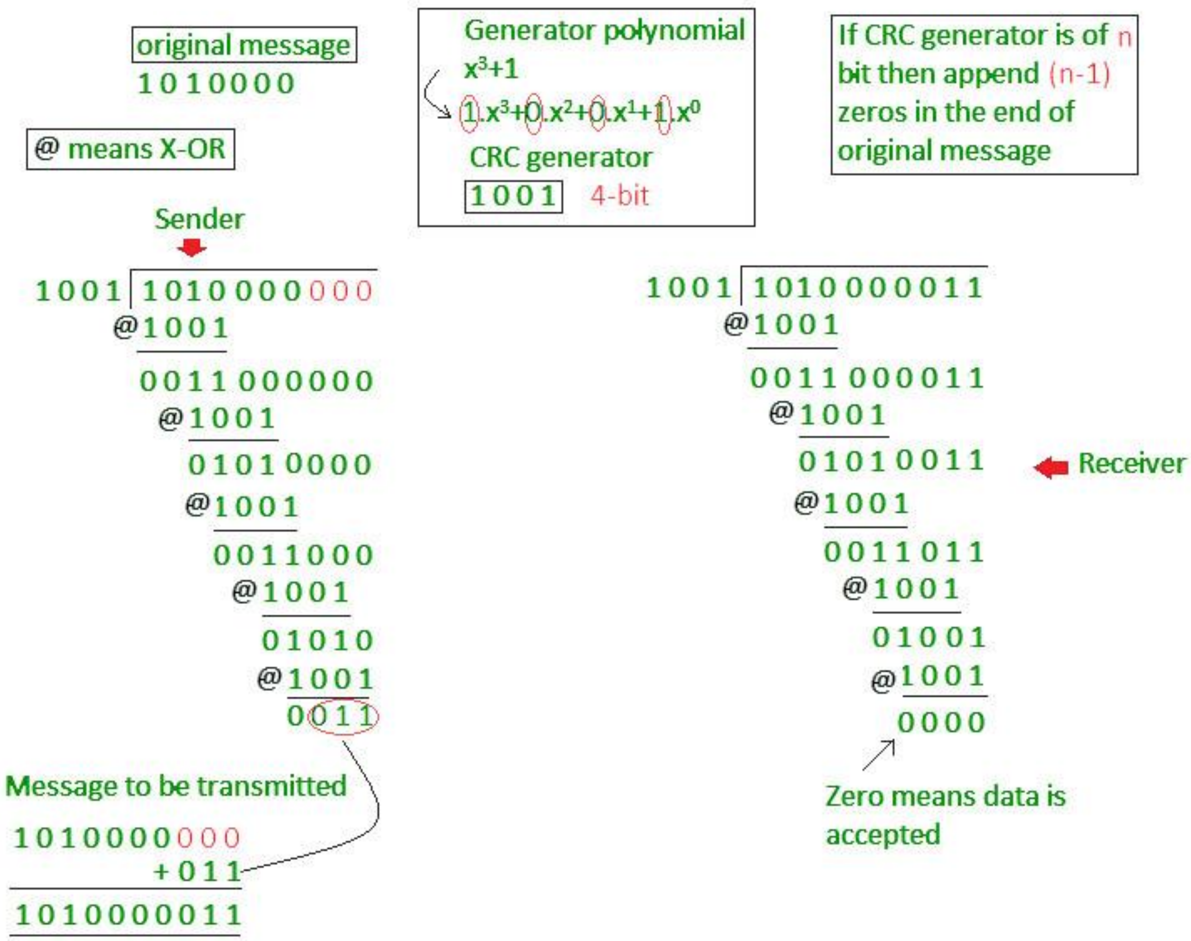
Disadvantages

- If one or more bits of a segment are damaged and the corresponding bit or bits of opposite value in a second segment are also damaged.

Cyclic Redundancy Check (CRC)

- Unlike the checksum scheme, which is based on addition, CRC is based on binary division.
- In CRC, a sequence of redundant bits, called cyclic redundancy check bits, are appended to the end of the data unit so that the resulting data unit becomes exactly divisible by a second, predetermined binary number.
- At the destination, the incoming data unit is divided by the same number. If at this step there is no remainder, the data unit is assumed to be correct and is therefore accepted.
- A remainder indicates that the data unit has been damaged in transit and therefore must be rejected.





Example: Previous year GATE questions based on error detection: GATE CS 2009 Question 48 GATE CS 2007 Question 68. This article has been contributed by Vikash Kumar. Please write comments if you find anything incorrect, or if you want to share more information about the topic discussed above.

Advantages:

Increased Data Reliability: Error detection ensures that the data transmitted over the network is reliable, accurate, and free from errors. This ensures that the recipient receives the same data that was transmitted by the sender.

Improved Network Performance: Error detection mechanisms can help to identify and isolate network issues that are causing errors. This can help to improve the overall performance of the network and reduce downtime.

Enhanced Data Security: Error detection can also help to ensure that the data transmitted over the network is secure and has not been tampered with.

Disadvantages:

Overhead: Error detection requires additional resources and processing power, which can lead to increased overhead on the network. This can result in slower network performance and increased latency.

False Positives**:** Error detection mechanisms can sometimes generate false positives, which can result in unnecessary retransmission of data. This can further increase the overhead on the network.

Limited Error Correction**:** Error detection can only identify errors but cannot correct them. This means that the recipient must rely on the sender to retransmit the data, which can lead to further delays and increased network overhead.

ERROR CORRECTION

Error Correction codes are used to detect and correct the errors when data is transmitted from the sender to the receiver.

Error Correction can be handled in two ways:

- **Backward error correction:** Once the error is discovered, the receiver requests the sender to retransmit the entire data unit.
- **Forward error correction:** In this case, the receiver uses the error-correcting code which automatically corrects the errors.

A single additional bit can detect the error, but cannot correct it.

For correcting the errors, one has to know the exact position of the error. For example, If we want to calculate a single-bit error, the error correction code will determine which one of seven bits is in error. To achieve this, we have to add some additional redundant bits.

Suppose r is the number of redundant bits and d is the total number of the data bits. The number of redundant bits r can be calculated by using the formula:

$2^r >= d+r+1$

The value of r is calculated by using the above formula. For example, if the value of d is 4, then the possible smallest value that satisfies the above relation would be 3.

To determine the position of the bit which is in error, a technique developed by R.W Hamming is Hamming code which can be applied to any length of the data unit and uses the relationship between data units and redundant units.

Hamming Code

Parity bits: The bit which is appended to the original data of binary bits so that the total number of 1s is even or odd.

Even parity: To check for even parity, if the total number of 1s is even, then the value of the parity bit is 0. If the total number of 1s occurrences is odd, then the value of the parity bit is 1.

Odd Parity: To check for odd parity, if the total number of 1s is even, then the value of parity bit is 1. If the total number of 1s is odd, then the value of parity bit is 0.

Algorithm of Hamming code:

- An information of 'd' bits are added to the redundant bits 'r' to form d+r.
- The location of each of the (d+r) digits is assigned a decimal value.
- The 'r' bits are placed in the positions 1,2,.....2^{k-1}.

- At the receiving end, the parity bits are recalculated. The decimal value of the parity bits determines the position of an error.

Relationship b/w Error position & binary number.

Error Position	Binary Number
0	000
1	001
2	010
3	011
4	100
5	101
6	110
7	111

Let's understand the concept of Hamming code through an example:

Suppose the original data is 1010 which is to be sent.

Total number of data bits 'd' = 4

Number of redundant bits r : $2^r >= d+r+1$

$2^r >= 4+r+1$

Therefore, the value of r is 3 that satisfies the above relation.

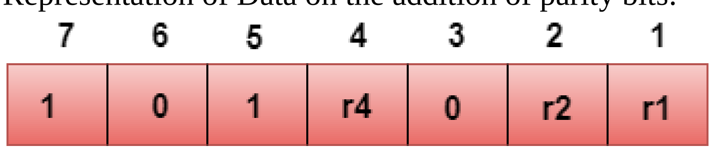
Total number of bits = d+r = 4+3 = 7;

Determining the position of the redundant bits

The number of redundant bits is 3. The three bits are represented by r1, r2, r4. The position of the redundant bits is calculated with corresponds to the raised power of 2. Therefore, their corresponding positions are **1, 2^1, 2^2**.

1. The position of r1 = 1
2. The position of r2 = 2
3. The position of r4 = 4

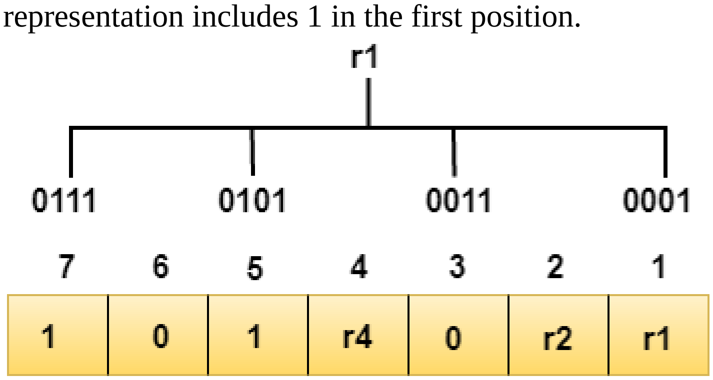
Representation of Data on the addition of parity bits:



Determining the Parity bits

Determining the r1 bit

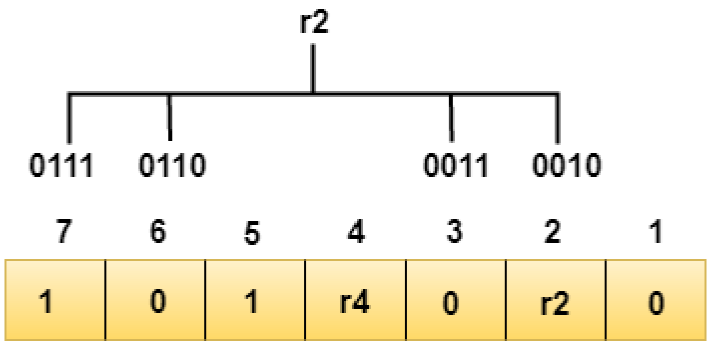
The r1 bit is calculated by performing a parity check on the bit positions whose binary representation includes 1 in the first position.



We observe from the above figure that the bit positions that includes 1 in the first position are 1, 3, 5, 7. Now, we perform the even-parity check at these bit positions. The total number of 1 at these bit positions corresponding to r1 is **even, therefore, the value of the r1 bit is 0**.

Determining r2 bit

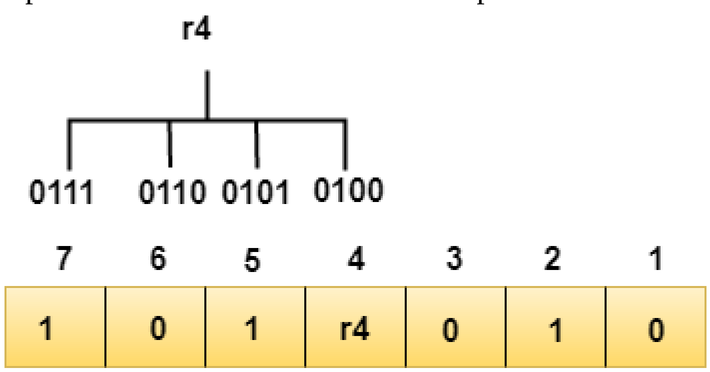
The r2 bit is calculated by performing a parity check on the bit positions whose binary representation includes 1 in the second position.



We observe from the above figure that the bit positions that includes 1 in the second position are **2, 3, 6, 7**. Now, we perform the even-parity check at these bit positions. The total number of 1 at these bit positions corresponding to r2 is **odd, therefore, the value of the r2 bit is 1**.

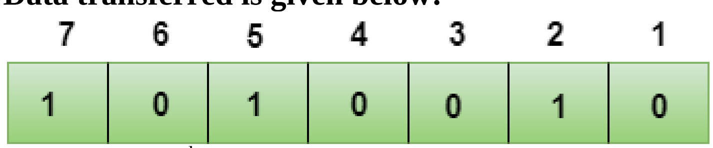
Determining r4 bit

The r4 bit is calculated by performing a parity check on the bit positions whose binary representation includes 1 in the third position.



We observe from the above figure that the bit positions that includes 1 in the third position are **4, 5, 6, 7**. Now, we perform the even-parity check at these bit positions. The total number of 1 at these bit positions corresponding to r4 is **even, therefore, the value of the r4 bit is 0**.

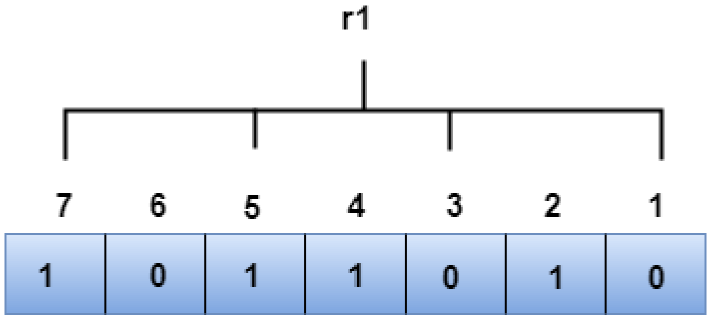
Data transferred is given below:



Suppose the 4^{th} bit is changed from 0 to 1 at the receiving end, then parity bits are recalculated.

R1 bit

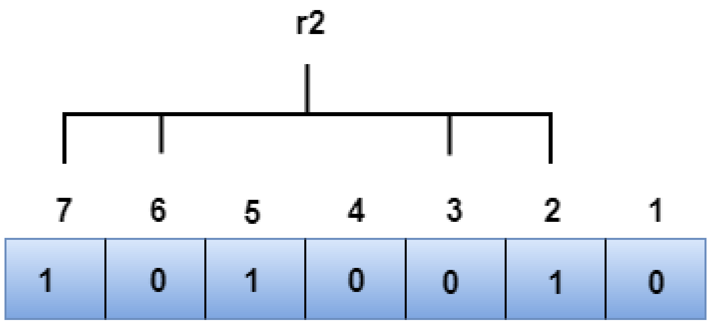
The bit positions of the r1 bit are 1,3,5,7



We observe from the above figure that the binary representation of r1 is 1100. Now, we perform the even-parity check, the total number of 1s appearing in the r1 bit is an even number. Therefore, the value of r1 is 0.

R2 bit

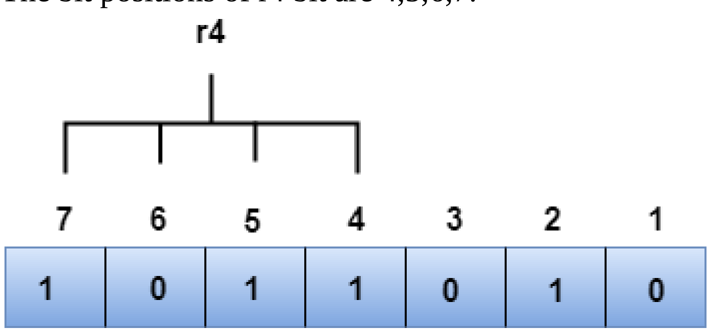
The bit positions of r2 bit are 2,3,6,7.



We observe from the above figure that the binary representation of r2 is 1001. Now, we perform the even-parity check, the total number of 1s appearing in the r2 bit is an even number. Therefore, the value of r2 is 0.

R4 bit

The bit positions of r4 bit are 4,5,6,7.



We observe from the above figure that the binary representation of r4 is 1011. Now, we perform the even-parity check, the total number of 1s appearing in the r4 bit is an odd number. Therefore, the value of r4 is 1.

- *The binary representation of redundant bits, i.e., r4r2r1 is 100, and its corresponding decimal value is 4. Therefore, the error occurs in a* 4^{th} *bit position. The bit value must be changed from 1 to 0 to correct the error.*

LINE CONFIGURATION

A network is two or more devices connected through a link. A link is a communication pathway that transfers data from one device to another. Devices can be a computer, printer, or any other device that is capable to send and receive data. For visualization purposes, imagine any link as a line drawn between two points.

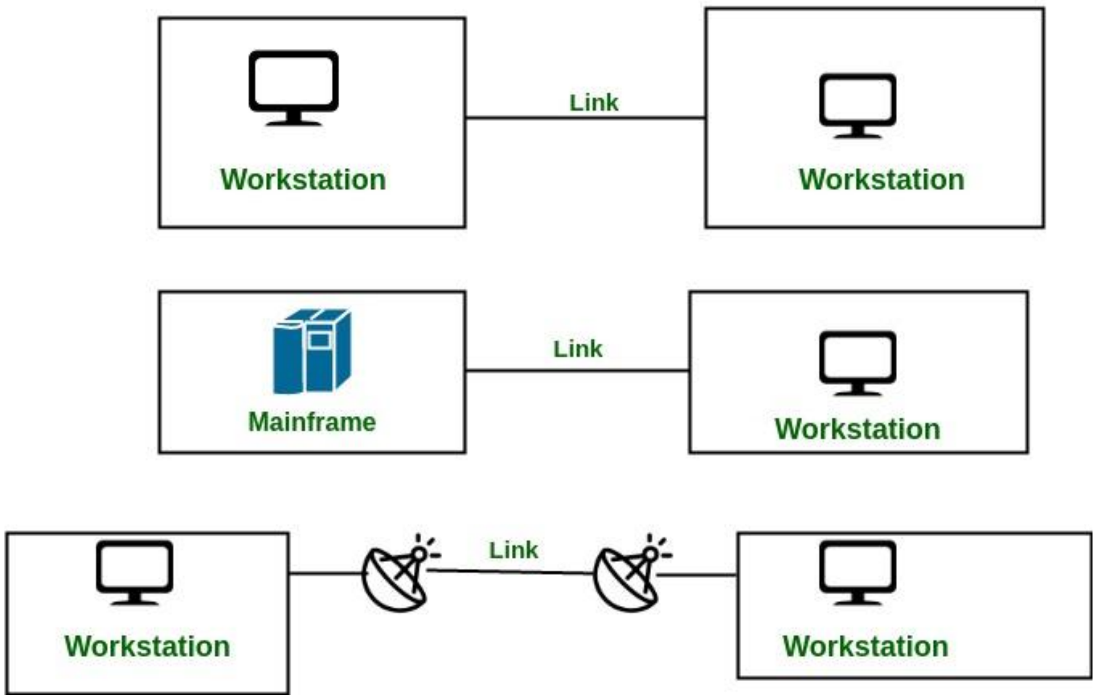
For communication to occur, two devices must be connected in some way to the same link at the same time. There are two possible types of connections:

1. **Point-to-Point Connection**
2. **Multipoint Connection**

Point-to-Point Connection:

1. A point-to-point connection provides a dedicated link between two devices.
2. The entire capacity of the link is reserved for transmission between those two devices.
3. Most point-to-point connections use an actual length of wire or cable to connect the two ends, but other options such as microwave or satellite links are also possible.
4. Point to point network topology is considered to be one of the easiest and most conventional networks topologies.
5. It is also the simplest to establish and understand.

Example: Point-to-Point connection between the remote control and Television for changing the channels.



Here are some features of different line configurations in computer networks:

Point-to-Point:

- Uses a dedicated link to connect two devices
- Simple and easy to set up
- Limited to two devices only
- Does not require a network interface card (NIC) or a hub/switch
- Can become complex and difficult to manage as the network grows

Multipoint:

- Uses a single link to connect three or more devices
- More complex than point-to-point configuration
- Can be more efficient and cost-effective for larger networks
- Devices share the same link, which can lead to collisions and lower performance
- Commonly used in LANs and MANs

Star:

- All devices in the network are connected to a central hub or switch
- Easy to manage and troubleshoot
- Provides good performance and reliability
- A single point of failure (the hub or switch) can affect the entire network
- Requires additional hardware and cabling

Mesh:

- Every device is connected to every other device in the network
- Provides the highest level of reliability and redundancy
- Can handle high traffic and heavy loads
- Very expensive and difficult to manage
- Commonly used in mission-critical networks and large WANs

Choosing the right line configuration depends on the specific needs of the network, including factors such as the size of the network, the type of data being transmitted, the level of reliability required, and the available resources. Different line configurations can offer various advantages and disadvantages, and the optimal configuration will depend on the specific use case.

Advantages of Point-to-Point Connection:

1. **High Bandwidth:** A point-to-point connection provides a dedicated link between two devices, which means that the entire capacity of the link is reserved for the two devices. As a result, point-to-point connections usually offer high bandwidth, which makes them suitable for transferring large amounts of data quickly.
2. **Security:** Point-to-point connections are more secure than multipoint connections because the link is dedicated to only two devices. There is no risk of other devices eavesdropping on the communication or interfering with it in any way.
3. **Reliability:** Because a point-to-point connection provides a dedicated link between two devices, it is usually more reliable than a shared link. If there is a problem with the link, it is easier to troubleshoot and fix because there are only two devices involved.
4. **Reduced Latency:** Point-to-point connections offer lower latency than multipoint connections because there is no contention for the link. This means that data can be transmitted more quickly, which is especially important for real-time applications such as video conferencing or online gaming.
5. **Increased Control:** Point-to-point connections provide greater control over network traffic and bandwidth allocation. This allows for more efficient use of network resources and can help to prevent issues such as network congestion and bottlenecks.
6. **Improved Performance:** Point-to-point connections can improve network performance by reducing packet loss and increasing the speed of data transmission. This can lead to faster data transfers, improved application performance, and a better overall user experience.

7. **Distance:** Point-to-point connections can be established over longer distances than multipoint connections. This is because the dedicated link provides a stronger signal, which can travel further without losing strength.
8. **Cost-Effective:** Point-to-point connections can be cost-effective in certain situations, such as connecting two buildings or offices that are located far apart. In some cases, it may be more cost-effective to establish a point-to-point connection than to invest in a more complex multipoint network.
9. **Easy to Manage:** Point-to-point connections are easy to manage because there are only two devices involved. This reduces the complexity of network administration and makes it easier to troubleshoot problems if they arise.

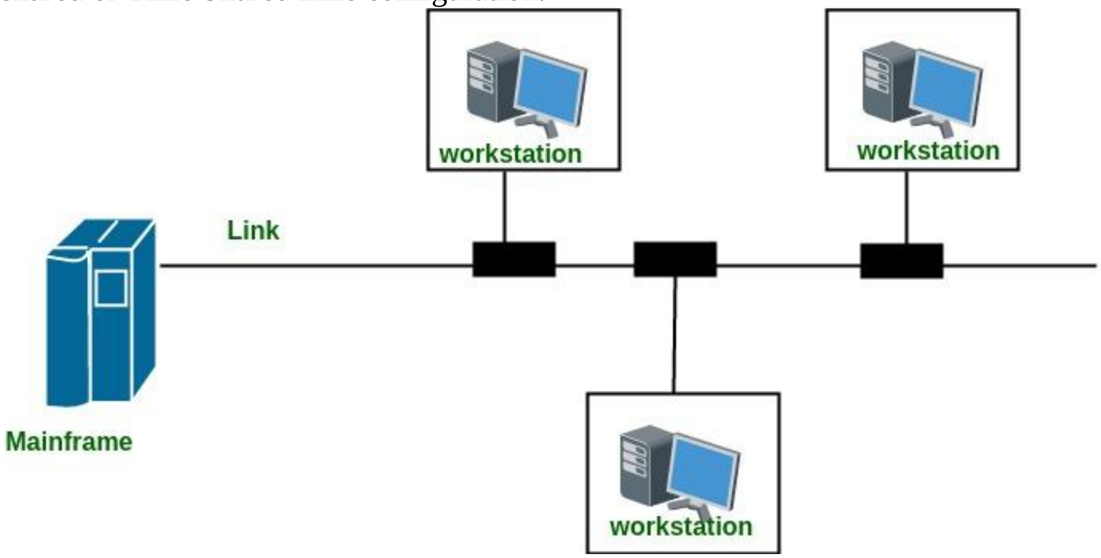
Disadvantages of Point-to-Point Connection:

1. **Cost:** Setting up a point-to-point connection can be more expensive than setting up a shared link. This is because a dedicated link requires its own infrastructure, such as cables, routers, and switches.
2. **Scalability:** Point-to-point connections are not easily scalable, as they require a separate link for each pair of devices. This can be a limitation for large networks that require many devices to be connected.
3. **Maintenance:** Because a point-to-point connection provides a dedicated link between two devices, it requires more maintenance than a shared link. If there is a problem with the link, it is the responsibility of the network administrator to troubleshoot and fix it.
4. **Limited Flexibility:** Point-to-point connections offer limited flexibility compared to multipoint connections because they only allow communication between two devices. This can be a limitation for applications that require collaboration or coordination between multiple devices.
5. **Time-consuming Installation:** Setting up a point-to-point connection can be time-consuming, as it requires a dedicated link to be established between two devices. This can be a disadvantage in situations where time is critical, such as in emergency response situations.
6. **Vulnerability to Failure:** Point-to-point connections are vulnerable to failure if there is a problem with one of the devices or the link itself. This can lead to downtime and disruption of network services, which can be costly for businesses.
7. **Limited Redundancy:** Point-to-point connections offer limited redundancy compared to multipoint connections, as there is no alternative link available if the primary link fails. This can be a disadvantage in situations where high availability is critical, such as in mission-critical applications.
8. **Limited Collaboration:** Point-to-point connections limit collaboration between multiple devices, which can be a disadvantage in situations where multiple devices need to work together to achieve a common goal. This can be a limitation for applications such as video conferencing or online gaming.
9. **Limited Interoperability:** Point-to-point connections may have limited interoperability with other devices or networks. This can be a disadvantage in situations where multiple devices or networks need to communicate with each other.

Multipoint Connection :

1. It is also called Multidrop configuration. In this connection, two or more devices share a single link.
2. If more than two devices share the link then the channel is considered a 'shared channel'. With shared capacity, there can be two possibilities in a Multipoint Line configuration:

Spatial Sharing: If several devices can share the link simultaneously, it's called Spatially shared line configuration.
Temporal (Time) Sharing: If users must take turns using the link, then it's called Temporally shared or Time Shared Line configuration.



Advantages of Multipoint Connection:

1. **Cost-Effective:** Multipoint connections are usually less expensive than point-to-point connections because they allow multiple devices to share the same resources, such as cables, routers, and switches.
2. **Scalability:** Multipoint connections are more scalable than point-to-point connections because they allow multiple devices to be connected to the same link. This makes them suitable for large networks that require many devices to be connected.
3. **Flexibility:** Multipoint connections are more flexible than point-to-point connections because they allow multiple devices to communicate with each other over the same link. This makes them suitable for applications that require collaboration or coordination between multiple devices.
4. **Increased Efficiency:** Multipoint connections can improve network efficiency by allowing multiple devices to transmit data simultaneously. This reduces the chances of network congestion and improves overall network performance.
5. **Simplified Management:** Multipoint connections simplify network management by reducing the number of physical connections that need to be managed. This reduces the complexity of network administration and makes it easier to troubleshoot problems.
6. **Enhanced Collaboration:** Multipoint connections enable multiple users to collaborate in real-time, regardless of their location. This allows teams to work together more efficiently and effectively, improving productivity and reducing delays.

7. **Improved Reliability:** Multipoint connections can improve network reliability by providing redundant paths for data transmission. If one path fails, data can be automatically rerouted through another path, ensuring that network connectivity is maintained.
8. **Greater Access:** Multipoint connections can provide greater access to network resources, such as servers, printers, and storage devices. This allows users to share resources and collaborate more effectively, improving productivity and reducing costs.
9. **Improved Security:** Multipoint connections can improve network security by allowing for centralized monitoring and control of network traffic. This makes it easier to detect and prevent security threats, such as unauthorized access or data breaches.

Disadvantages of Multipoint Connection:

1. **Limited Bandwidth:** Multipoint connections usually offer limited bandwidth because the link is shared by multiple devices. As a result, the speed of the link may be affected by the number of devices using it.
2. **Security:** Multipoint connections are less secure than point-to-point connections because the link is shared by multiple devices. There is a risk of other devices eavesdropping on the communication or interfering with it in some way.
3. **Reliability:** Multipoint connections are less reliable than point-to-point connections because the link is shared by multiple devices. If there is a problem with the link, it can affect multiple devices, which can be difficult to troubleshoot and fix.
4. **Latency:** Multipoint connections may have higher latency than point-to-point connections due to the increased number of devices accessing the same link. This can lead to delays in data transmission and affect the overall performance of the network.
5. **Complexity:** Multipoint connections can be more complex to set up and configure than point-to-point connections. This is because multiple devices need to be connected and configured to work together on the same link, which can be challenging to manage.
6. **Network Congestion:** Multipoint connections can be prone to network congestion, especially during peak usage periods. When multiple devices are using the same link simultaneously, it can cause a bottleneck, resulting in slower network speeds and performance issues.
7. **Limited Control:** Multipoint connections may provide limited control over network traffic and bandwidth allocation. This can result in some devices consuming more bandwidth than others, leading to issues such as slow network speeds and poor performance.
8. **Interference:** Multipoint connections may be more susceptible to interference from external sources such as electromagnetic interference or radio-frequency interference. This can lead to degraded network performance and connectivity issues.
9. **Limited Distance:** Multipoint connections may be limited in terms of distance due to the shared nature of the link. As the distance increases, the signal strength may weaken, leading to connectivity issues and lower network performance.