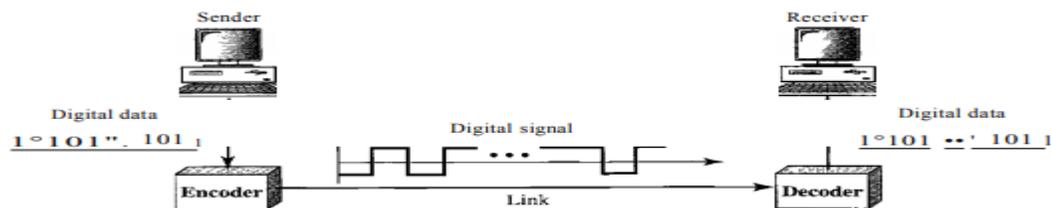


UNIT-II

Physical layer: Line encoding, block encoding, scrambling, modulation demodulation (both analog and digital), errors in transmission, multiplexing (FDM, TDM, WDM, OFDM, DSSS), Different types of transmission media. Data Link Layer services: framing, error control, flow control, medium access control. Error & Flow control mechanisms: stop and wait, Go back N and selective repeat. MAC protocols: Aloha, slotted aloha, CSMA, CSMA/CD, CSMA/CA, polling, token passing, scheduling.

Physical layer: Line Encoding:

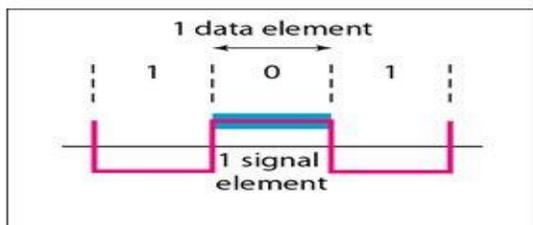
Line Coding Line coding is the process of converting digital data to digital signals. We assume that data, in the form of text, numbers, graphical images, audio, or video, are stored in computer memory as sequences of bits. Line coding converts a sequence of bits to a digital signal. At the sender, digital data are encoded into a digital signal; at the receiver, the digital data are recreated by decoding the digital signal.



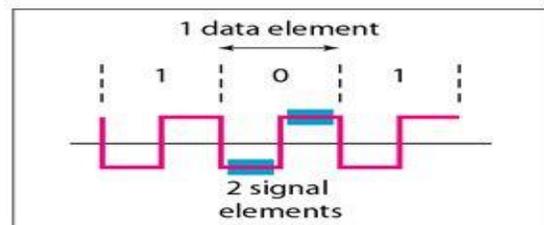
Characteristics

1. Signal Element versus Data Element:

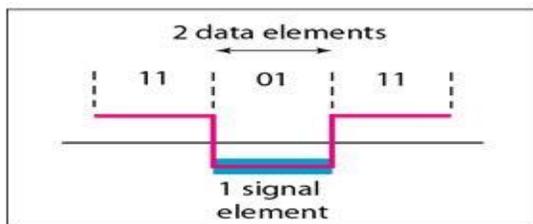
A data element is the smallest entity that can represent a piece of information. This is the bit. In digital data communications, a signal element carries data elements. A signal element is the shortest unit (time wise) of a digital signal. In other words, data elements are what we need to send; signal elements are what we can send. Data elements are being carried; signal elements are the carriers.



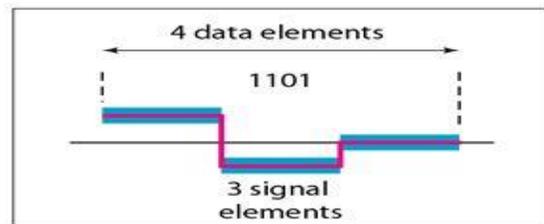
a. One data element per one signal element ($r = 1$)



b. One data element per two signal elements ($r = \frac{1}{2}$)



c. Two data elements per one signal element ($r = 2$)



d. Four data elements per three signal elements ($r = \frac{4}{3}$)

2. Data Rate versus Signal Rate:

The data rate defines the number of data elements (bits) sent in 1s. The unit is bits per second (bps). The signal rate is the number of signal elements sent in 1s. The unit is the baud. The data rate is sometimes called the bit rate; the signal rate is sometimes called the pulse rate, the modulation rate, or the baud rate.

3. Bandwidth:

Digital signal that carries information is non-periodic. The bandwidth of a non-periodic signal is continuous with an infinite range. However, most digital signals we encounter in real life have a bandwidth with finite values. In other words, the bandwidth is theoretically infinite, but many of the components have such a small amplitude that they can be ignored. The effective bandwidth is finite.

4. Baseline Wandering:

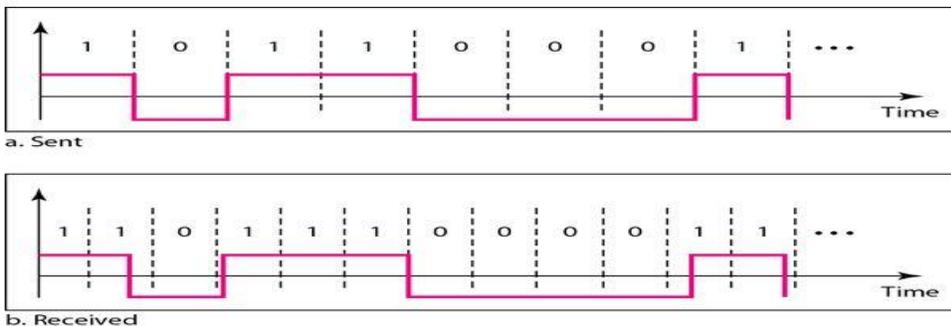
In decoding a digital signal, the receiver calculates a running average of the received signal power. This average is called the baseline. The incoming signal power is evaluated against this baseline to determine the value of the data element. A long string of 0s or 1s can cause a drift in the baseline (baseline wandering) and make it difficult for the receiver to decode correctly. A good line coding scheme needs to prevent baseline wandering.

5. DC Components:

When the voltage level in a digital signal is constant for a while, the spectrum creates very low frequencies (results of Fourier analysis). These frequencies around zero, called DC (direct-current) components, present problems for a system that cannot pass low frequencies or a system that uses electrical coupling (via a transformer).

6. Self-synchronization:

To correctly interpret the signals received from the sender, the receiver's bit intervals must correspond exactly to the sender's bit intervals. If the receiver clock is faster or slower, the bit intervals are not matched and the receiver might misinterpret the signals. The following figure represents the synchronization problem.



7. Built-in Error Detection:

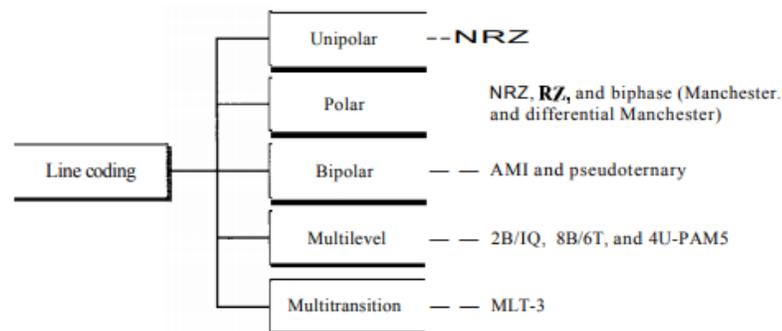
It is desirable to have a built-in error-detecting capability in the generated code to detect some of or all the errors that occurred during transmission.

8. Immunity to Noise and Interference: Another desirable code characteristic is a code that is immune to noise and other interferences.

9. Complexity:

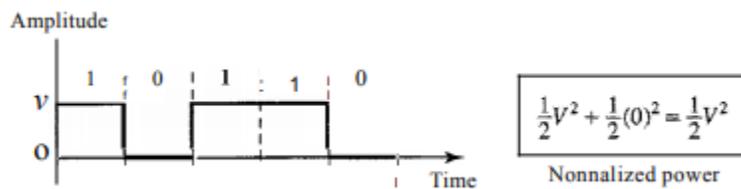
A complex scheme is more costly to implement than a simple one. For example, a scheme that uses four signal levels is more difficult to interpret than one that uses only two levels.

Line Coding Schemes



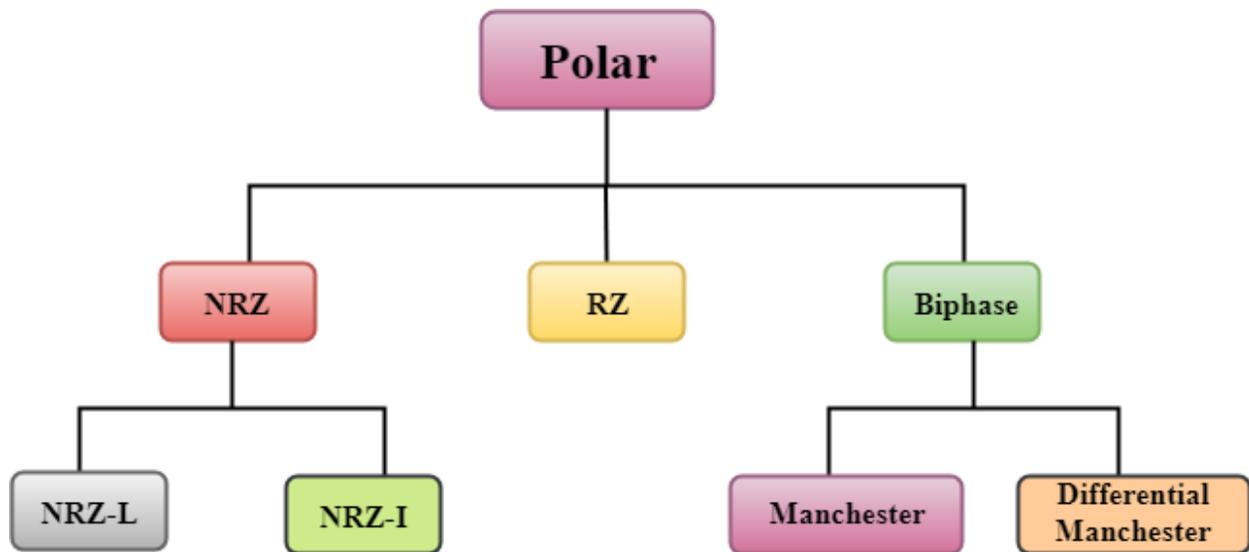
Unipolar Scheme

In a unipolar scheme, all the signal levels are on one side of the time axis, either above or below. NRZ (Non-Return-to-Zero) Traditionally, a unipolar scheme was designed as a non-return-to-zero (NRZ) scheme in which the positive voltage defines bit 1 and the zero voltage defines bit 0. It is called NRZ because the signal does not return to zero at the middle of the bit. Figure 4.5 show a unipolar NRZ scheme.



Polar

- Polar encoding is an encoding scheme that uses two voltage levels: one is positive, and another is negative.
- By using two voltage levels, an average voltage level is reduced, and the DC component problem of unipolar encoding scheme is alleviated.



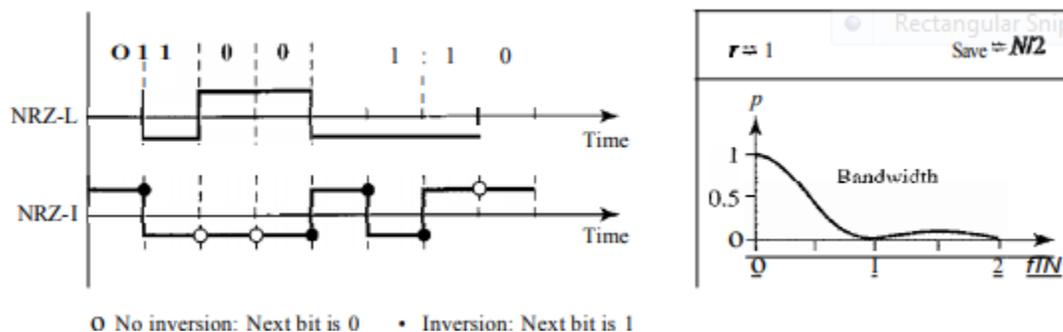
NRZ

- NRZ stands for Non-return zero.
- In NRZ encoding, the level of the signal can be represented either positive or negative.

The two most common methods used in NRZ are:

NRZ-L: In NRZ-L encoding, the level of the signal depends on the type of the bit that it represents. If a bit is 0 or 1, then their voltages will be positive and negative respectively. Therefore, we can say that the level of the signal is dependent on the state of the bit.

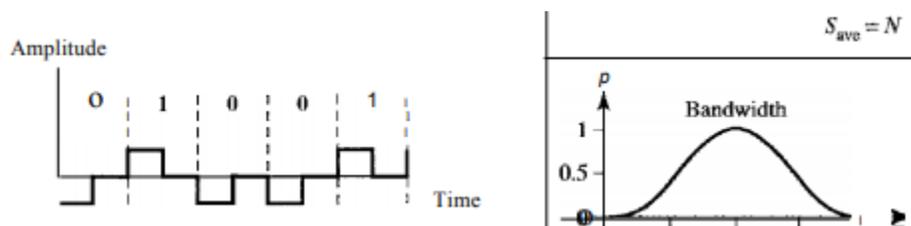
NRZ-I: NRZ-I is an inversion of the voltage level that represents 1 bit. In the NRZ-I encoding scheme, a transition occurs between the positive and negative voltage that represents 1 bit. In this scheme, 0 bit represents no change and 1 bit represents a change in voltage level.



RZ

- RZ stands for Return to zero.
- There must be a signal change for each bit to achieve synchronization. However, to change with every bit, we need to have three values: positive, negative and zero.
- RZ is an encoding scheme that provides three values, positive voltage represents 1, the negative voltage represents 0, and zero voltage represents none.
- In the RZ scheme, halfway through each interval, the signal returns to zero.

In RZ scheme, 1 bit is represented by positive-to-zero and 0 bit is represented by negative-to-zero



Disadvantage of RZ:

It performs two signal changes to encode one bit that acquires more bandwidth.

Biphase

- Biphase is an encoding scheme in which signal changes at the middle of the bit interval but does not return to zero.

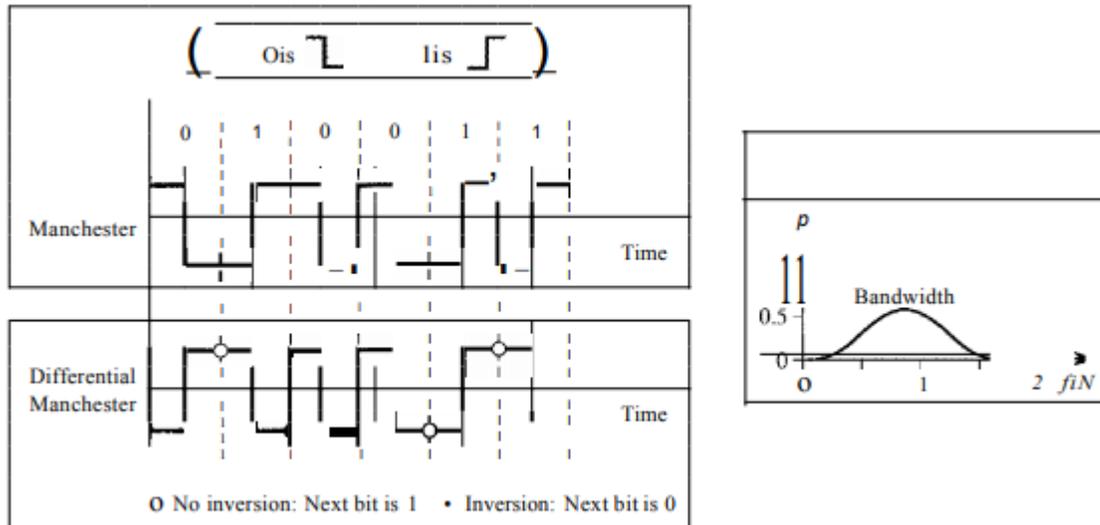
Biphase encoding is implemented in two different ways:

Manchester

- It changes the signal at the middle of the bit interval but does not return to zero for synchronization.
- In Manchester encoding, a negative-to-positive transition represents binary 1, and positive-to-negative transition represents 0.
- Manchester has the same level of synchronization as RZ scheme except that it has two levels of amplitude.

Differential Manchester

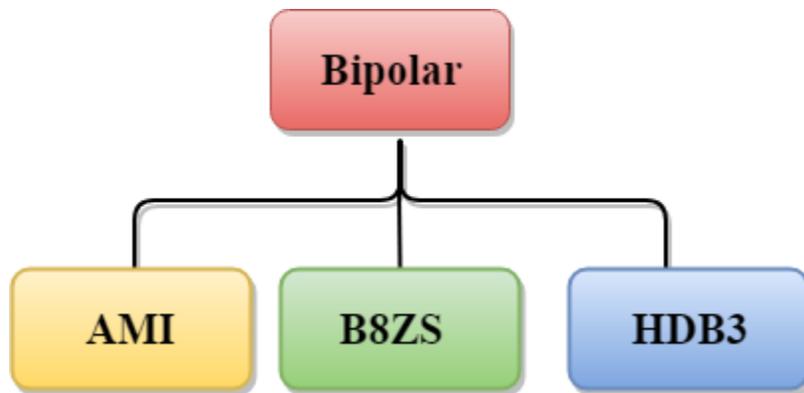
- It changes the signal at the middle of the bit interval for synchronization, but the presence or absence of the transition at the beginning of the interval determines the bit. A transition means binary 0 and no transition means binary 1.
- In Manchester Encoding scheme, two signal changes represent 0 and one signal change represent 1.



Bipolar

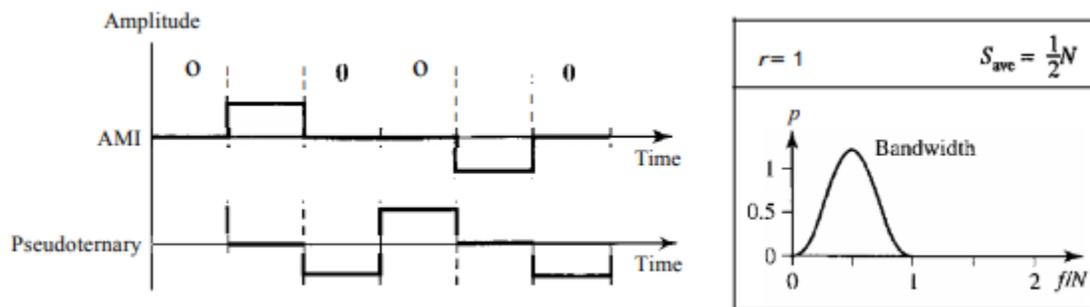
- Bipolar encoding scheme represents three voltage levels: positive, negative, and zero.
- In Bipolar encoding scheme, zero level represents binary 0, and binary 1 is represented by alternating positive and negative voltages.
- If the first 1 bit is represented by positive amplitude, then the second 1 bit is represented by negative voltage, third 1 bit is represented by the positive amplitude and so on. This alternation can also occur even when the 1bits are not consecutive.

Bipolar can be classified as:



AMI

- AMI stands for *alternate mark inversion* where mark work comes from telegraphy which means 1. So, it can be redefined as **alternate 1 inversion**.
- In Bipolar AMI encoding scheme, 0 bit is represented by zero level and 1 bit is represented by alternating positive and negative voltages.



Advantage:

- DC component is zero.
- Sequence of 1s bits are synchronized.

Disadvantage:

- This encoding scheme does not ensure the synchronization of a long string of 0s bits.

Scrambling

A computer network is designed to send information from one point to another.

Data that we send can either be digital or analog.

Also signals that represent data can also be digital or analog.

Thus to send data by using signals, we must be able to convert data into signals this conversion can be Analog to Analog, Analog to Digital, Digital to Analog or Digital to Digital.

Digital to Digital conversion involves three techniques – Line Coding, Block Coding, and Scrambling. Line Coding is always needed, whereas Block Coding and Scrambling may or may not be needed depending upon need.

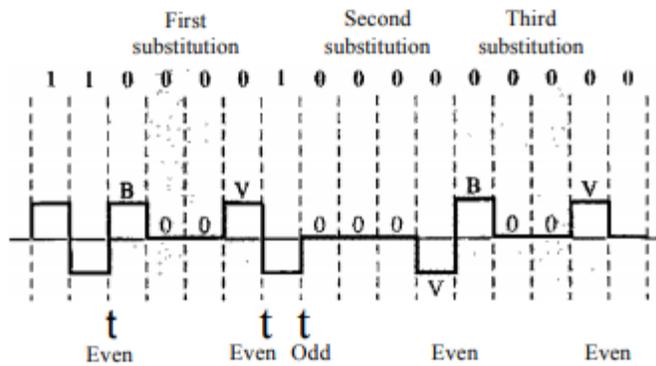
Scrambling is a technique that does not increase the number of bits and does provide synchronization. Problem with technique like Bipolar AMI(Alternate Mark Inversion) is that continuous sequence of zero's create synchronization problems one solution to this is Scrambling.

There are two common scrambling techniques:

1. B8ZS(Bipolar with 8-zero substitution)
2. HDB3(High-density bipolar3-zero)

B8ZS

- B8ZS stands for **Bipolar 8-Zero Substitution**.
- This technique is adopted in North America to provide synchronization of a long sequence of 0s bits.
- In most of the cases, the functionality of B8ZS is similar to the bipolar AMI, but the only difference is that it provides the synchronization when a long sequence of 0s bits occur.
- B8ZS ensures synchronization of a long string of 0s by providing force artificial signal changes called violations, within 0 string pattern.
- When eight 0 occurs, then B8ZS implements some changes in 0s string pattern based on the polarity of the previous 1 bit.
- If the polarity of the previous 1 bit is positive, the eight 0s will be encoded as zero, zero, zero, positive, negative, zero, negative, positive.
- If the polarity of previous 1 bit is negative, then the eight 0s will be encoded as zero, zero, zero, negative, positive, zero, positive, negative.

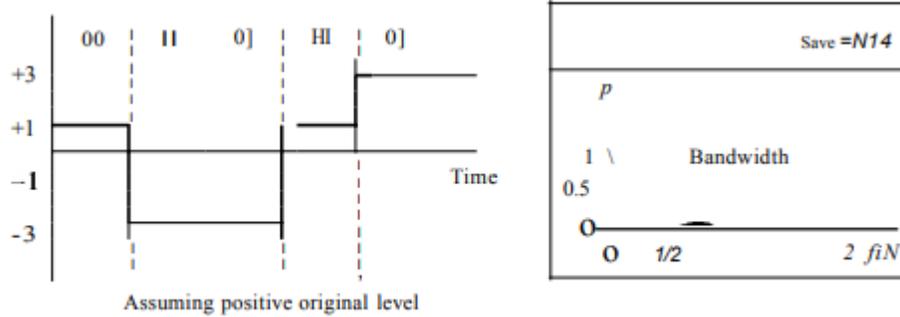


Multilevel Schemes The desire to increase the data speed or decrease the required bandwidth has resulted in the creation of many schemes. The goal is to increase the number of bits per baud by encoding a pattern of m data elements into a pattern of n signal elements. We only have two types of data elements (0s and 1s), which means that a group of m data elements can produce a combination of 2^m data patterns

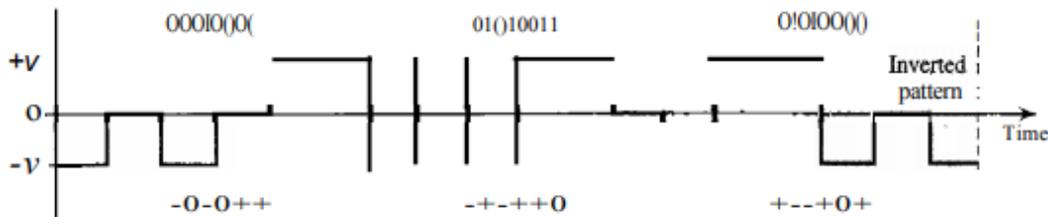
2B1Q The first mBnL scheme we discuss, two binary, one quaternary (2B1Q), uses data patterns of size 2 and encodes the 2-bit patterns as one signal element belonging to a four-level signal. In this type of encoding $m = 2$, $n = 1$, and $L = 4$ (quaternary). Figure 4.10 shows an example of a 2B1Q signal

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

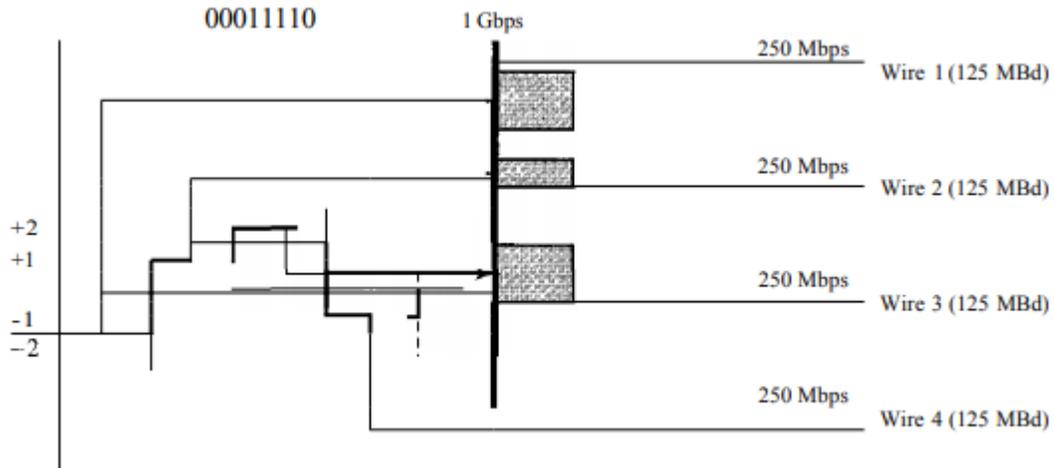
Transition table



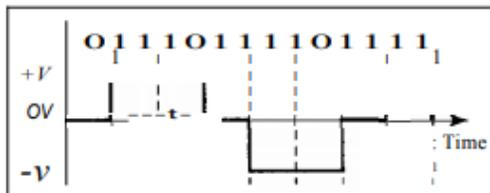
8B6T A very interesting scheme is eight binary, six ternary (8B6T). This code is used with 100BASE-4T cable, as we will see in Chapter 13. The idea is to encode a pattern of 8 bits as a pattern of 6 signal elements, where the signal has three levels (ternary). In this type of scheme, we can have $2^8 = 256$ different data patterns and $3^6 = 729$ different signal patterns



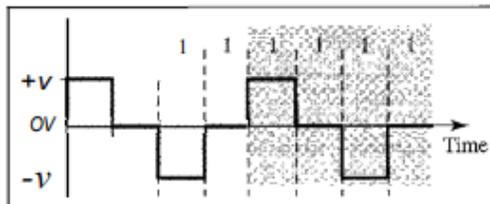
4D-PAM5 The last signaling scheme we discuss in this category is called fourdimensional five-level pulse amplitude modulation (4D-PAM5). The 4D means that data is sent over four wires at the same time. It uses five voltage levels, such as -2, -1, 0, 1, and 2. However, one level, level 0, is used only for forward error detection



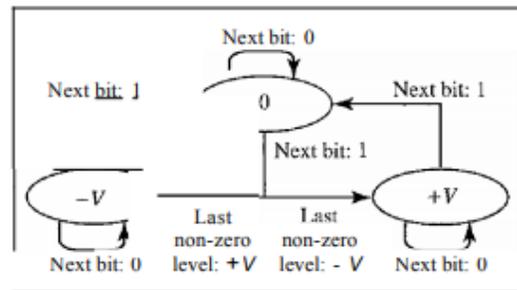
Multiline Transmission: MLT-3 NRZ-I and differential Manchester are classified as differential encoding but use two transition rules to encode binary data (no inversion, inversion). If we have a signal with more than two levels, we can design a differential encoding scheme with more than two transition rules. MLT-3 is one of them. The multiline transmission, three level (MLT-3) scheme uses three levels (+v, 0, and -V) and three transition rules to move between the levels. 1. If the next bit is 0, there is no transition. 2. If the next bit is 1 and the current level is not 0, the next level is 0. 3. If the next bit is 1 and the current level is 0, the next level is the opposite of the last nonzero level



a. Typical case



b. Worse case



c. Transition states

Summary of Line Coding Schemes

Category	Scheme	Bandwidth (average)	Characteristics
Unipolar	NRZ	$B=N/2$	Costly, no self-synchronization if long 0s or 1s, DC
Unipolar	NRZ-L	$B=N/2$	No self-synchronization if long 0s or 1s, DC
	NRZ-I	$B=N/2$	No self-synchronization for long aS, DC
	Biphase	$B=N$	Self-synchronization, no DC, high bandwidth

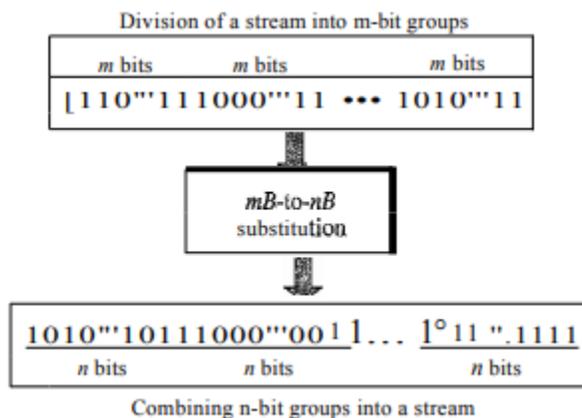
TABLE 4.1 Summary of line coding schemes (continued)

Category	Scheme	Bandwidth (average)	Characteristics
Bipolar	AMI	$B=N/2$	No self-synchronization for long 0s, DC
Multilevel	2B1Q	$B=N/4$	No self-synchronization for long same do
	8B6T	$B=3N/4$	Self-synchronization, no DC
	4D-PAM5	$B=N/8$	Self-synchronization, no DC
Multiline	MLT-3	$B=N/3$	No self-synchronization for long 0s

Block coding :

Block coding helps in error detection and re-transmission of the signal. It is normally referred to as mB/nB coding as it replaces each m -bit data group with an n -bit data group (where $n>m$). Thus, it adds extra bits (redundancy bits) which helps in synchronization at receiver's and sender's end and also providing some kind of error detecting capability.

It normally involves three steps: division, substitution, and combination. In the division step, a sequence of bits is divided into groups of m -bits. In the substitution step, we substitute an m -bit group for an n -bit group. Finally, the n -bit groups are combined together to form a stream which has more bits than the original bits.

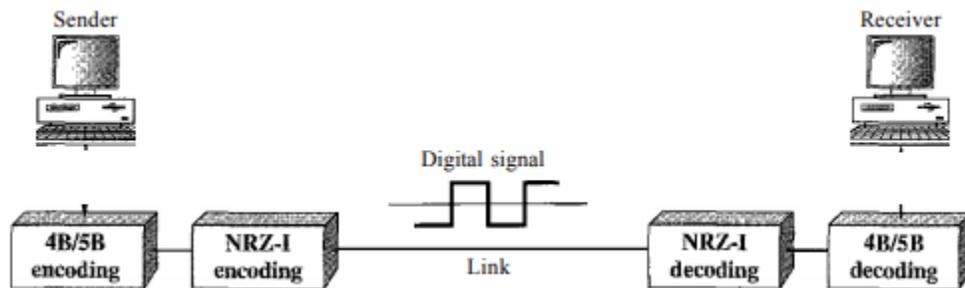


Examples of mB/nB coding:

4B/5B (four binary/five binary) –

This coding scheme is used in combination with NRZ-I. The problem with NRZ-I was that it has a synchronization problem for long sequences of zeros. So, to overcome it we substitute the bit stream from 4-bit to 5-bit data group **before encoding it with NRZ-I**. So that it does not have a long stream of zeros. The block-coded stream does not have more than three consecutive zeros

At the receiver, the NRZ-I encoded digital signal is first decoded into a stream of bits and then decoded again to remove the redundancy bits.

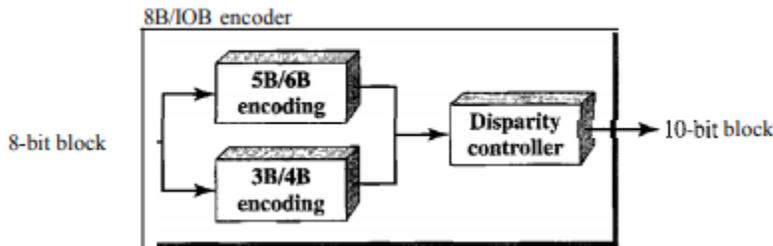


Drawback – Though 4B/5B encoding solves the problem of synchronization, it increases the signal rate of NRZ-L. Moreover, it does not solve the DC component problem of NRZ-L.

8B/10B (eight binary/ten binary) –

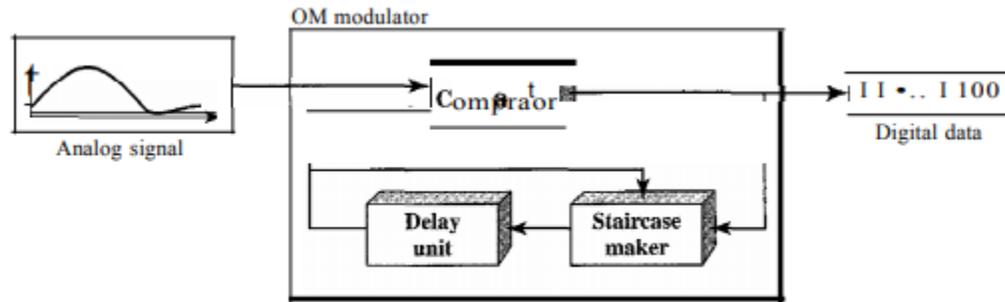
This encoding is similar to 4B/5B encoding except that a group of 8 bits of data is now substituted by a 10-bit code and it provides greater error detection capability than 4B/5B.

It is actually a combination of 5B/6B and 3B/4B encoding. The most five significant bits of a 10-bit block is fed into the 5B/6B encoder; the least 3 significant bits is fed into a 3B/4B encoder



Modulator

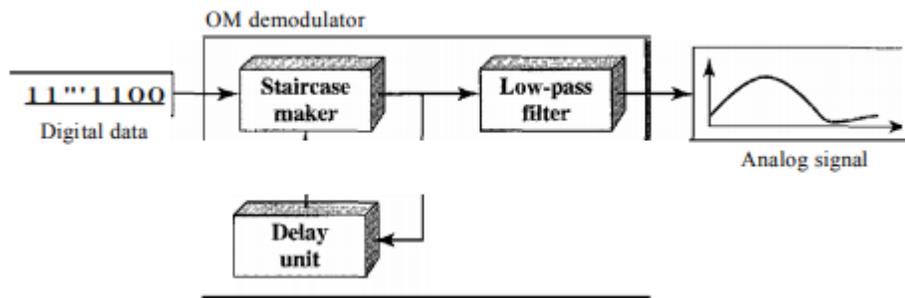
The modulator is used at the sender site to create a stream of bits from an analog signal. The process records the small positive or negative changes, called delta δ . If the delta is positive, the process records a 1; if it is negative, the process records a 0. However, the process needs a base against which the analog signal is compared. The modulator builds a second signal that resembles a staircase. Finding the change is then reduced to comparing the input signal with the gradually made staircase signal. Figure 4.29 shows a diagram of the process.



The modulator, at each sampling interval, compares the value of the analog signal with the last value of the staircase signal. If the amplitude of the analog signal is larger, the next bit in the digital data is 1; otherwise, it is 0. The output of the comparator, however, also makes the staircase itself. If the next bit is 1, the staircase maker moves the last point of the staircase signal δ up; if the next bit is 0, it moves it δ down. Note that we need a delay unit to hold the staircase function for a period between two comparisons.

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. Figure 4.30 shows the schematic diagram.

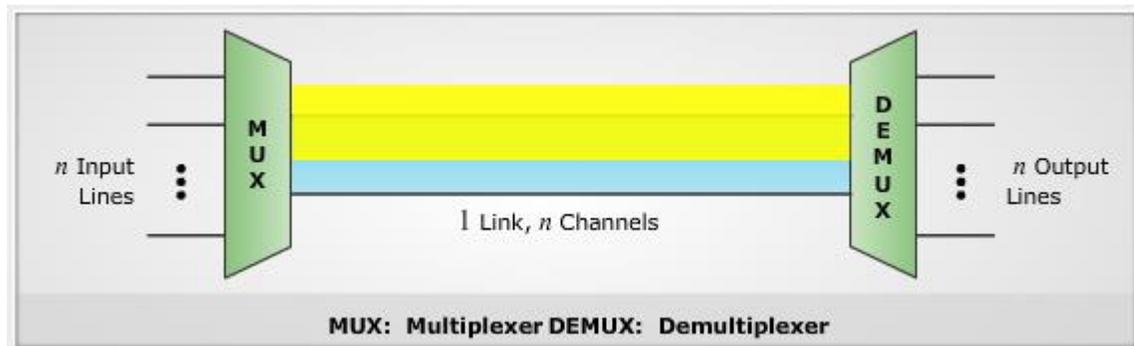


The

MULTIPLEXING:

- Multiplexing allows the simultaneous transmission of multiple signals across data link. A device that performs the multiplexing is called a multiplexer (MUX).
- Multiplexer combines n input lines to generate one output line.
- DE multiplexer (DEMUX) separates the stream back into its component transmissions and directs them to their corresponding lines.

- DE multiplexer has one input and n outputs.
- The word link refers to the physical path.
- The word channel refers to the portion of a link that carries a transmission between a given pair of lines. One link can have many (n) channels.



MULTIPLEXING TECHNIQUES:

1. Frequency-division multiplexing.
2. Time-division multiplexing.
3. Code Division multiplexing

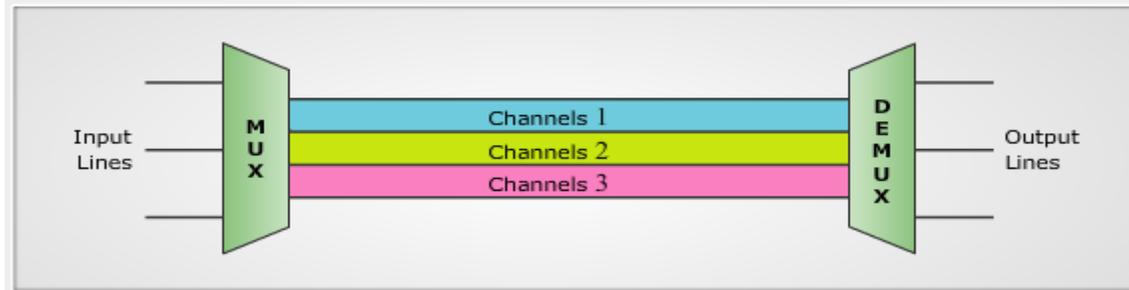
The first two are techniques designed for analog signals and the third for digital signals.

2.1 MULTIPLEXING

Multiplexing is the set of techniques that allows the simultaneous transmission of multiple signals across a single data link.

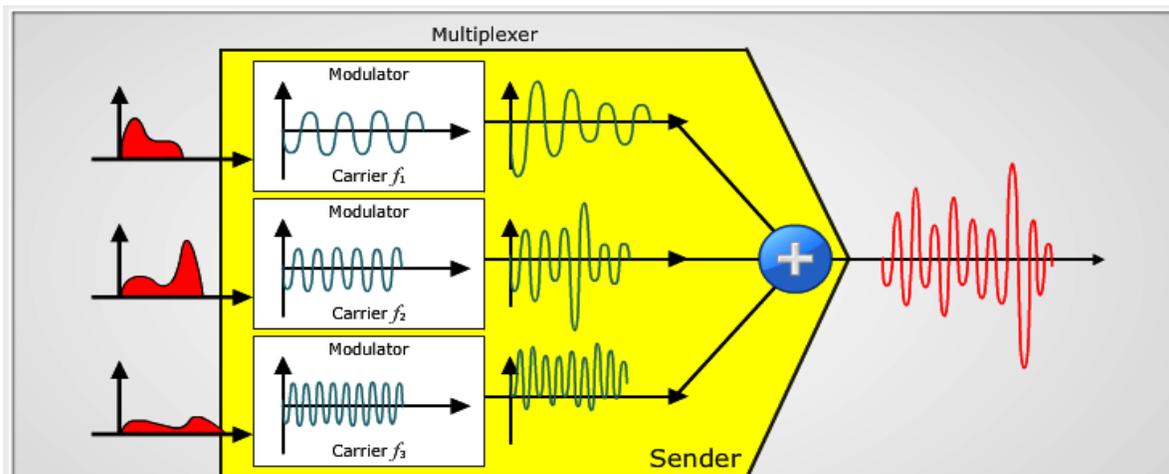
2.4.1 FREQUENCY-DIVISION MULTIPLEXING:

- Frequency-Division Multiplexing can be applied when the bandwidth of a link is greater than the combined bandwidths of the signals to be transmitted.
- FDM is an analog multiplexing technique that combines analog signals.
- In FDM, signals generated by each sending device modulate different carrier frequencies. These modulated signals are then combined into a single composite signal that can be transported by the link.



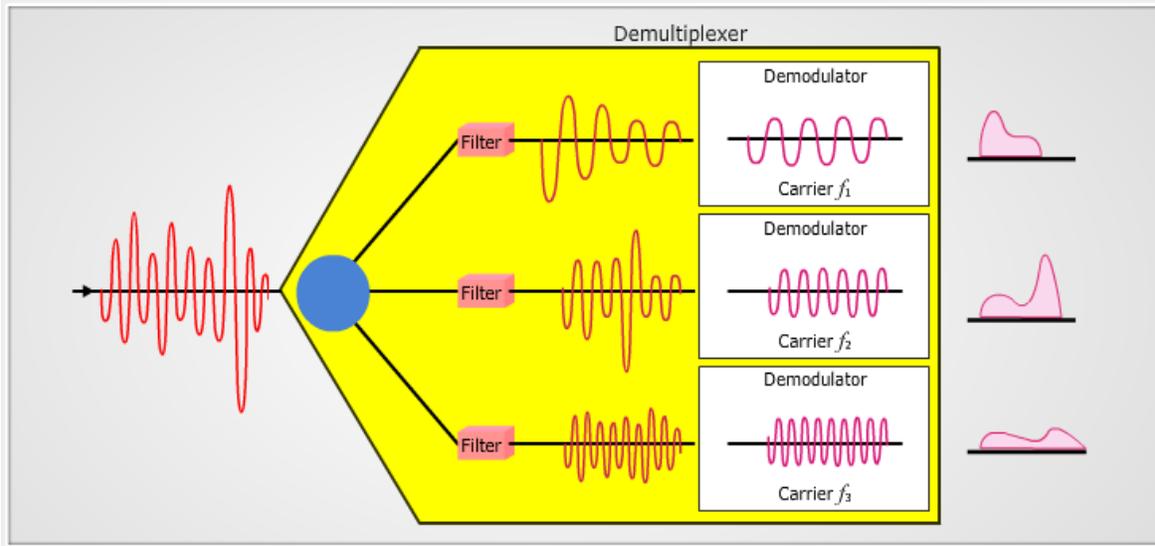
Multiplexing process:

- Source generates a signal of a similar frequency range.
- Signals modulate different carrier frequencies (f_1 , f_2 and f_3) inside the multiplexer.
- The resulting modulated signals are then combined into a single composite signal that is sent out over a media link that has enough bandwidth to accommodate it.



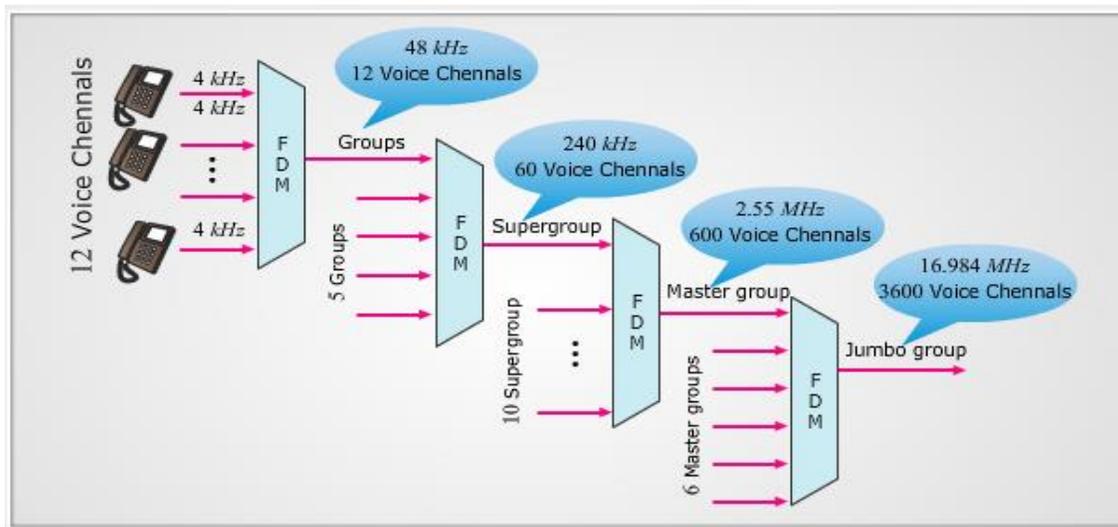
DE multiplexing process:

- The demultiplexer uses a series of filters to decompose the multiplexed signal into its constituent component signals.
- The individual signals are then passed to a demodulator that separates them from their carriers and passes them to the output lines.



Analog Carrier System:

- Switched or leased lines can be combined into bigger channels maximize the efficiency.
- One of these hierarchical systems used by AT & T is made up of groups, super groups, master groups and jumbo groups.
- In this analog hierarchy, 12 voice channels are multiplexed onto a higher-bandwidth line to create a group.



Advantages of FDM:

- A large of signals (channels) can be transmitted simultaneously
- FDM does not need synchronization between its transmitter and receiver for proper operation
- Demodulation of FDM is easy

- Due to slow narrow band fading only a single channel gets affected.

Disadvantages of FDM:

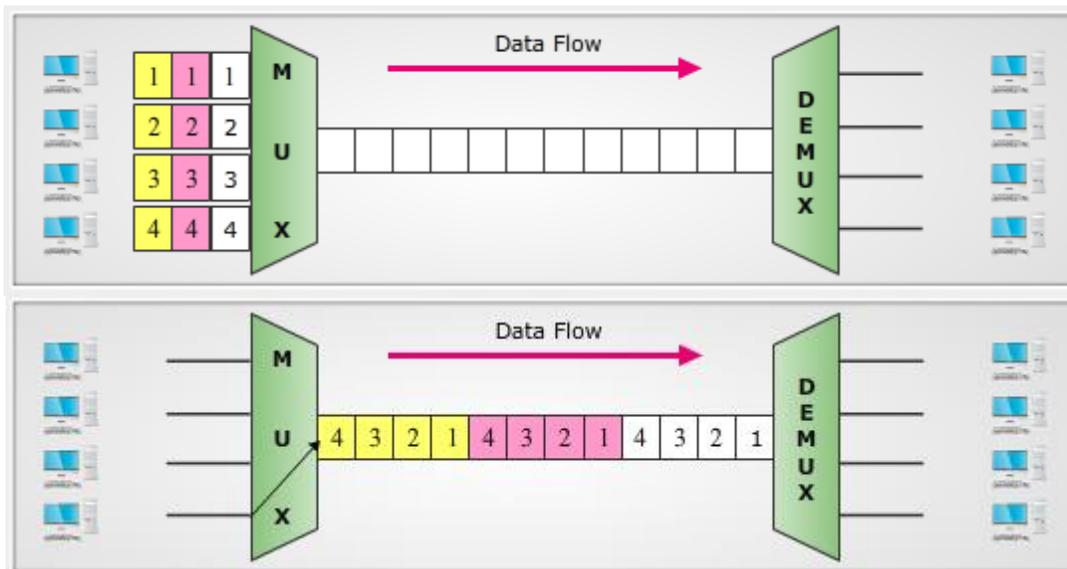
- The communication channel must have a very large bandwidth
- Intermodulation distortion takes place
- Large number of modulators and filters are required.
- FDM suffers from the problem of crosstalk.

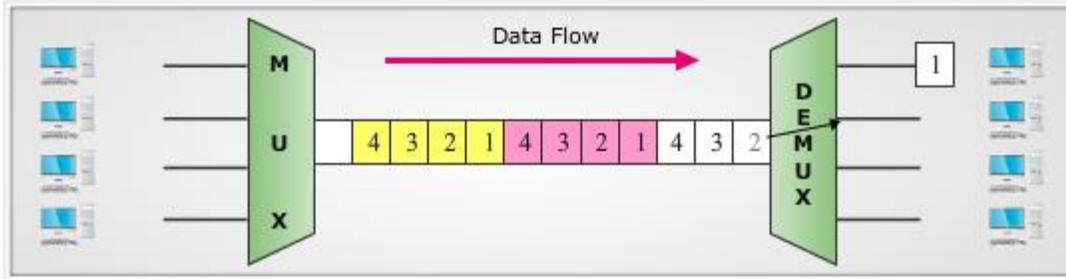
Application of FDM:

- FDM is used for FM & AM radio broadcasting
- FDM is used in television broadcasting
- First generation cellular telephone also uses FDM

2.4.2 TIME DIVISION MULTIPLEXING:

- Time-Division Multiplexing (TDM) is a digital process that allows several connections to share the high bandwidth of a link. Each connection occupies a portion of time in the link.
- TDM is a digital multiplexing technique for combining several low-rate channels into one high-rate one.





Types of TDM:

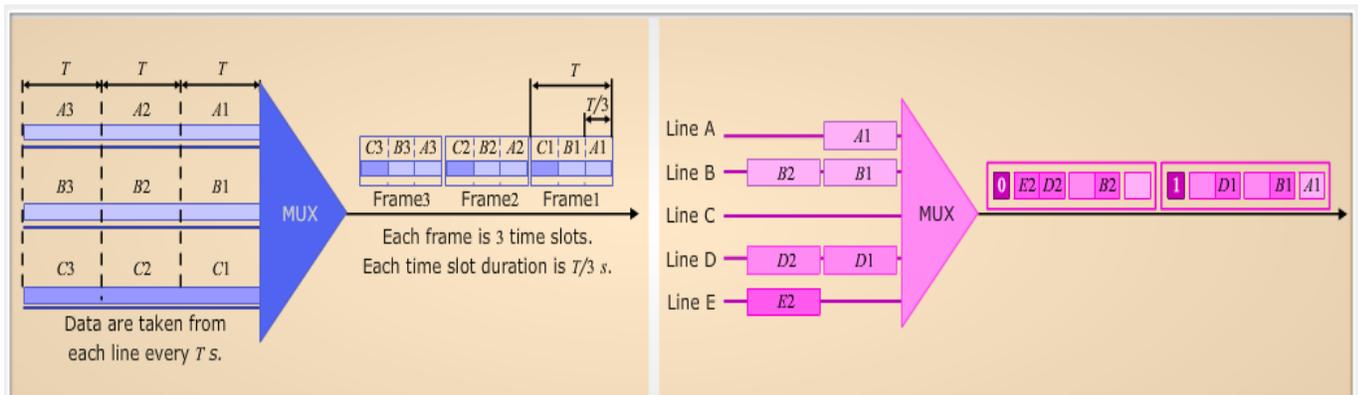
- I. Synchronous TDM
- II. Statistical TDM

2.4.2.1 Synchronous TDM:

- In synchronous TDM, each input connection has an allotment in the output even if it is not sending data.

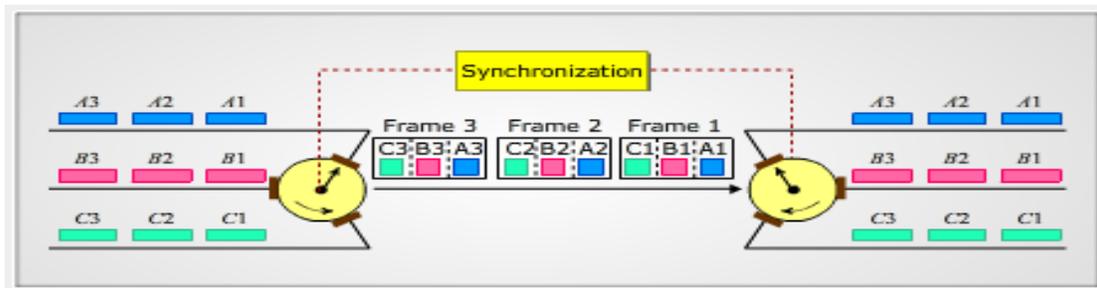
Time Slots and Frames:

- The data flow of each input connection is divided into units, where each input occupies one input time slot.
- Each input unit becomes one output unit and occupies one output time slot.
- A round of data units from each input connection is collected into a frame.
- Data rate of the link is n times faster and the unit duration is n times shorter.
- Time slots are grouped into frames. A frame consists of one complete cycle of time slots, with one slot dedicated to each sending device.



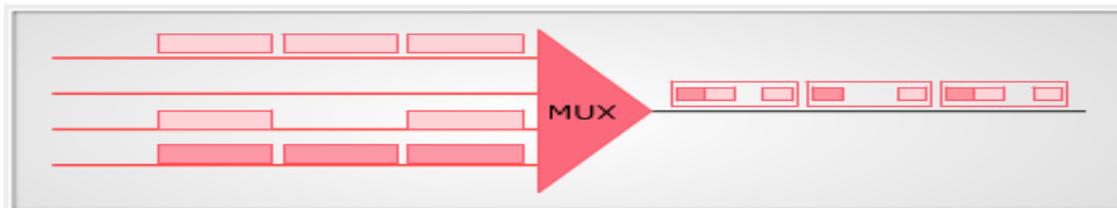
Interleaving:

- On the multiplexing side, as the switch opens in front of a connection, that connection has the opportunity to send a unit onto the path. This process is called interleaving.
- On the demultiplexing side, as the switch opens in front of a connection, that connection has the opportunity to receive a unit from the path.



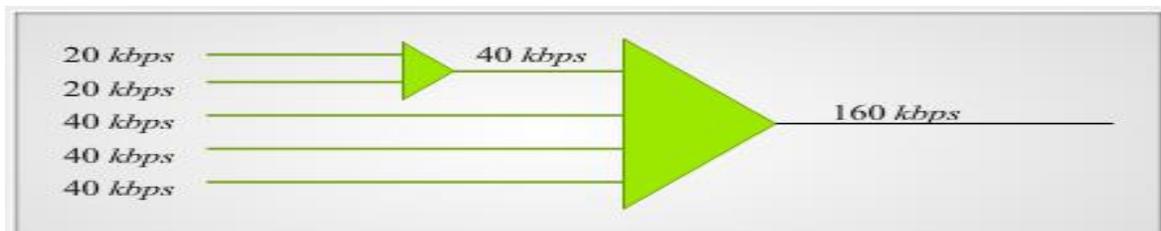
Empty slots:

- Synchronous TDM is not as efficient as it could be. If a source does not have data to send, the corresponding slot in the output frame is empty.
- The first output frame has three slots filled, the second frame has two slots filled and the third frame has three slots filled. No frame is full.

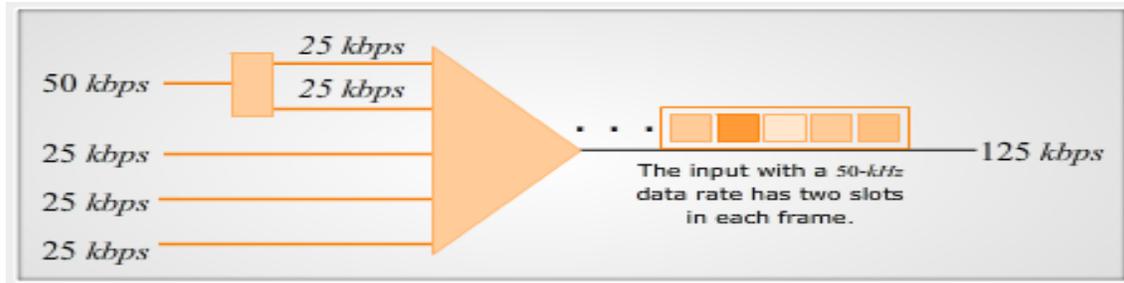


Data Rate Management: The data rates of all input lines are the same otherwise three strategies can be used. They are multilevel multiplexing, multiple-slot allocation, and pulse stuffing.

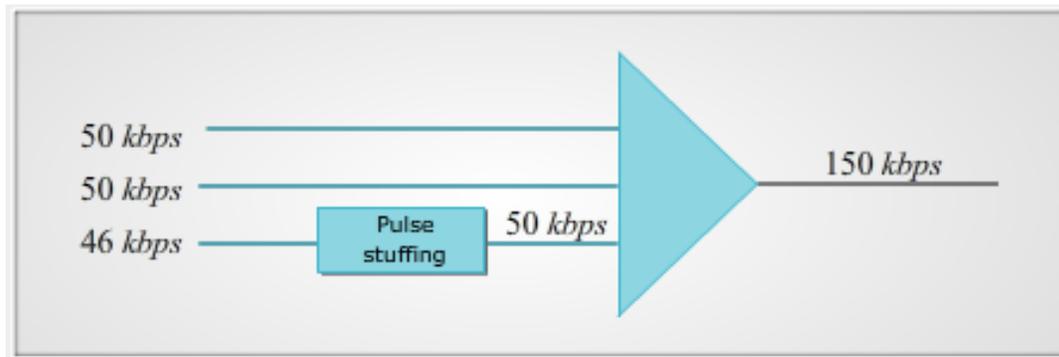
Multilevel Multiplexing: Multilevel multiplexing is a technique used when the data rate of an input line is a multiple of others.



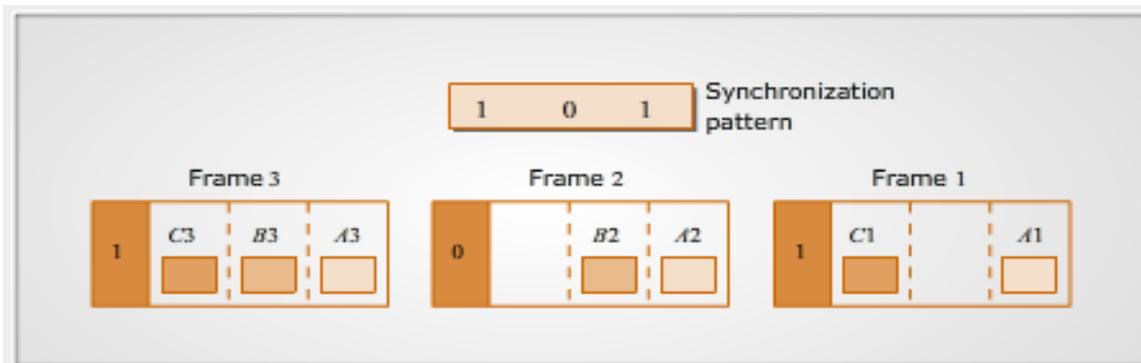
Multiple-Slot Allocation: Allocating more than one slot in a frame to a single input line.



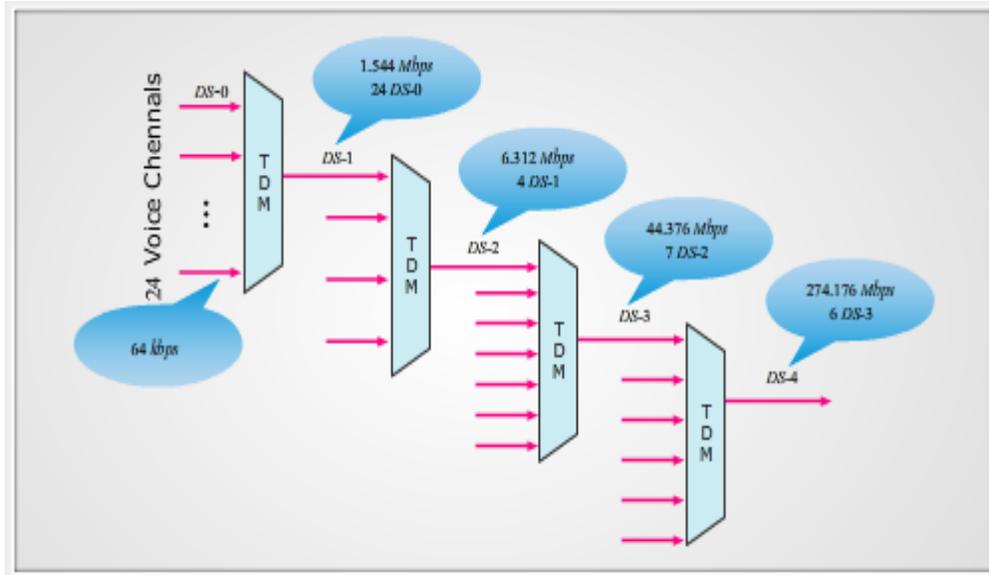
Pulse Stuffing: Adding dummy bits to the input lines with lower rates to make the highest input data rate is called **pulse stuffing**.



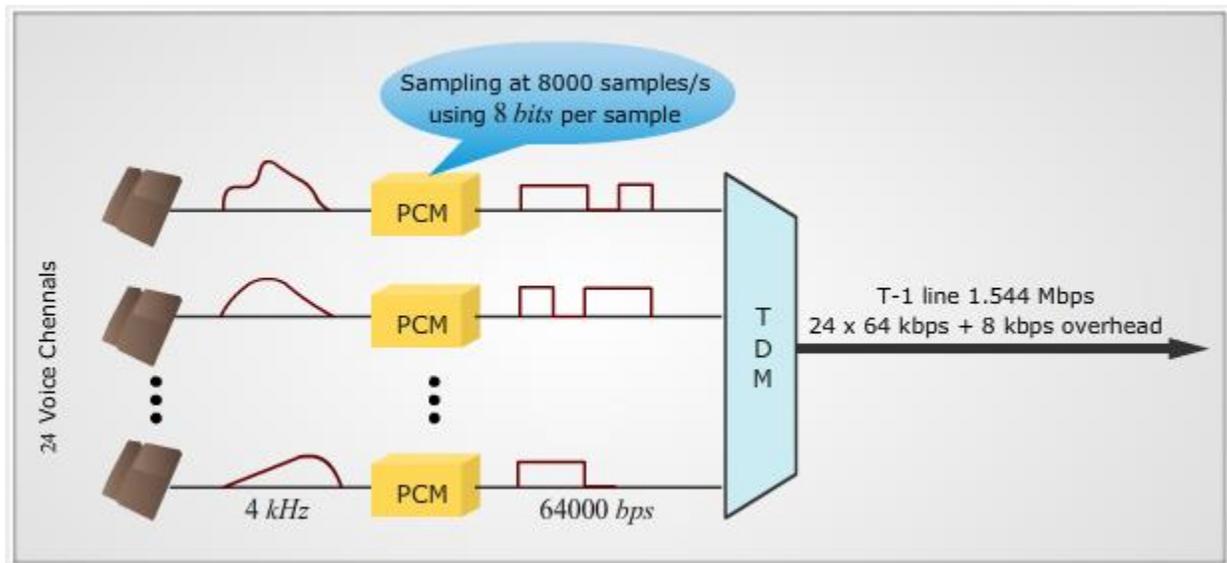
Frame Synchronizing: If the multiplexer and the demultiplexer are not synchronized, a bit belonging to one channel may be received by the wrong channel. For this reason, one or more synchronization bits are usually added to the beginning of each frame. These bits, called **framing bits**.



Digital Signal service: implementation of TDM through a hierarchy of digital signals is called digital signal service or digital hierarchy.



T Lines for Analog Transmission: T lines are digital lines designed for the transmission of digital data, audio, or video.

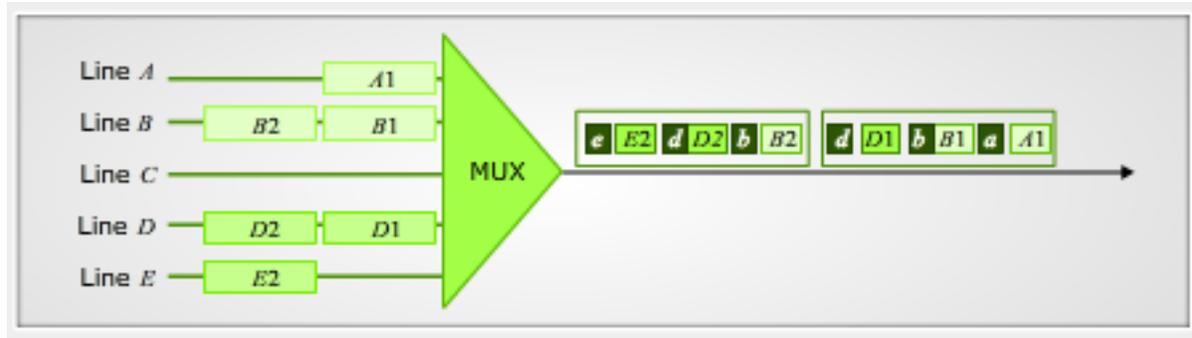


Application:

- Cellular telephone companies use synchronous TDM.
- Cellular telephony divides the available bandwidth into 30-kHz bands.

2.4.2.2 Statistical TDM

Allocation of slots to improve bandwidth efficiency is called Statistical TDM. Number of slots in each frame is less than the number of input lines in statistical TDM.



Addressing: In statistical multiplexing, there is no fixed relationship between the inputs and outputs because there are no reassigned or reserved slots. We need to include the address of the receiver inside each slot to show where it is to be delivered.

Slot Size: A slot carried both data and an address in statistical TDM, the ratio of the data size to address size must be reasonable to make transmission efficient.

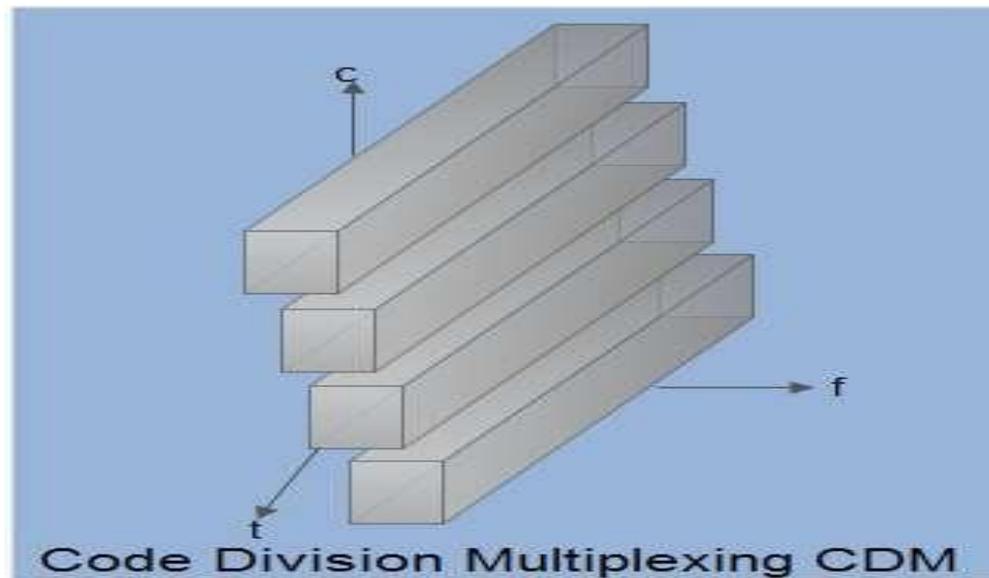
No Synchronization Bit: The frames in statistical TDM need not be synchronized, so we do not need synchronization bits.

Bandwidth: In statistical TDM, the capacity of the link is normally less than the sum of the capacities of each channel. The designers of statistical TDM define the capacity of the link based on the statistical of the load for each channel.

2.4.3 Code Division Multiplexing

Multiple data signals can be transmitted over a single frequency by using Code Division Multiplexing. FDM divides the frequency in smaller channels but CDM allows its users to full bandwidth and transmit signals all the time using a unique code. CDM uses orthogonal codes to spread signals.

Each station is assigned with a unique code, called chip. Signals travel with these codes independently, inside the whole bandwidth. The receiver knows in advance the chip code signal it has to receive.



Disadvantages:

1. Each user's transmitted bandwidth is enlarged than the digital data rate of the source. The result is an occupied bandwidth approximately equal to the coded rate. Therefore, CDM and spread spectrum are used interchangeably.
2. The transmitter and receiver require a complex electronic circuitry.

Advantages:

1. CDM is protection from interference and tapping because only the sender the receiver knows the spreading code.

Poll/Select

The Poll/Select method of line discipline works with those topologies where one device is designated as a primary station, and other devices are secondary stations.

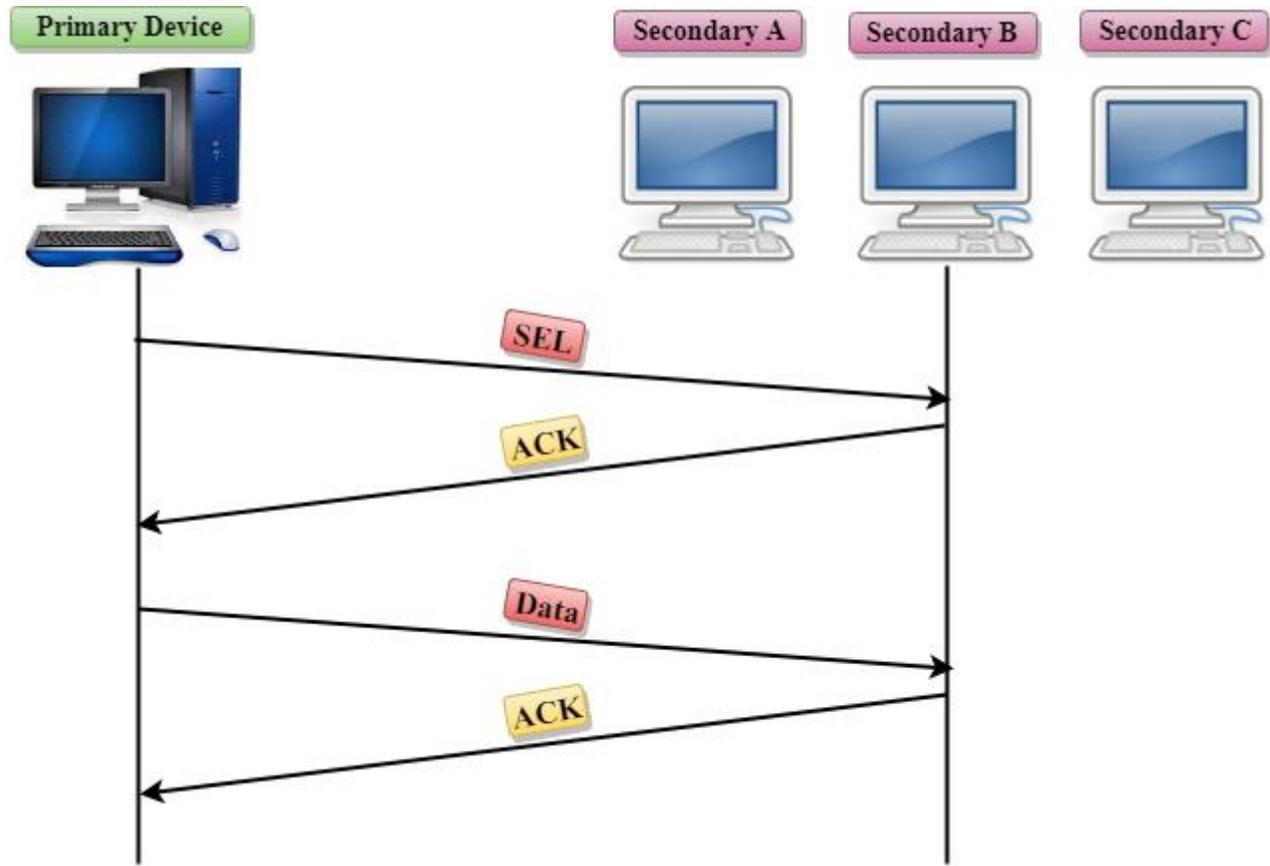
Working of Poll/Select

- In this, the primary device and multiple secondary devices consist of a single transmission line, and all the exchanges are made through the primary device even though the destination is a secondary device.
- The primary device has control over the communication link, and the secondary device follows the instructions of the primary device.

- The primary device determines which device is allowed to use the communication channel. Therefore, we can say that it is an initiator of the session.
- If the primary device wants to receive the data from the secondary device, it asks the secondary device that they anything to send, this process is known as polling.
- If the primary device wants to send some data to the secondary device, then it tells the target secondary to get ready to receive the data, this process is known as selecting.

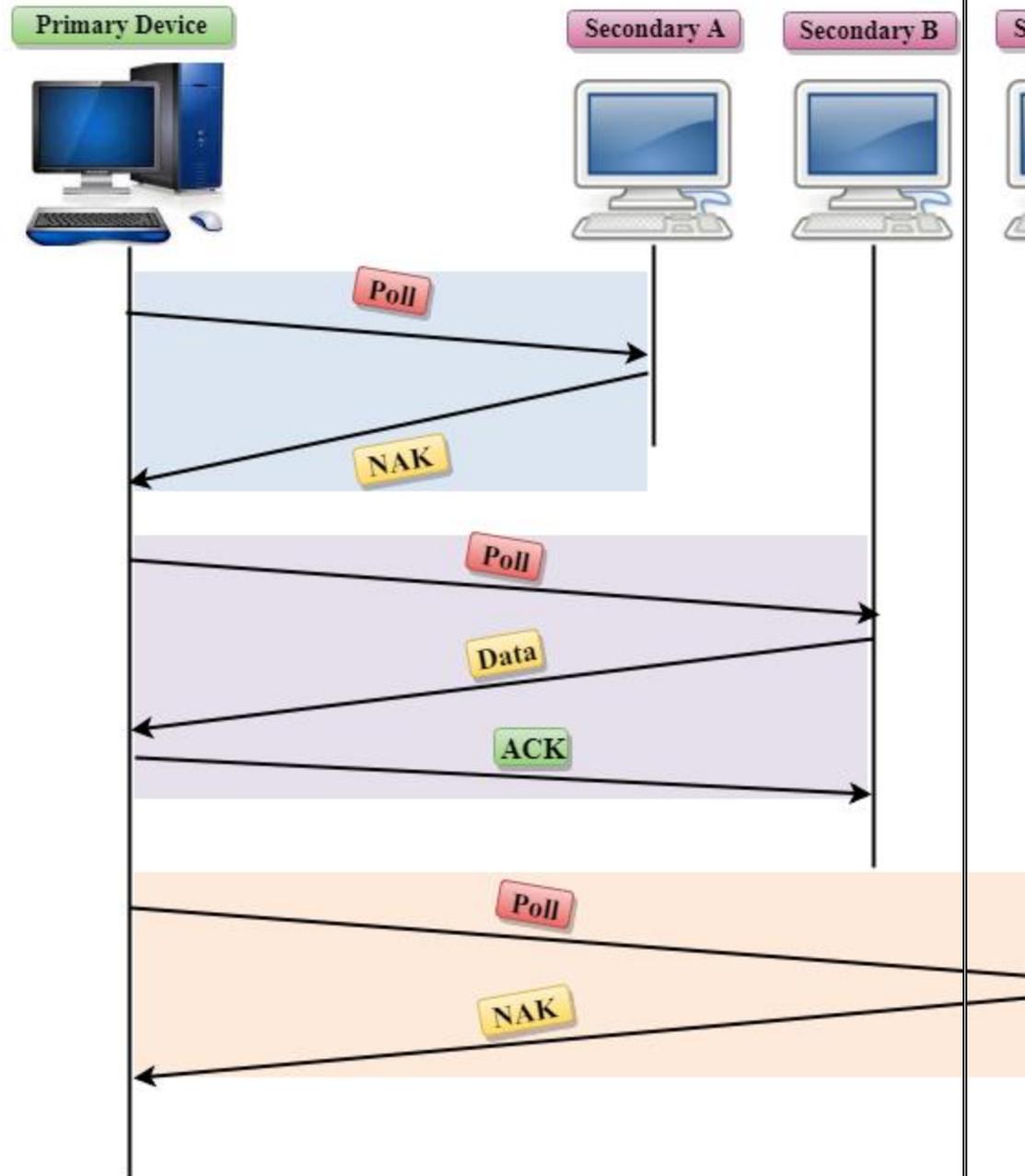
Select

- The select mode is used when the primary device has something to send.
- When the primary device wants to send some data, then it alerts the secondary device for the upcoming transmission by transmitting a Select (SEL) frame, one field of the frame includes the address of the intended secondary device.
- When the secondary device receives the SEL frame, it sends an acknowledgement that indicates the secondary ready status.
- If the secondary device is ready to accept the data, then the primary device sends two or more data frames to the intended secondary device. Once the data has been transmitted, the secondary sends an acknowledgement specifies that the data has been received.



Poll

- The Poll mode is used when the primary device wants to receive some data from the secondary device.
- When a primary device wants to receive the data, then it asks each device whether it has anything to send.
- Firstly, the primary asks (poll) the first secondary device, if it responds with the NACK (Negative Acknowledgement) means that it has nothing to send. Now, it approaches the second secondary device, it responds with the ACK means that it has the data to send. The secondary device can send more than one frame one after another or sometimes it may be required to send ACK before sending each one, depending on the type of the protocol being used.



Flow Control

- It is a set of procedures that tells the sender how much data it can transmit before the data overwhelms the receiver.

- The receiving device has limited speed and limited memory to store the data. Therefore, the receiving device must be able to inform the sending device to stop the transmission temporarily before the limits are reached.
- It requires a buffer, a block of memory for storing the information until they are processed.

Two methods have been developed to control the flow of data:

- Stop-and-wait
- Sliding window

Stop-and-wait

- In the Stop-and-wait method, the sender waits for an acknowledgement after every frame it sends.
- When acknowledgement is received, then only next frame is sent. The process of alternately sending and waiting of a frame continues until the sender transmits the EOT (End of transmission) frame.

Advantage of Stop-and-wait

The Stop-and-wait method is simple as each frame is checked and acknowledged before the next frame is sent.

Disadvantage of Stop-and-wait

Stop-and-wait technique is inefficient to use as each frame must travel across all the way to the receiver, and an acknowledgement travels all the way before the next frame is sent. Each frame sent and received uses the entire time needed to traverse the link.

Sliding Window

- The Sliding Window is a method of flow control in which a sender can transmit the several frames before getting an acknowledgement.
- In Sliding Window Control, multiple frames can be sent one after the another due to which capacity of the communication channel can be utilized efficiently.
- A single ACK acknowledge multiple frames.

- Sliding Window refers to imaginary boxes at both the sender and receiver end.
- The window can hold the frames at either end, and it provides the upper limit on the number of frames that can be transmitted before the acknowledgement.
- Frames can be acknowledged even when the window is not completely filled.
- The window has a specific size in which they are numbered as modulo-n means that they are numbered from 0 to n-1. For example, if $n = 8$, the frames are numbered from 0,1,2,3,4,5,6,7,0,1,2,3,4,5,6,7,0,1.....
- The size of the window is represented as n-1. Therefore, maximum n-1 frames can be sent before acknowledgement.
- When the receiver sends the ACK, it includes the number of the next frame that it wants to receive. For example, to acknowledge the string of frames ending with frame number 4, the receiver will send the ACK containing the number 5. When the sender sees the ACK with the number 5, it got to know that the frames from 0 through 4 have been received.

Sender Window

- At the beginning of a transmission, the sender window contains n-1 frames, and when they are sent out, the left boundary moves inward shrinking the size of the window. For example, if the size of the window is w if three frames are sent out, then the number of frames left out in the sender window is w-3.
- Once the ACK has arrived, then the sender window expands to the number which will be equal to the number of frames acknowledged by ACK.
- For example, the size of the window is 7, and if frames 0 through 4 have been sent out and no acknowledgement has arrived, then the sender window contains only two frames, i.e., 5 and 6. Now, if ACK has arrived with a number 4 which means that 0 through 3 frames have arrived undamaged and the sender window is expanded to include the next four frames. Therefore, the sender window contains six frames (5,6,7,0,1,2).

Sender window



**This wall moves to the right
When a frame is sent.**

**This wall moves to
When an ACK is received.**

Receiver Window

- At the beginning of transmission, the receiver window does not contain n frames, but it contains $n-1$ spaces for frames.
- When the new frame arrives, the size of the window shrinks.

- The receiver window does not represent the number of frames received, but it represents the number of frames that can be received before an ACK is sent. For example, the size of the window is w , if three frames are received then the number of spaces available in the window is $(w-3)$.
- Once the acknowledgement is sent, the receiver window expands by the number equal to the number of frames acknowledged.
- Suppose the size of the window is 7 means that the receiver window contains seven spaces for seven frames. If the one frame is received, then the receiver window shrinks and moving the boundary from 0 to 1. In this way, window shrinks one by one, so window now contains the six spaces. If frames from 0 through 4 have sent, then the window contains two spaces before an acknowledgement is sent.

Receiver window



**This wall moves to the right
When a frame is received.**

**This wall moves to
When an ACK is**

Error Control

Error Control is a technique of error detection and retransmission.

Categories of Error Control:



Stop-and-wait ARQ

Stop-and-wait ARQ is a technique used to retransmit the data in case of damaged or lost frames.

This technique works on the principle that the sender will not transmit the next frame until it receives the acknowledgement of the last transmitted frame.

Four features are required for the retransmission:

- The sending device keeps a copy of the last transmitted frame until the acknowledgement is received. Keeping the copy allows the sender to retransmit the data if the frame is not received correctly.
- Both the data frames and the ACK frames are numbered alternately 0 and 1 so that they can be identified individually. Suppose data 1 frame acknowledges the data 0 frame means that the data 0 frame has been arrived correctly and expects to receive data 1 frame.
- If an error occurs in the last transmitted frame, then the receiver sends the NAK frame which is not numbered. On receiving the NAK frame, sender retransmits the data.
- It works with the timer. If the acknowledgement is not received within the allotted time, then the sender assumes that the frame is lost during the transmission, so it will retransmit the frame.

Two possibilities of the retransmission:

- **Damaged Frame:** When the receiver receives a damaged frame, i.e., the frame contains an error, then it returns the NAK frame. For example, when the data 0 frame is sent, and then the receiver sends the ACK 1 frame means that the data 0 has arrived correctly, and transmits the data 1 frame. The sender transmits the next frame: data 1. It reaches undamaged, and the receiver returns ACK 0. The sender transmits the next frame: data 0. The receiver reports an error and returns the NAK frame. The sender retransmits the data 0 frame.
- **Lost Frame:** Sender is equipped with the timer and starts when the frame is transmitted. Sometimes the frame has not arrived at the receiving end so that it can be acknowledged neither positively nor negatively. The sender waits for acknowledgement until the timer goes off. If the timer goes off, it retransmits the last transmitted frame.

Sliding Window ARQ

SlidingWindow ARQ is a technique used for continuous transmission error control.

Three Features used for retransmission:

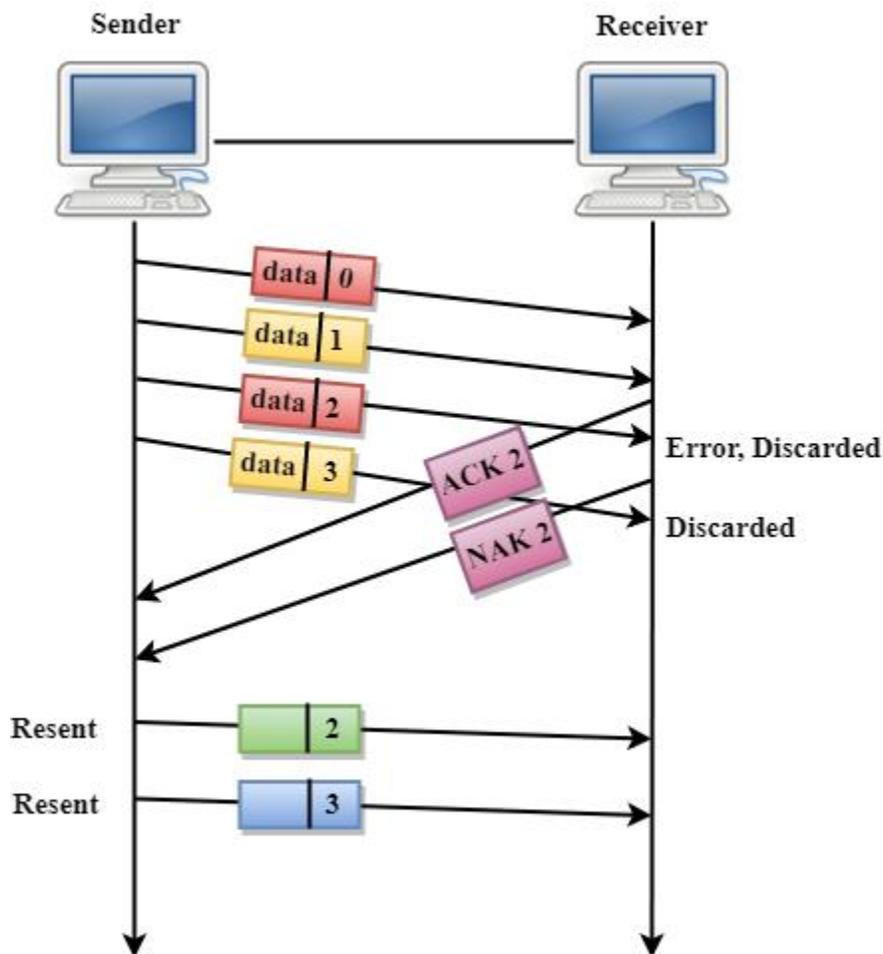
- In this case, the sender keeps the copies of all the transmitted frames until they have been acknowledged. Suppose the frames from 0 through 4 have been transmitted, and the last acknowledgement was for frame 2, the sender has to keep the copies of frames 3 and 4 until they receive correctly.
- The receiver can send either NAK or ACK depending on the conditions. The NAK frame tells the sender that the data have been received damaged. Since the sliding window is a continuous transmission mechanism, both ACK and NAK must be numbered for the identification of a frame. The ACK frame consists of a number that represents the next frame which the receiver expects to receive. The NAK frame consists of a number that represents the damaged frame.
- The sliding window ARQ is equipped with the timer to handle the lost acknowledgements. Suppose then $n-1$ frames have been sent before receiving any acknowledgement. The sender waits for the acknowledgement, so it starts the timer and waits before sending any more. If the allotted time runs out, the sender retransmits one or all the frames depending upon the protocol used.

Two protocols used in sliding window ARQ:

- **Go-Back-n ARQ:** In Go-Back-N ARQ protocol, if one frame is lost or damaged, then it retransmits all the frames after which it does not receive the positive ACK.

Three possibilities can occur for retransmission:

- **Damaged Frame:** When the frame is damaged, then the receiver sends a NAK frame.



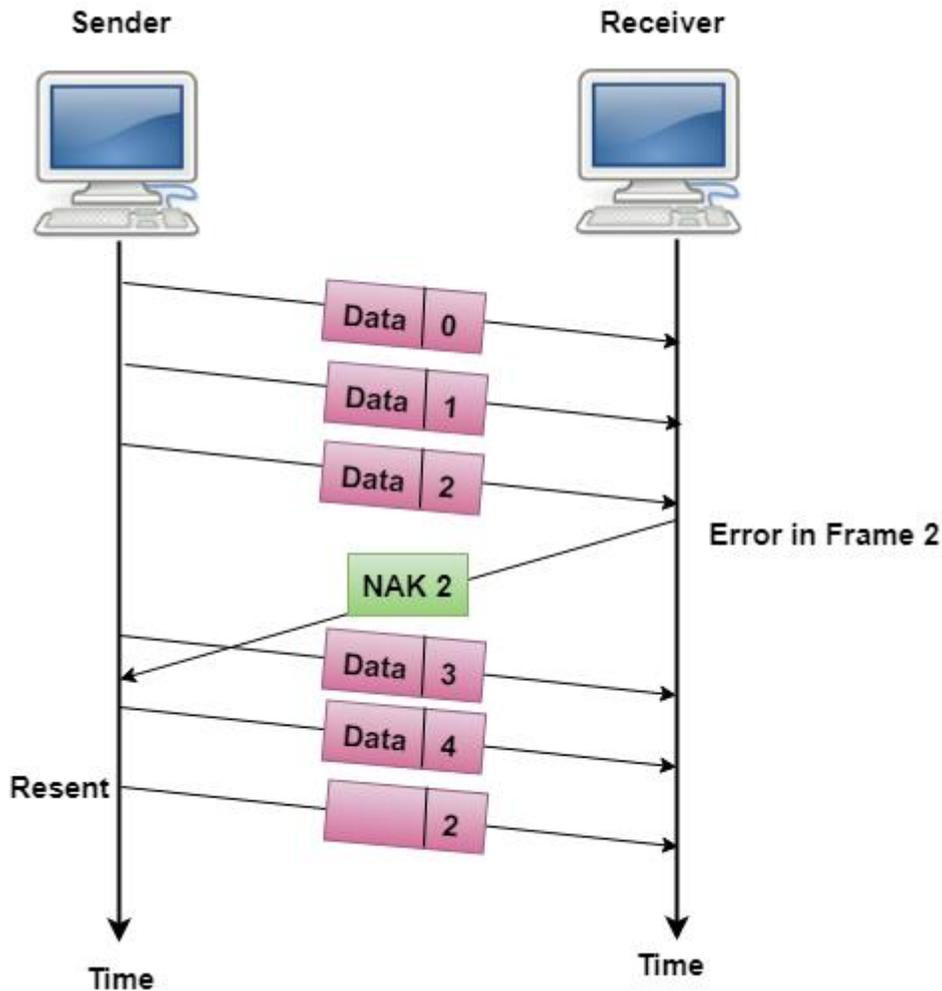
In the above figure, three frames have been transmitted before an error discovered in the third frame. In this case, ACK 2 has been returned telling that the frames 0,1 have been received successfully without any error. The receiver discovers the error in data 2 frame, so it returns the NAK 2 frame. The frame 3 is also discarded as it is transmitted after the damaged frame. Therefore, the sender retransmits the frames 2,3.

- **Lost Data Frame:** In Sliding window protocols, data frames are sent sequentially. If any of the frames is lost, then the next frame arrive at the receiver is out of sequence. The receiver checks the sequence number of each of the frame, discovers the frame that has been skipped, and returns the NAK for the missing frame. The sending device retransmits the frame indicated by NAK as well as the frames transmitted after the lost frame.

Lost Acknowledgement: The sender can send as many frames as the windows allow before waiting for any acknowledgement. Once the limit of the window is reached, the sender has no more frames to send; it must wait for the acknowledgement. If the acknowledgement is lost, then the sender could wait forever. To avoid such situation, the sender is equipped with the timer that starts counting whenever the window capacity is reached. If the acknowledgement

Selective-Reject ARQ

- Selective-Reject ARQ technique is more efficient than Go-Back-n ARQ.
- In this technique, only those frames are retransmitted for which negative acknowledgement (NAK) has been received.
- The receiver storage buffer keeps all the damaged frames on hold until the frame in error is correctly received.
- The receiver must have an appropriate logic for reinserting the frames in a correct order.
- The sender must consist of a searching mechanism that selects only the requested frame for retransmission.



Multiple access protocol- ALOHA, CSMA, CSMA/CA and CSMA/CD

Data Link Layer

The [data link layer](#)

is used in a computer network to transmit the data between two devices or nodes. It divides the layer into parts such as **data link control** and the **multiple access resolution/protocol**. The upper layer has the responsibility to flow control and the error control in the data link layer, and hence it is termed as **logical of data link control**. Whereas the lower sub-layer is used to handle and reduce the collision or multiple access on a channel. Hence it is termed as [media access control](#)

or the multiple access resolutions.

Data Link Control

A [data link control](#)

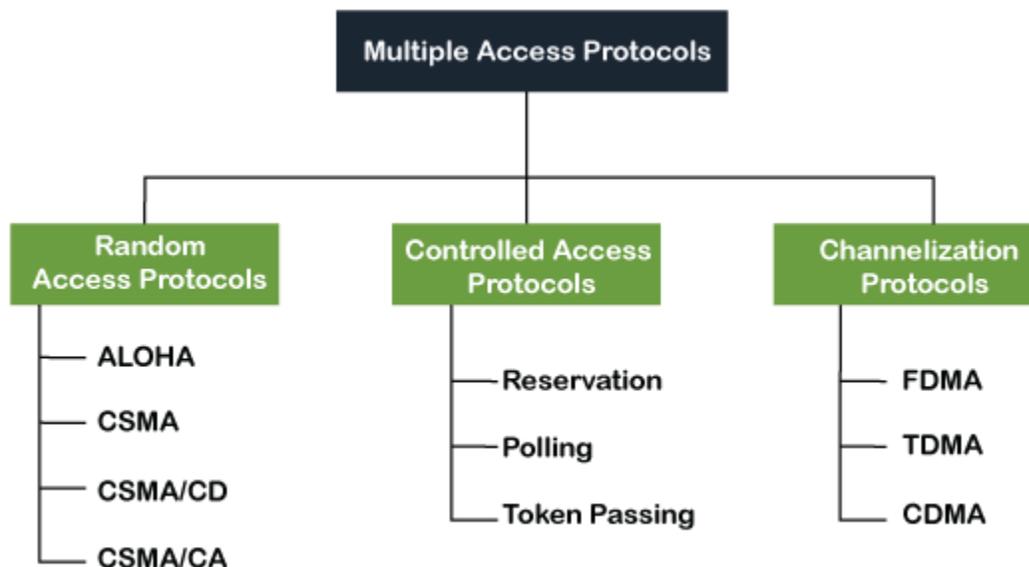
is a reliable channel for transmitting data over a dedicated link using various techniques such as framing, error control and flow control of data packets in the computer network.

What is a multiple access protocol?

When a sender and receiver have a dedicated link to transmit data packets, the data link control is enough to handle the channel. Suppose there is no dedicated path to communicate or transfer the data between two devices. In that case, multiple stations access the channel and simultaneously transmits the data over the channel. It may create collision and cross talk. Hence, the multiple access protocol is required to reduce the collision and avoid crosstalk between the channels.

For example, suppose that there is a classroom full of students. When a teacher asks a question, all the students (small channels) in the class start answering the question at the same time (transferring the data simultaneously). All the students respond at the same time due to which data is overlap or data lost. Therefore it is the responsibility of a teacher (multiple access protocol) to manage the students and make them one answer.

Following are the types of multiple access protocol that is subdivided into the different process as:



A. Random Access Protocol

In this protocol, all the station has the equal priority to send the data over a channel. In random access protocol, one or more stations cannot depend on another station nor any station control another station. Depending on the channel's state (idle or busy), each station transmits the data frame. However, if more than one station sends the data over a channel, there may be a collision or data conflict. Due to the collision, the data frame packets may be lost or changed. And hence, it does not receive by the receiver end.

Following are the different methods of random-access protocols for broadcasting frames on the channel.

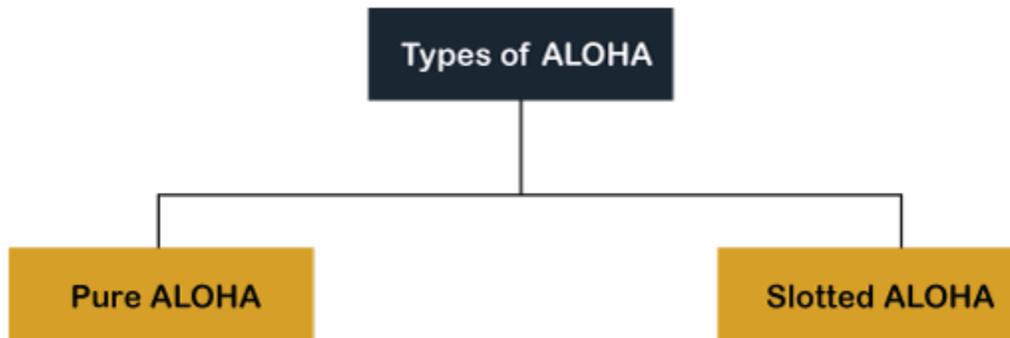
- Aloha
- CSMA
- CSMA/CD
- CSMA/CA

ALOHA Random Access Protocol

It is designed for wireless LAN (Local Area Network) but can also be used in a shared medium to transmit data. Using this method, any station can transmit data across a network simultaneously when a data frameset is available for transmission.

Aloha Rules

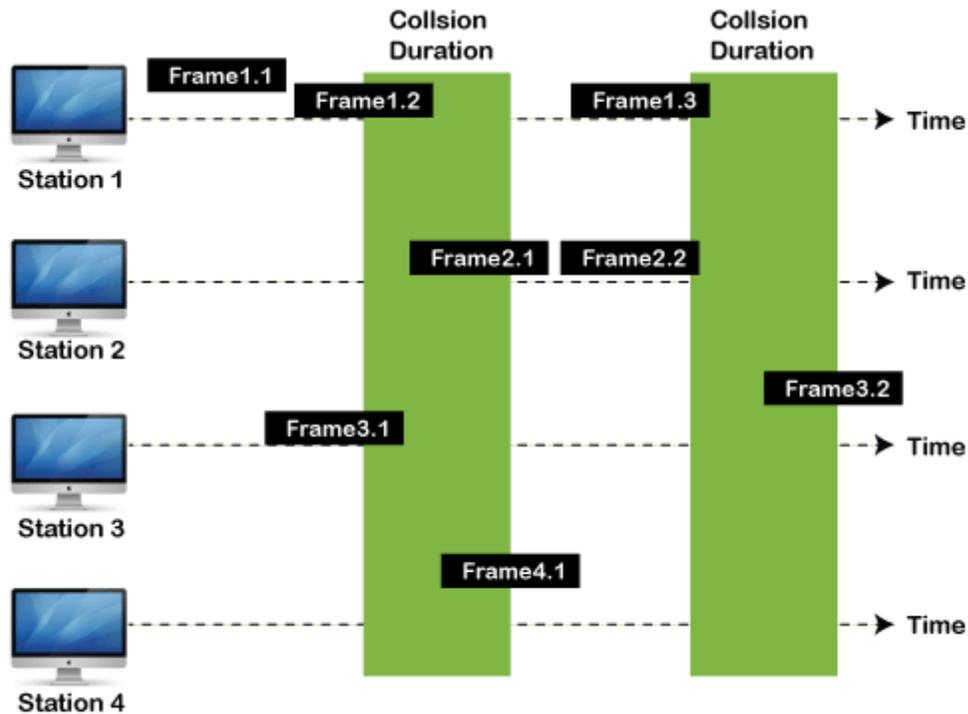
1. Any station can transmit data to a channel at any time.
2. It does not require any carrier sensing.
3. Collision and data frames may be lost during the transmission of data through multiple stations.
4. Acknowledgment of the frames exists in Aloha. Hence, there is no collision detection.
5. It requires retransmission of data after some random amount of time.



Pure Aloha

Whenever data is available for sending over a channel at stations, we use Pure Aloha. In pure Aloha, when each station transmits data to a channel without checking whether the channel is idle or not, the chances of collision may occur, and the data frame can be lost. When any station transmits the data frame to a channel, the pure Aloha waits for the receiver's acknowledgment. If it does not acknowledge the receiver end within the specified time, the station waits for a random amount of time, called the backoff time (T_b). And the station may assume the frame has been lost or destroyed. Therefore, it retransmits the frame until all the data are successfully transmitted to the receiver.

1. The total vulnerable time of pure Aloha is $2 * T_{fr}$.
2. Maximum throughput occurs when $G = 1/2$ that is 18.4%.
3. Successful transmission of data frame is $S = G * e^{-2G}$.



Frames in Pure ALOHA

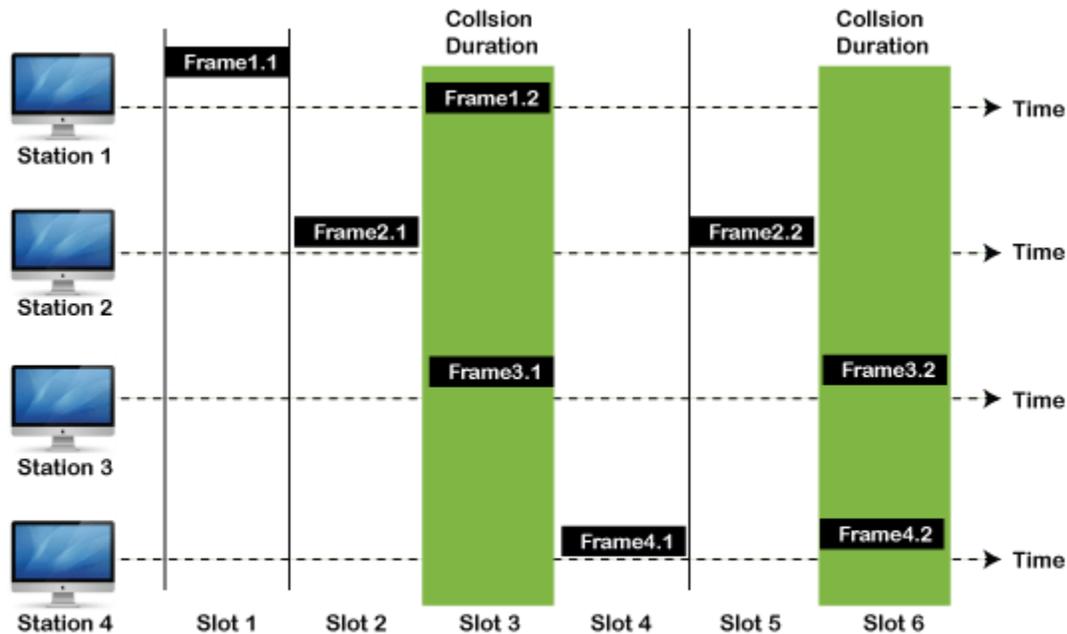
As we can see in the figure above, there are four stations for accessing a shared channel and transmitting data frames. Some frames collide because most stations send their frames at the same time. Only two frames, frame 1.1 and frame 2.2, are successfully transmitted to the receiver end. At the same time, other frames are lost or destroyed. Whenever two frames fall on a shared channel simultaneously, collisions can occur, and both will suffer damage. If the new frame's first bit enters the channel before finishing the last bit of the second frame. Both frames are completely finished, and both stations must retransmit the data frame.

Slotted Aloha

The slotted Aloha is designed to overcome the pure Aloha's efficiency because pure Aloha has a very high possibility of frame hitting. In slotted Aloha, the shared channel is divided into a fixed time interval called **slots**. So that, if a station wants to send a frame to a shared channel, the frame can only be sent at the beginning of the slot, and only one frame is allowed to be sent to each slot. And if the stations are unable to send data to the beginning of the slot, the station will have to wait until the beginning of the slot for the next time. However, the possibility of a collision remains when trying to send a frame at the beginning of two or more station time slot.

1. Maximum throughput occurs in the slotted Aloha when $G = 1$ that is 37%.

- The probability of successfully transmitting the data frame in the slotted Aloha is $S = G * e^{-2G}$.
- The total vulnerable time required in slotted Aloha is T_{fr} .



Frames in Slotted ALOHA

CSMA (Carrier Sense Multiple Access)

It is a **carrier sense multiple access** based on media access protocol to sense the traffic on a channel (idle or busy) before transmitting the data. It means that if the channel is idle, the station can send data to the channel. Otherwise, it must wait until the channel becomes idle. Hence, it reduces the chances of a collision on a transmission medium.

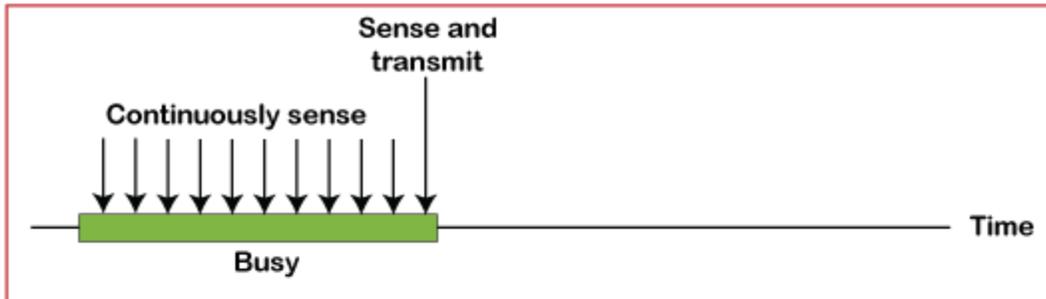
CSMA Access Modes

1-Persistent: In the 1-Persistent mode of CSMA that defines each node, first sense the shared channel and if the channel is idle, it immediately sends the data. Else it must wait and keep track of the status of the channel to be idle and broadcast the frame unconditionally as soon as the channel is idle.

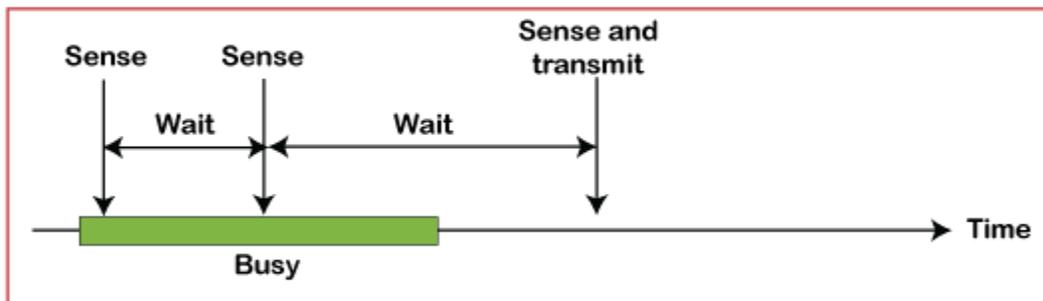
Non-Persistent: It is the access mode of CSMA that defines before transmitting the data, each node must sense the channel, and if the channel is inactive, it immediately sends the data. Otherwise, the station must wait for a random time (not continuously), and when the channel is found to be idle, it transmits the frames.

P-Persistent: It is the combination of 1-Persistent and Non-persistent modes. The P-Persistent mode defines that each node senses the channel, and if the channel is inactive, it sends a frame with a **P** probability. If the data is not transmitted, it waits for a (**q = 1-p probability**) random time and resumes the frame with the next time slot.

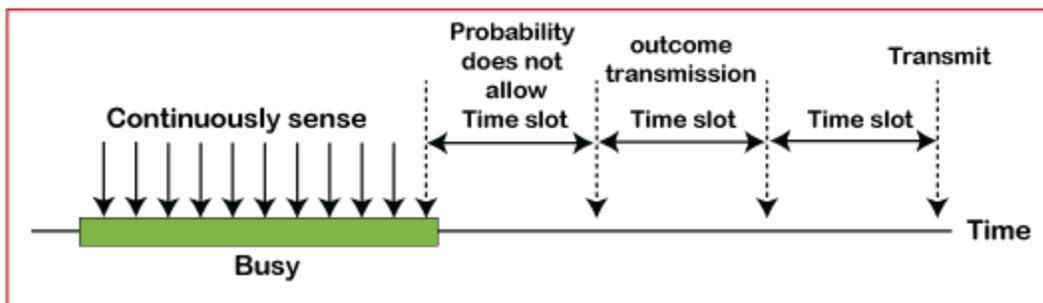
O- Persistent: It is an O-persistent method that defines the superiority of the station before the transmission of the frame on the shared channel. If it is found that the channel is inactive, each station waits for its turn to retransmit the data.



a. 1-persistent



b. Nonpersistent



c. p-persistent

CSMA/ CD

It is a **carrier sense multiple access/ collision detection** network protocol to transmit data frames. The CSMA/CD protocol works with a medium access control layer. Therefore, it first senses the shared channel before broadcasting the frames, and if the

channel is idle, it transmits a frame to check whether the transmission was successful. If the frame is successfully received, the station sends another frame. If any collision is detected in the CSMA/CD, the station sends a jam/ stop signal to the shared channel to terminate data transmission. After that, it waits for a random time before sending a frame to a channel.

CSMA/ CA

It is a **carrier sense multiple access/collision avoidance** network protocol for carrier transmission of data frames. It is a protocol that works with a medium access control layer. When a data frame is sent to a channel, it receives an acknowledgment to check whether the channel is clear. If the station receives only a single (own) acknowledgment, that means the data frame has been successfully transmitted to the receiver. But if it gets two signals (its own and one more in which the collision of frames), a collision of the frame occurs in the shared channel. Detects the collision of the frame when a sender receives an acknowledgment signal.

Following are the methods used in the [CSMA/ CA](#)

to avoid the collision:

Interframe space: In this method, the station waits for the channel to become idle, and if it gets the channel is idle, it does not immediately send the data. Instead of this, it waits for some time, and this time period is called the **Interframe** space or IFS. However, the IFS time is often used to define the priority of the station.

Contention window: In the Contention window, the total time is divided into different slots. When the station/ sender is ready to transmit the data frame, it chooses a random slot number of slots as **wait time**. If the channel is still busy, it does not restart the entire process, except that it restarts the timer only to send data packets when the channel is inactive.

Acknowledgment: In the acknowledgment method, the sender station sends the data frame to the shared channel if the acknowledgment is not received ahead of time.

B. Controlled Access Protocol

It is a method of reducing data frame collision on a shared channel. In the controlled access method, each station interacts and decides to send a data frame by a particular station approved by all other stations. It means that a single station cannot send the

data frames unless all other stations are not approved. It has three types of controlled access: **Reservation**, **Polling**, and **Token Passing**.

In the Controlled access technique, all stations need to consult with one another in order to find out which station has the right to send the data.

- The controlled access protocols mainly grant permission to send only one node at a time; thus in order to avoid the collisions among the shared mediums.
- No station can send the data unless it has been authorized by the other stations.

The protocols lies under the category of Controlled access are as follows

:

1. Reservation
2. Polling
3. Token Passing

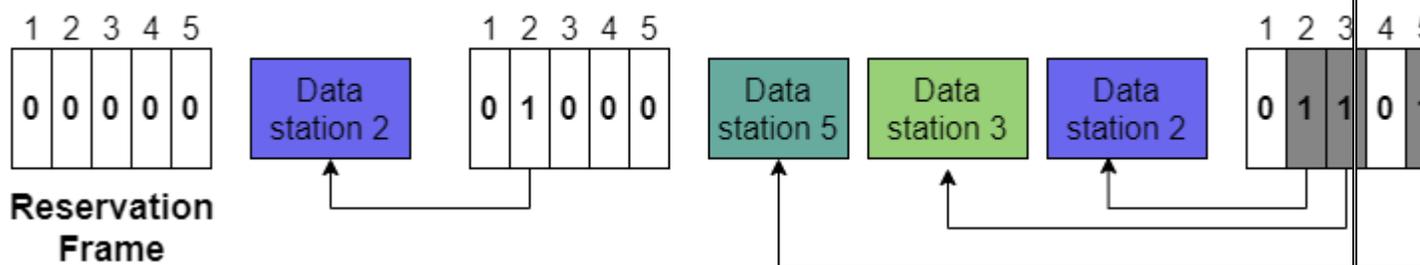
Let us discuss each protocol one by one:

1. Reservation

In this method, a station needs to make a reservation before sending the data.

- Time is mainly divided into intervals.
- Also, in each interval, a reservation frame precedes the data frame that is sent in that interval.

- Suppose if there are '**N**' stations in the system in that case there are exactly '**N**' reservation minislots in the reservation frame; where each minislot belongs to a station.
- Whenever a station needs to send the data frame, then the station makes a reservation in its own minislot.
- Then the stations that have made reservations can send their data after the reservation frame.
- **Example**
- Let us take an example of 5 stations and a 5-minislot reservation frame. In the first interval, the station 2,3 and 5 have made the reservations. While in the second interval only station 2 has made the reservations.



2. Polling

The polling method mainly works with those topologies where one device is designated as the primary station and the other device is designated as the secondary station.

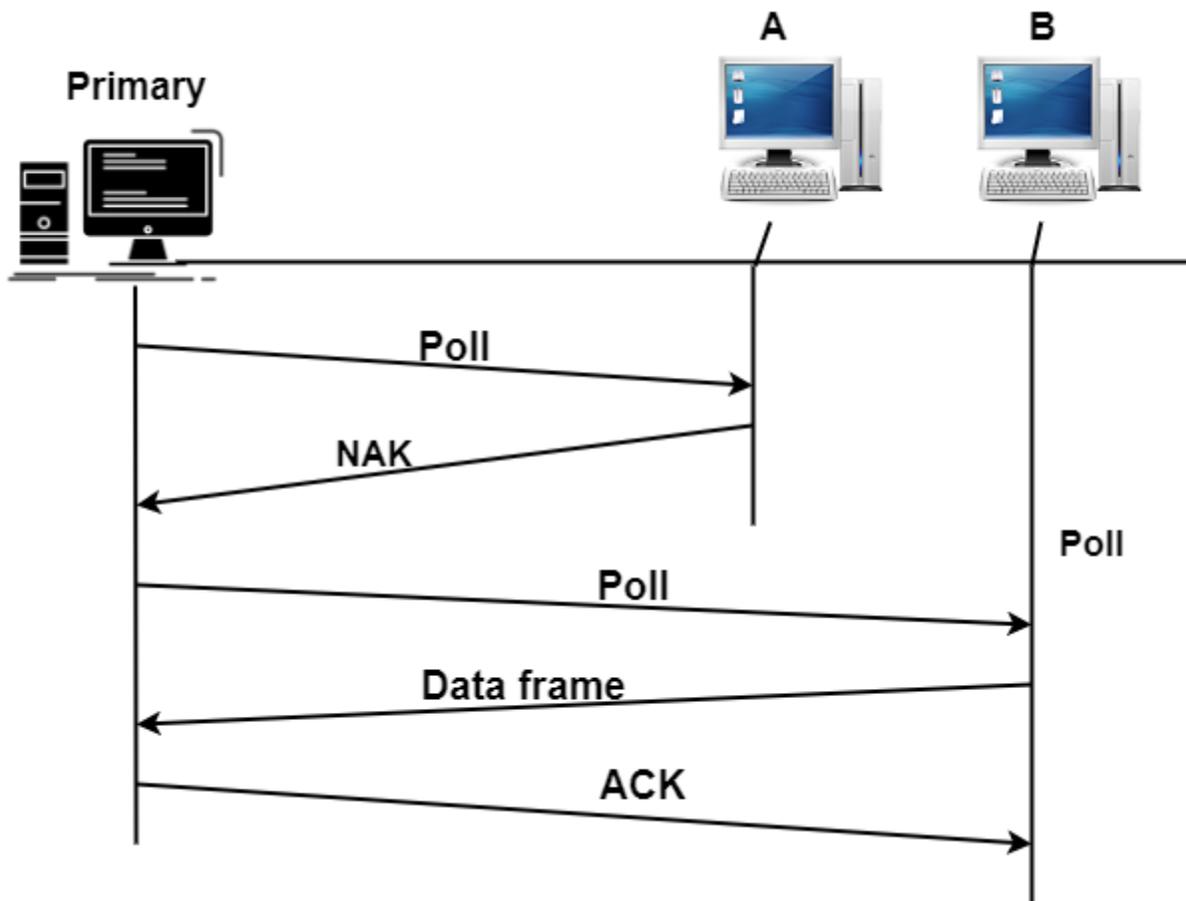
- All the exchange of data must be made through the primary device even though the final destination is the secondary device.
- Thus to impose order on a network that is of independent users, and in order to establish one station in the network that will act as a controller and periodically polls all other stations is simply referred to as **polling**.

- The Primary device mainly controls the link while the secondary device follows the instructions of the primary device.
- The responsibility is on the primary device in order to determine which device is allowed to use the channel at a given time.
- Therefore the primary device is always an initiator of the session.

Poll Function

In case if primary devices want to receive the data, then it usually asks the secondary devices if they have anything to send. This is commonly known as **Poll Function**.

- There is a **poll function** that is mainly used by the primary devices in order to solicit transmissions from the secondary devices.
- When the primary device is ready to receive the data then it must **ask(poll)** each secondary device in turn if it has anything to send.
- If the secondary device has data to transmit then it sends the data frame, otherwise, it sends a **negative acknowledgment (NAK)**.
- After that in case of the negative response, the primary then polls the next secondary, in the same manner until it finds the one with the data to send. When the primary device received a positive response that means (a data frame), then the primary devices reads the frame and then returns an acknowledgment (**ACK**) frame,

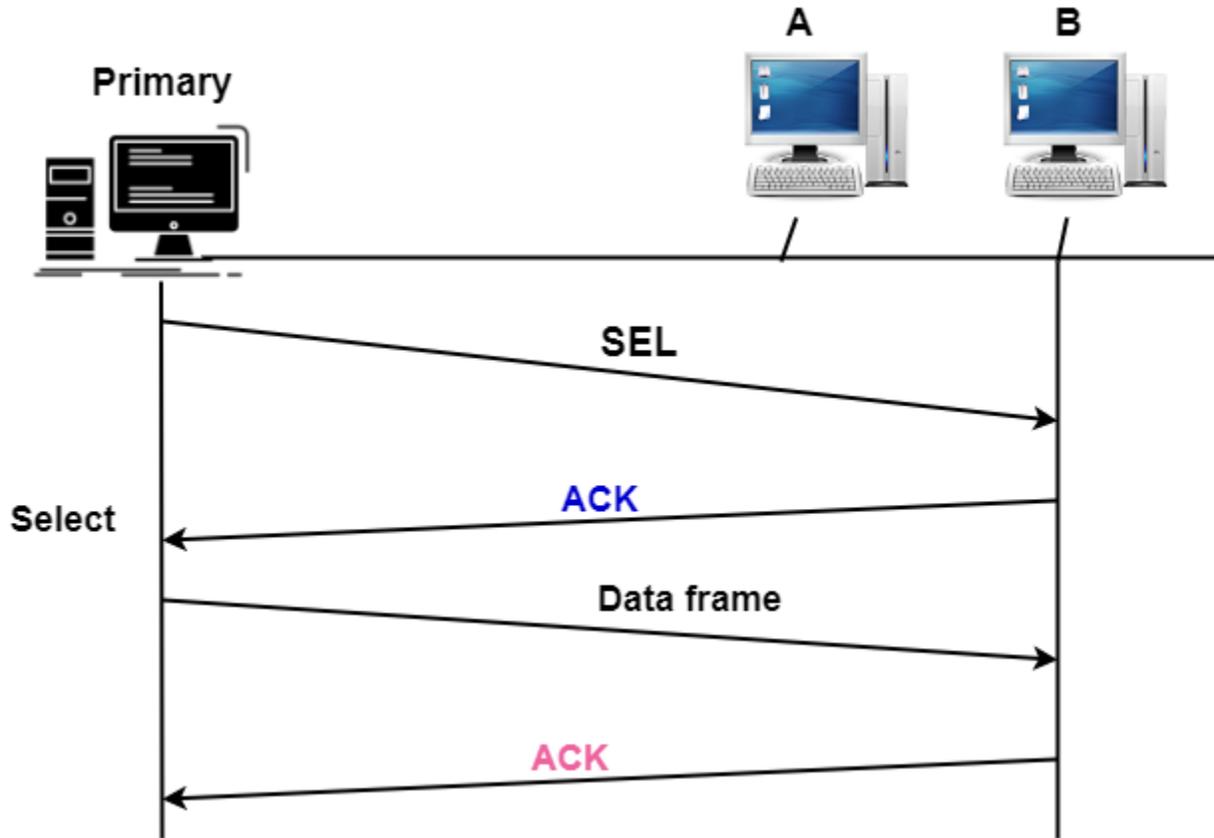


Select Function

In case, if the primary device wants to send the data then it tells the secondary devices in order to get ready to receive the data. This is commonly known as the **Select function**.

- Thus the **select function** is used by the primary device when it has something to send.
- We had already told you that the **primary device** always **controls the link**.
- Before sending the data frame, a select (**SEL**) **frame is** created and transmitted by the primary device, and one field of the SEL frame includes the address of the intended secondary.

- The primary device alerts the secondary devices for the upcoming transmission and after that wait for an acknowledgment (ACK) of the secondary devices.



Advantages of Polling

Given below are some benefits of the Polling technique:

1. The minimum and maximum access times and data rates on the channel are predictable and fixed.
2. There is the assignment of priority in order to ensure faster access from some secondary.

Drawbacks

There are some cons of the polling method and these are as follows:

- There is a high dependency on the reliability of the controller
- The increase in the turnaround time leads to the reduction of the data rate of the channel under low loads.

3. Token Passing

In the token passing methods, all the stations are organized in the form of a logical ring. We can also say that for each station there is a predecessor and a successor.

- The predecessor is the station that is logically before the station in the ring; while the successor is the station that is after the station in the ring. The station that is accessing the channel now is the **current station**.
- Basically, a special bit pattern or a small message that circulates from one station to the next station in some predefined order is commonly known as a **token**.
- Possessing the token mainly gives the station the right to access the channel and to send its data.
- When any station has some data to send, then it waits until it receives a token from its predecessor. After receiving the token, it holds it and then sends its data. When any station has no more data in order to send then it releases the token and then passes the token to the next logical station in the ring.
- Also, the station cannot send the data until it receives the token again in the next round.
- In Token passing, when a station receives the token and has no data to send then it just passes the token to the next station.
- The problem that occurs due to the Token passing technique is the duplication of tokens or loss of tokens. The insertion of the new station, removal of a station, also needs to be tackled for correct and reliable operation of the token passing technique.

The performance of a token ring is governed by 2 parameters, which are delay and throughput.

Delay is a measure of the time; it is the time difference between a packet ready for transmission and when it is transmitted. Hence, the average time required to send a token to the next station is a/N .

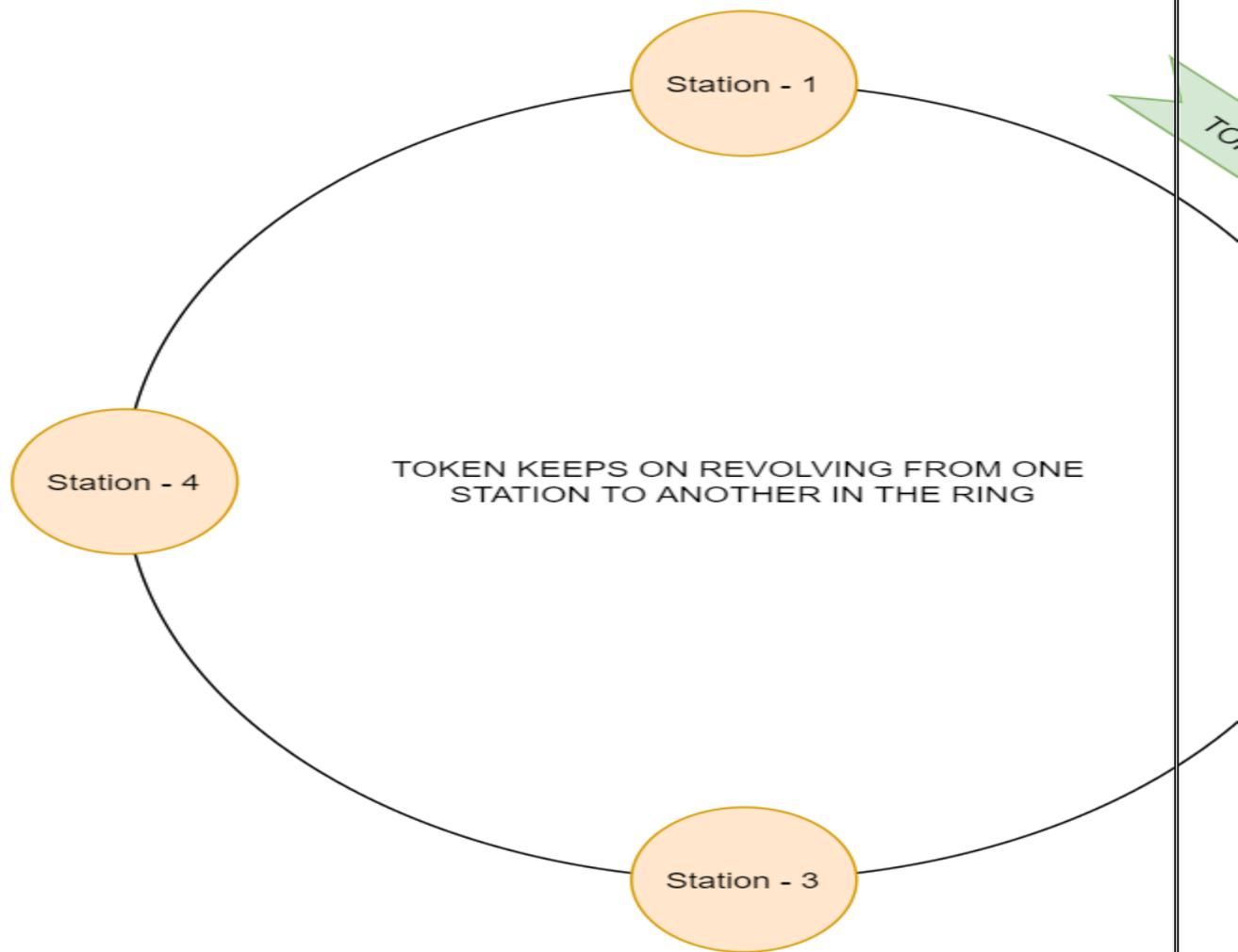
Throughput is a measure of the successful traffic in the communication channel.

Throughput, $S = 1 / (1 + a/N)$ for $a < 1$

$S = 1/[a(1+1/N)]$ for $a > 1$, here $N = \text{number of stations}$ & $a = T_p/T_t$

$T_p = \text{propagation delay}$ & $T_t = \text{transmission delay}$

In the diagram below when station-1 posses the token, it starts transmitting all the data-frames which are in its queue. now after transmission, station-1 passes the token to station-2 and so on. Station-1 can now transmit data again, only when all the stations in the network have transmitted their data and passed the token.



Note: It is important to note that A token can only work in that channel, for which it is generated, and not for any other.