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Computer Networks → A collection of autonomous computers interconnected by a single technology. Two computers are said to be interconnected if they are able to exchange infoⁿ.

Distributed System : The key distinction is that in distributed system, a collection of independent computers appears to users as a single coherent system. A layer of s/w on top of OS called middleware is responsible for implementing. e.g. WWW run on top of Internet & presents a model in which everything looks like document.

→ Uses of Computer N/ws.

1. Business Applications : VPNs (Virtual Private N/w) is used to join individual n/ws at different sites into one extended n/w.
Client Server Model : The most popular realization is that of Web Application.
Telephone calls b/w employees may be carried out by n/w. This technology is called IP Telephony or Voice over IP (VOIP), when Internet technology is used.
Desktop Sharing.

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Goals are :
1. Resource Sharing
2. Commn medium
3. Doing business electronically

2) Home Applications : Used for entertainment.
- → Online digital library (ACM, IEEE)
- → Instant Messaging (Unix talk prog.)
- → Twitter (Short msgs)
- → Social n/w appln
- → IPTV

⇒ N/w Hardware
→ Transmission Technology
- Broadcast link
- Point-to-Point link

P-2P → connect individual pair of m/cs. Short messages called packets have to visit one or more intermediate m/cs. ~~P2P~~ P2P transmission w/h exactly one sender and exactly one reciever is called unicasting.

Broadcast : The commn channel is shared by all m/cs on the n/w. Packets send by any m/c are recieved by all others. An address field w/hin each packet specifies recipient. If packet is intended for recieving m/c, m/c processes the packet, otherwise ignored.

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Broadcast sys. usually allow possibility of addressing a packet to all destinations by using special code in address field. When a packet is recieved & processed by every m/c, this mode is called broadcasting. Some broadcast sys. also supports transmission to subset of m/cs, known as multicasting.

Another criteria of classifying n/w is by scale:

① PAN (Personal Area N/w): let devices communicate over range of person. A common e.g. is wireless n/w that connects a computer w/ its peripherals

② LAN (Local Area N/w): Privately owned n/w that operates w/hin & nearby single building like home, office etc.
- widely used to connect personal computers & consumer electronics to share resources.
- Std for wireless LAN - 802.11 known as Wifi
- Topology for wired LAN is built from P2P. Std → 802.3, called Ethernet.
- Mostly copper wires are used but some uses Optical fibre.

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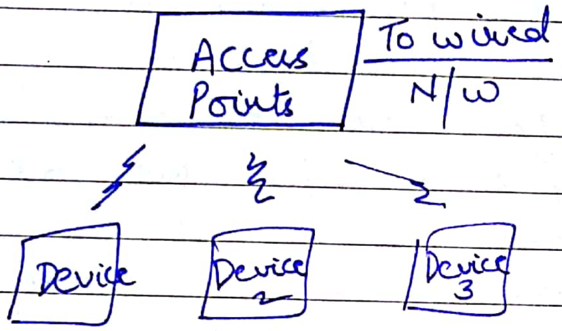
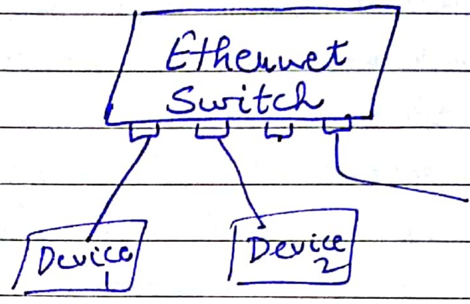


Wireless



Switched Ethernet

(3) MAN (Metropolitan Area N/w) : covers a city. The best known e.g. is cable television n/w. Recent devⁿ in high speed wireless Internet access have resulted in another MAN which has standardised as IEEE 802.16 & is known as WiMax.

(4) WAN (Wide Area N/w) : spans a large geographical area, often a country.

→ Comparison of LAN & WAN

LAN	WAN
- High Speed	- Less Speed (150mbps)
- High Data Transfer Rate	- Lower data transfer Rate
- Office Building	- Internet
- Use Ethernet & Token Ring for connectivity	- Uses ATM, Frame Relay, X.25 for connectivity

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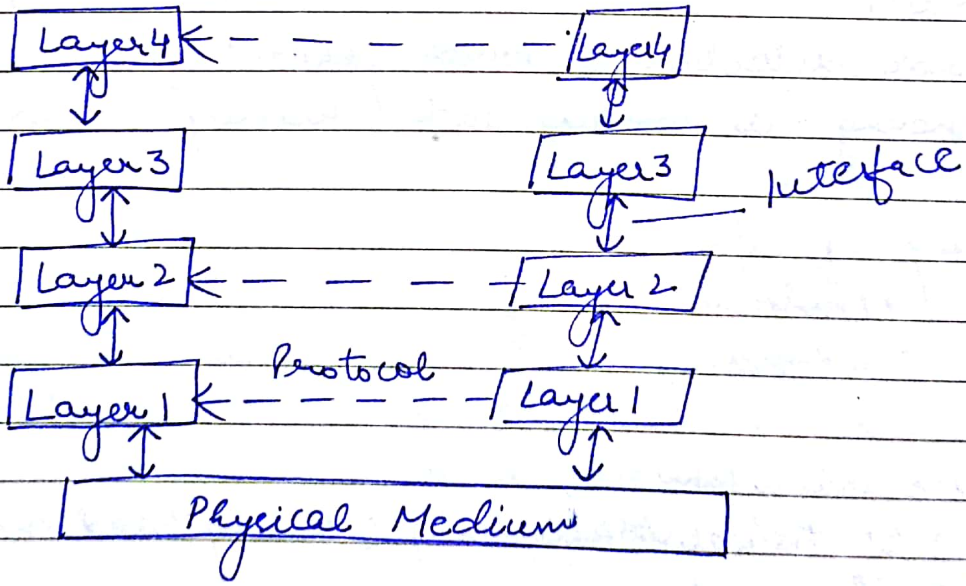
- Can be connected via radio waves
- Components are layer1 & Layer 2 devices

- Connected thru public n/w or satellites
- Components are layer3 devices

→ **Protocol Hierarchies**

Most n/w are organised as a stack of layers or levels each built upon one below it. The purpose of layer is to offer certain services to higher layers while hiding the details how these services are implemented. This is similar as data abstraction. Protocol is an agreement b/w communicating parties on how commu^n is to proceed.



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The interface defines which f^n & services the layer should make available to other.
A set of layers & protocols is called n/w arch.
A list of protocols used by a certain system, one protocol per layer is called protocol stack.

The Key elements of Protocol are :
① Syntax : defines structure or format of data.
② Semantics : refers to meaning of each section of bits.
③ Timing : when data to be sent & how fast to be sent.

→ Design Issue for the Layers

① Reliability
- Error detection & error correction
- Finding a working path (routing)

② Evolution of n/w
- ↳ Protocol Layering
- ↳ Addressing

③ Resource Allocation
- ↳ Statistical Multiplexing (sharing based on demand)
- ↳ Flow control

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④ Security
- ↳ Authentication
- ↳ Integrity
- ↳ Confidentiality

Data Communication : Exchange of data b/w two devices via some form of transmission medium.

Data commⁿ depends on 3 characteristics :
1. Delivery
2. Accuracy
3. Timeliness

DC systems has 5 components
1. Message
2. Sender
3. Receiver
4. Medium
5. Protocol

Direction of Data Flow
1. Simplex e.g. Keyboard, Mouse
2. Half Duplex eg Walkie-Talkie
3. Full Duplex eg Telephone line

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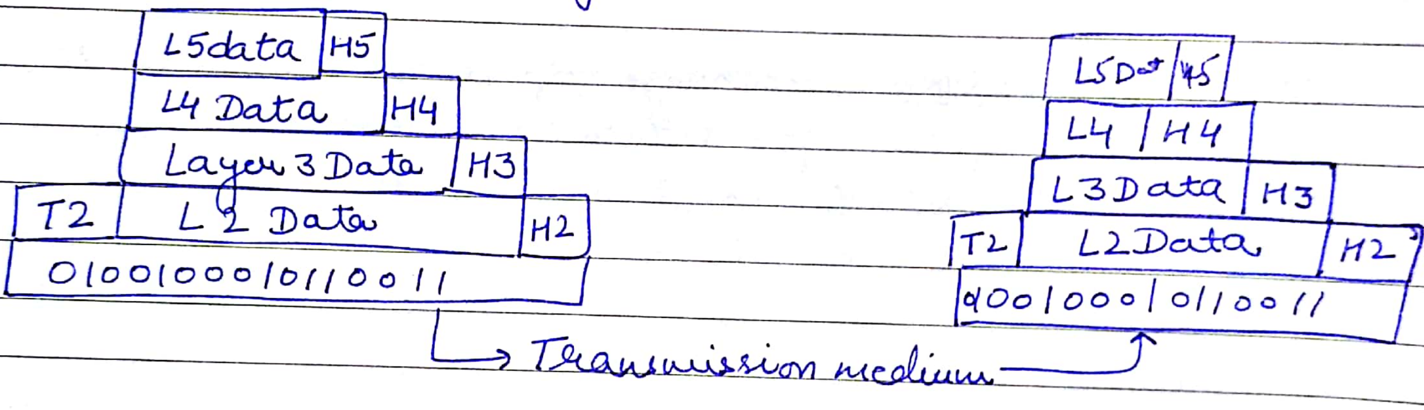
⇒ ~~ISO OSI Model~~ INTERNET MODEL / TCP/IP PROTOCOL SUITE.

— Composed of 5 layers

Organization of Layers



Layer 1, 2 & 3 are n/w support layers; they deal w/h physical aspects of moving data from one device to another. Layer 5 is user support layer; it provides interoperability among unrelated s/w systems.
Layer 4 links two subgroups & ensures that what the lower layers have transmitted is in the form the upper layer can use.
At each layer a header is added. When formatted data unit pass thru physical layer it is changed into electromagnetic signal & transported along physical link. Upon reaching destination signal is transformed back into digital form.

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Physical Layer
└ Responsible for transmitting bits from one node to next.
- Physical characteristics of interface & media
- Representation of bits
- Data rate
- Synchronization of bits

Data Link Layer (hop-to-hop | node-to-node delivery)
- Framing
- Physical addressing
- Flow control
- Error control
- Access control

Network Layer (source-to-destination delivery)
└ responsible for delivery of packets from original source to final destination.
If two sys. are connected on same link, there is no need of n/w layer.
- Logical Addressing
- Routing

Transport Layer (Process-to-Process delivery)
- Port addressing
- Segmentation & Reassembly

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- Connection Control
- Flow control (end-to-end)
- Error control

Application Layer
└ responsible for providing services to the user.
- Mail Services
- File Transfer & access
- Remote log-in
- Accessing WWW

⇒ OSI Model
Session Layer
└ N/w dialog controller.
- Establish, maintain & synchronize interaction b/w communicating systems.

Presentation Layer
└ designed to handle syntax & semantics of info" exchanged b/w 2 systems.
- Data translation
- Encryption & Decryption
- Compression

SNA, Apple Talk, Netware

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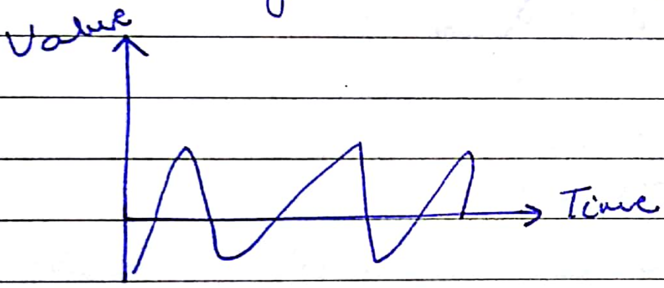
⇒ PHYSICAL LAYER

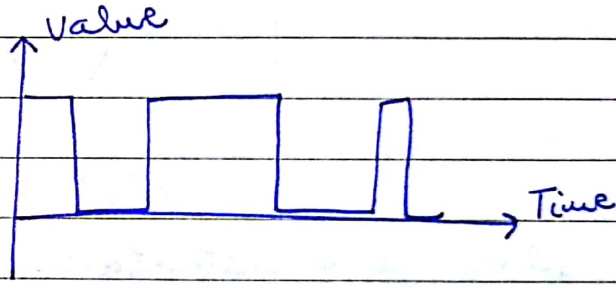
One of the major concern of physical layer lies in moving data in form of electromagnetic signals across transmission medium.

Signals

Signals can be analog or digital. Analog signals have an infinite no. of values in a range; digital signals have only limited no. of values.



Analog



Digital

Periodic Signal : completes a pattern w/hin a measurable time frame, called period & repeat that pattern over subsequent identical period. The completion of one full pattern is called cycle.

Aperiodic Signal : changes w/hout exhibiting a pattern or cycle that repeats over time.

In DC, we use periodic analog signals & aperiodic digital signals.

Need less bandwidth (periodic analog)

Represent variation in data (aperiodic digital)

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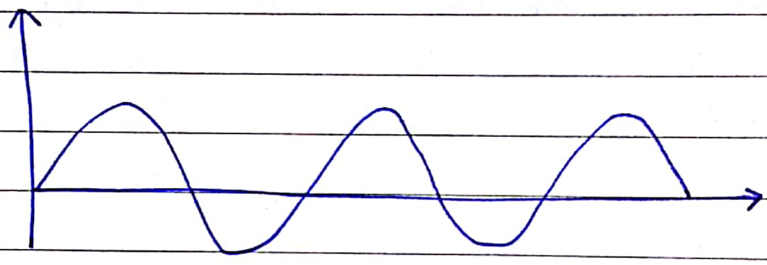
→ Analog Signals

Simple
- Cannot be decomposed

Composite
- Composed of multiple sine waves



$$s(t) = A \sin(2\pi f t + \phi)$$

where s → instantaneous Amplitude

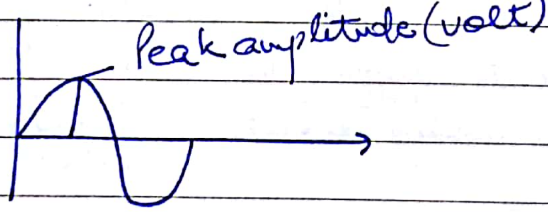
A → peak amplitude

f → Frequency

ϕ → Phase

} fully describe sine wave

Peak Amplitude → represents the absolute value of its highest intensity proportional to energy it carries.



Period refers to amount of time, in seconds a signal needs to complete one cycle.

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Frequency → No. of periods in one second. (Hertz)
↳ also defined as rate of change w.r.t time.

Ques Express a period of 100 us & express frequency in kHz.

Solⁿ $100 ms = 100 \times 10^{-3} s$

$= 100 \times 10^{-3} \times 10^{-6} \mu s$

$= 10^{5} \mu s$

$100 ms = 100 \times 10^{-3} = 10^{-1} s$

$f = \frac{1}{10^{-1}} Hz = 10 \times 10^{-3} kHz$

$= 10^{-2} kHz$.

Phase → describes the position of waveform relative to time zero.

Ques A sine wave is offset one-sixth of cycle w.r.t zero. What is its phase in degrees & radians

Solⁿ We know one complete cycle is 360°

$\frac{1}{6} \times 360° = 60°$

$\frac{60 \times 2\pi}{360} = \frac{\pi}{3} = 1.046$ rad.

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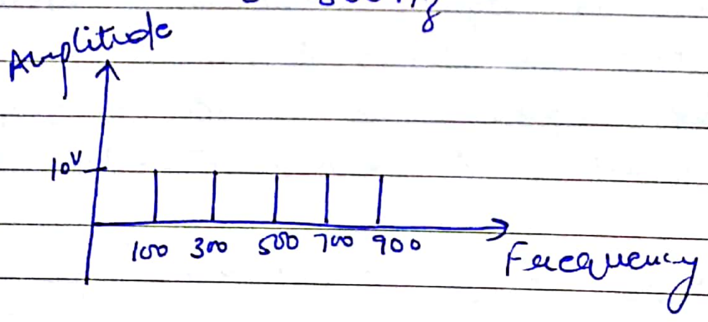
When we change one or more characteristics of a single frequency signal, it becomes a composite signal made of many frequencies.

<u>Bandwidth</u> : The range of frequencies that a medium can pass is called its bandwidth.
- Property of a medium
- Diff. b/w highest frequency & lowest frequency that medium can pass.

<u>Ques</u> If periodic signal composed of five sine waves w/h frequencies of 100, 300, 500, 700, 900 Hz. What is bandwidth? Draw spectrum assuming all components having max. amplitude of 10 V.

<u>Solⁿ</u>

$$B = 900 - 100$$
$$= 800\ Hz$$



<u>Digital Signal</u> (can have more than two levels)

Bit Rate : No. of bit intervals per second. i.e. no. of bits sent in 1s.

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Bit length : Propogation speed x Bit interval
Bit interval : Time reqd. to send one single bit.

Ques Digital signal has a bit rate of 2000 bps. What is duration of each bit.

Solⁿ

$$= \frac{1}{\text{Bit rate}} = \frac{1}{2000}$$

$$= .000500 \times 10^6 \mu s$$

$$= 500 \mu s$$

Wavelength : binds period or frequency of simple sine wave to propagation speed of medium.
- depends both on frequency & medium.

$$\text{Wavelength} = \text{propogation speed} \times \text{period}$$
$$= \frac{\text{propogation speed}}{\text{frequency}}$$

Digital signal is transmitted by using one of two diff. approach :
1. Baseband Transmission
2. Broadband Transmission

Baseband → means sending a digital signal over a channe[l] w/out changing digital signal to analog signal.
- Requires low pass channel (channel w/a BW that starts from zero)

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Broadband → means changing digital signal to analog signal for transmission.
- Uses band pass channel (BW doesn't start w/h zero).

→ Data Rate Limits

How fast we can send data, in bits per second, over a channel.

Data rate depends on three factors:

1. Bandwidth available
2. Level of signals
3. Quality of channel

For Noiseless channel : Nyquist Bit rate

$$\text{Bit Rate} = 2 \times BW \times \log_2 \underbrace{L}_{\text{no. of signal levels used to represent data}}$$

Ques Consider a noiseless channel w/h BW of 3000Hz transmitting a signal w/h 2 signal levels. Calculate bit rate.

$$\text{BitRate} = 2 \times 3000 \times \log_2 2$$
$$= 6000\,bps$$

Noisy Channel : Shannon Capacity

$$\text{Capacity} = BW \times \log_2 (1 + \underbrace{SNR}_{\text{Signal-to-Noise Ratio}})$$

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Ques A telephone line has a BW of 3000Hz. The SNR is usually 3162. Calculate capacity

Solⁿ

$$C = B \log_2 (1+SNR)$$
$$= 3000 \log_2 (3163)$$
$$= 3000 \times 11.62$$
$$= 34860 \text{ bps}$$

Ques We have a channel of 1MHz bandwidth. The SNR for this channel is 63. What is bit rate & level.

Solⁿ

$$C = B \log_2 (1+SNR)$$
$$= 10^6 \log_2 (64)$$
$$= 6 \text{ Mbps}$$

Use Nyquist Theorem

$$4 = 2 \times 1 \times \log_2 L$$
$$\underline{L = 4}$$

→ **Transmission Impairment**

- **Attenuation** (loss of energy)
  - amplifiers are used
  - Decibel
  - $dB = 10 \log P_2/P_1$
  - Negative if attenuated other positive
- **Noise**
  - Thermal
  - Induced
  - Crosstalk
  - Impulse (spike)
- **Distortion**
  - Signal changes shape
  - Occurs in composite signal made of diff. frequencies

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⇒ Data Encoding Techniques

Encoding is the process of converting the data or given sequence of characters, symbols, alphabets etc into specified format, for secured transmission of data.

Data Encoding → process of using various patterns of voltage or current levels to represent 1s or 0s of digital signals on transmission link.

→ Encoding Techniques

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

1. Analog data to Analog signals : AM, FM, PM.
2. Analog data to Digital Signals : This process can be termed as digitization which is done by Pulse Code Modulation (PCM).
3. Digital Data to Analog signals : ASK, FSK, PSK.
4. Digital Data to Digital Signals

→ Digital to Digital Conversion

1. Line Coding
2. Block Coding
3. Scrambling

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→ Line Coding

– Converting a string of 1's & 0's into sequence of signals that denote 1's & 0's.

Signal Rate / Baud Rate : No. of signal elements sent in a second. It is also referred as modulation rate.

$$\text{Baud Rate} = C \times N \times 1/r$$

N → DataRate

C → Casefactor

r → ratio b/w signal element & data element

Ques A signal is carrying data in which one data element is encoded as one signal element. If bit rate is 100kbps, what is average value of baud rate if c is b/w 0 & 1.

Sol

$$S = C \times N \times 1/r$$

$$= 1/2 \times 100\,000 \times 1$$

$$= 50000 = \underline{50\text{k baud}}.$$

→ Line coding Schemes

- Unipolar – NRZ
- Polar – NRZ, RZ, Manchester & Differential Manchester
- Bipolar – AMI, Pseudoternary
- Multilevel – 2B/1Q, 8B/6T, 4D-PAM5
- Multitransition – MLT-3.

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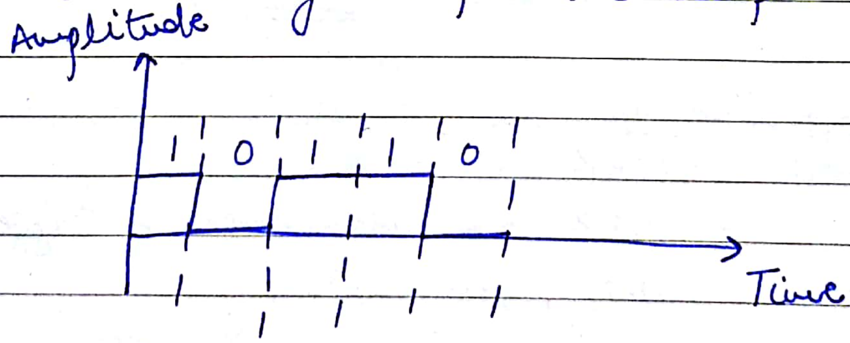
Considerations for choosing good signal element

- Baseline wandering : a reciever will evaluate avg power of recieved signal (called baseline), & use that to determine value of incoming data. If incoming signal doesnot vary over long period of time, baseline will drift & cause errors.
- DC Component : when voltage level remains constant for long period of time, there is increase in low frequencies of signal. Most channels are bandpass & donot support low frequencies.
- Self Synchronization : The clocks at sender & receiver must have same bit interval.

Unipolar NRZ

- All signal levels are on one side of time axis.
- Prone to baseline wandering & DC component
- Simple but costly in power consumption.



Polar NRZ

- Both sides of time axis
- +V for 1 & −V for 0.

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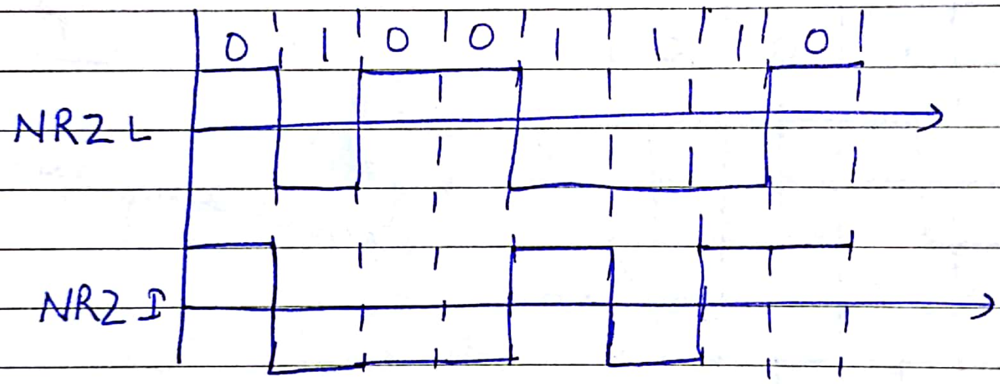
Two versions

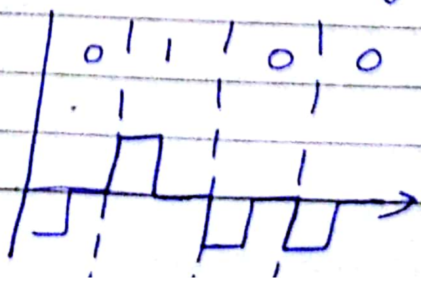
NRZ-L : Voltage is constant during bit interval.
1 → negative voltage
0 → positive voltage
- used for short distances b/w terminal & modem.

NRZ-I : 1 → existence of signal Transition
0 → no signal transition



NRZ L & NRZ I both have avg. signal rate of N/2 Bd

RZ (Return-to-zero)
- uses 3 voltage value +, 0, -
- Each symbol has transition in the middle
- Has more signal transitions & therefore requires a wider bandwidth.
- No DC Component or baseline wandering
- Self Synchronization



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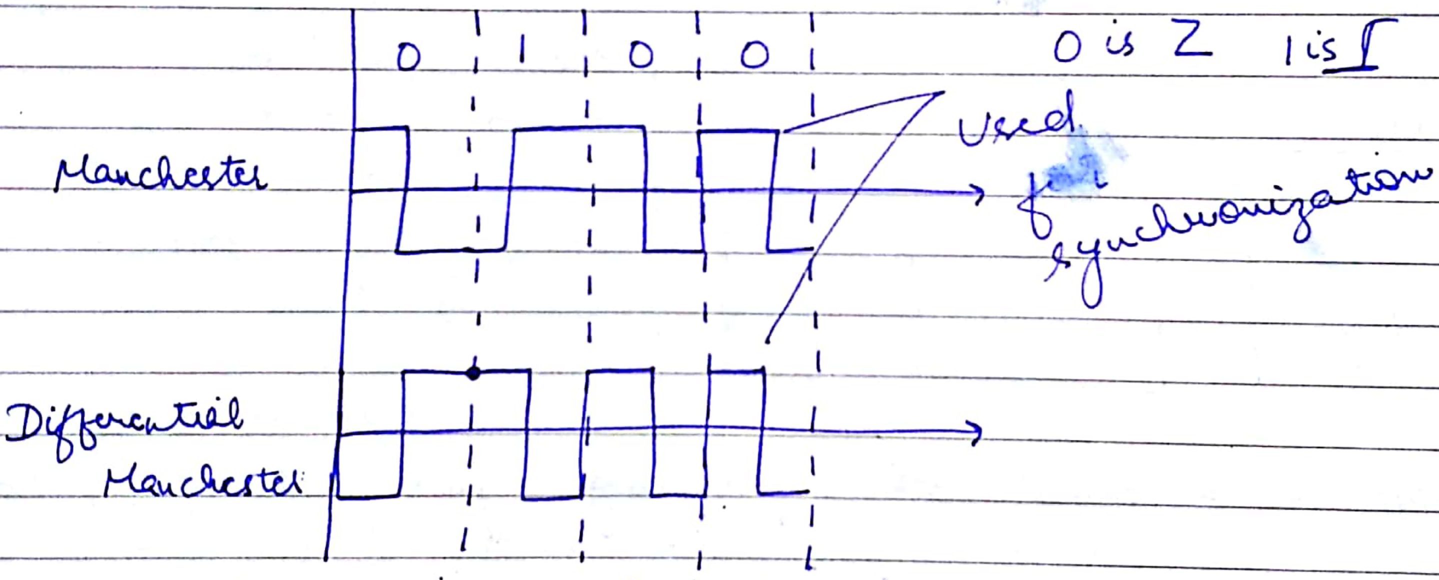
Manchester

- NRZL + RZ
- Uses 2 voltage levels.

Differential Manchester

- NRZI + RZ



No inversion - Next bit 1

Inversion - Next bit 0

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⇒ CRC (Cyclic Redundancy Check)

- based on binary division
- CRC bits are appended at the end of data unit.
- If K bit msg is to be transmitted, transmitter generates r bit sequence called Frame check sequence (FCS)

Procedure at Sender
1. Determine size of original msg
2. Establish Generator Polynomial
3. Append r zeros w/h original msg
4. Divide by generator polynomial
5. Append remainder w/h original msg
6. Transmit data

Procedure at reciever side.
1. Recieve k+r bits
2. Establish Generator Polynomial
3. Divide by Generator Polynomial
4. If remainder zero, no error

How to represent binary sequence using polynomial

$0x^7 + 0x^6 + 1x^5 + \cancel{1}0x^4 + 1x^3 + 1x^2 + 0x^1 + \cancel{1}x^0$

$= 0010110\cancel{0}$

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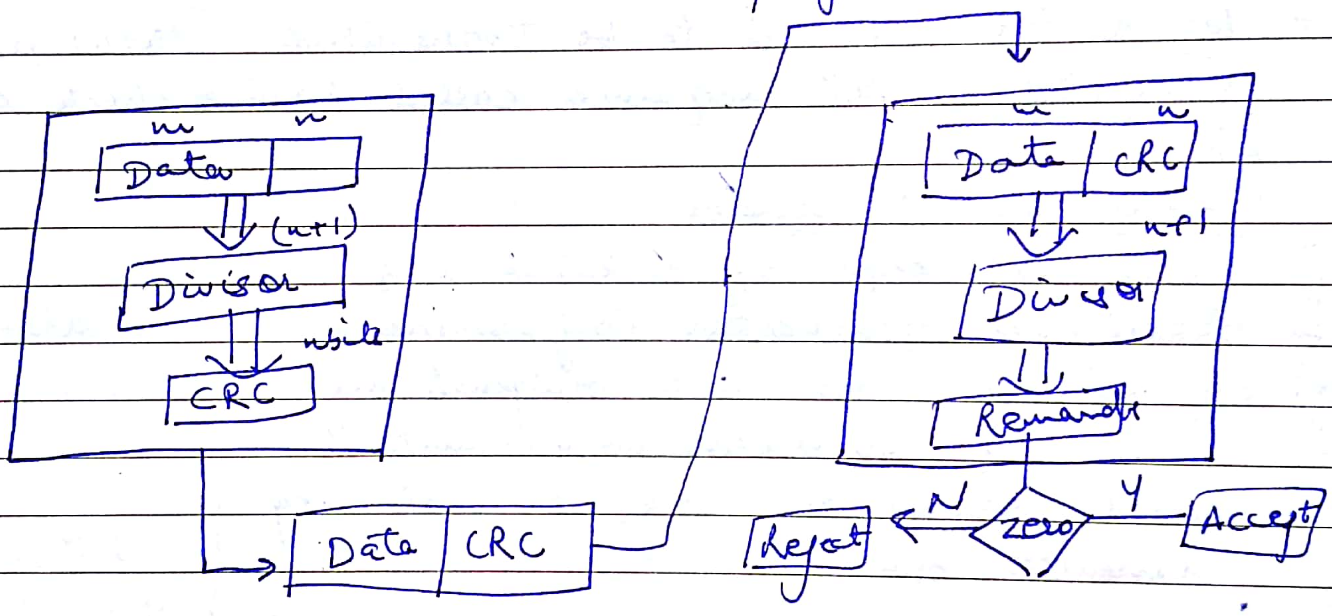
Que How to subtract or add 2 polynomials
- Represent polynomial using binary sequence
- Perform bit wise XOR b/w 2 sequence
- Convert result back to polynomial



Polynomial Division

```
1101 | 1001011010 1
       1101
       1000
       1101
        1011
        1101
         110
         1101
         0101 ← Remainder
```

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Eg Generator Polynomial : x^3+x+1

Data : x^3+x^2+1

What will be FCS? What will be final bits being transmitted

Redundancy → Instead of repeating entire data a shorter grp. of bits may be appended at the end of each unit. This technique is called redundancy bcoz extra bit are redundant to infoⁿ. They are discarded as soon as accuracy of transmission has been determined.

Certain polynomials have become international std.

eg IEEE 802 uses

$x^{32}+x^{26}+x^{23}+x^{22}+x^{16}+x^{12}+x^{11}+x^{10}+x^{8}+x^{7}+x^{5}+x^{4}+x^{2}+x^{1}+1$

It detects all burst error of length ≤ 32 & burst error affecting odd no. of bits.

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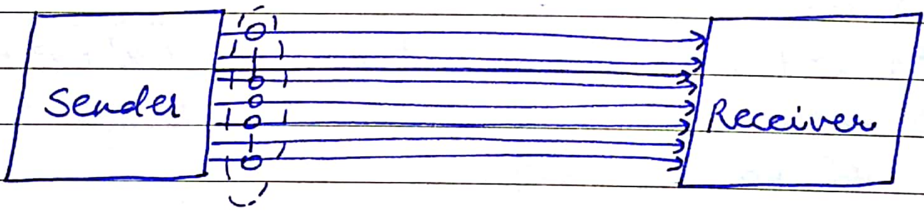
⇒ Data Transmission

- Parallel
- Serial
  - Synchronous
  - Asynchronous

→ **Parallel** : Binary data consisting of 1s & 0s may be organised into groups of n bits each. By grouping, n bits data can be send at a time instead of 1. n wires are used to send n bits at one time. That way each bit has its own wire, & all n bits of one group can be transmitted w/h each clock tick from one device to another.



* The advantage of parallel transmission is speed.
* Disadvantage is cost. Bcoz this is expensive, parallel transmission is usually limited to short distances.

→ **Serial** : One bit follows another, so we need only one communication channel rather than n to transmit data. Since commⁿ w/hin devices is parallel, conversion devices are required at the interface

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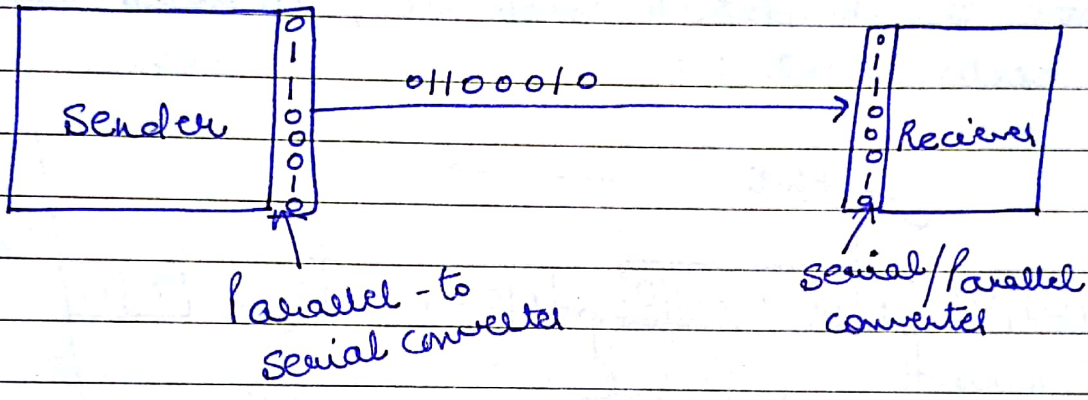
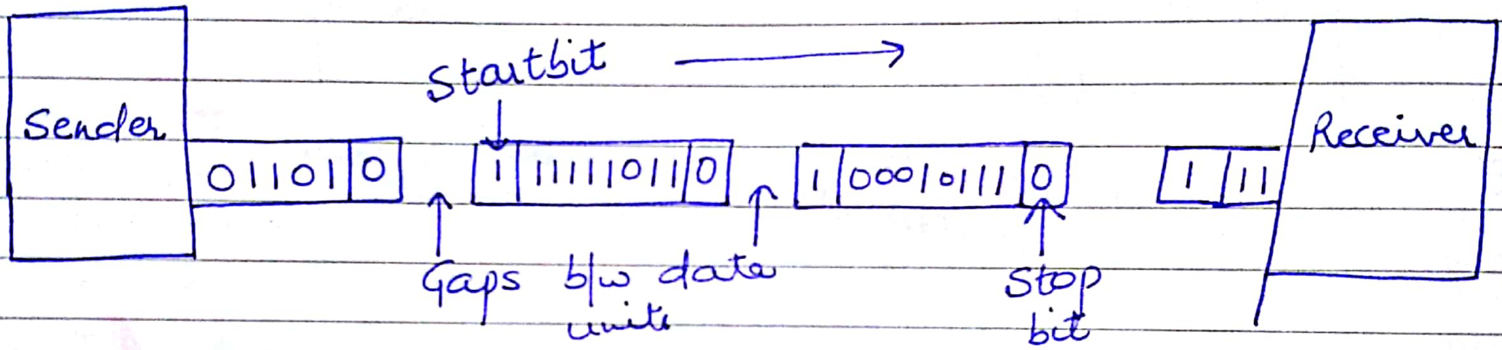
b/w sender & line (parallel-to serial) & b/w the line & receiver (serial-to-parallel).

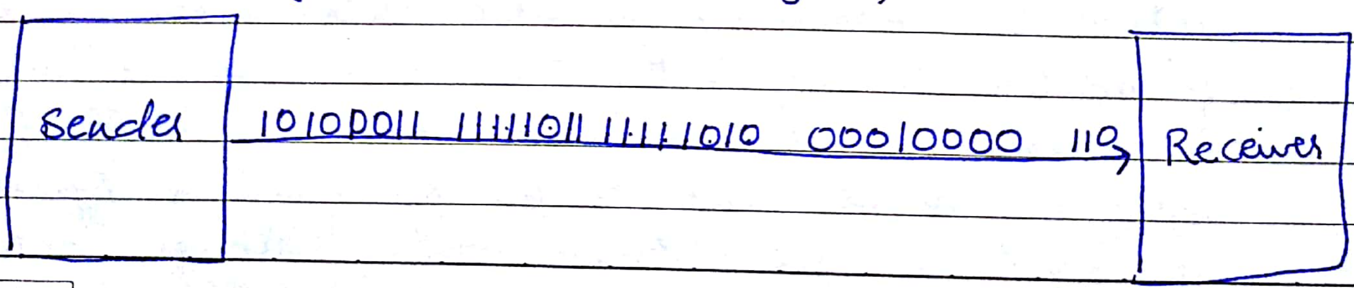


Asynchronous Transmission: Infoⁿ is received & translated by agreed upon patterns. Patterns are based on grouping bit stream into bytes. w/hout synchronization receiver cannot use timing to predict when the next group will arrive. To ~~att~~ alert the reciever to the arrival of new group, an extra bit is added to the beginning of each byte. This bit usually 0 is called start bit. To the end of each byte 1 is appended. These bits are called stop bits. Transmission of each byte may be followed by a gap of varying duration. This gap can be represented either by an idle channel or by stream of additional stop bits. This mechanism is called asynchronous bcoz at byte level the sender & receiver donot have to be synchronized. Synchronization is reqd at bit stream. when receiver detects a start bit it sets a timer & begins counting bits as they come in. After n bits reciever looks for stop bit. As soon as it detects stop bit, it waits until it detects next start bit.



As it is cheap & effective so it is a good choice for low speed communication.
e.g. Connection of Keyboard to computer is natural appl^n for asynchronous transmission.

<u>Synchronous</u> <u>Transmission</u> : Data are transmitted as an unbroken string of 1s & 0s, & the receiver seperates that string into bytes, or characters. It is the responsibility of receiver to group the bits.



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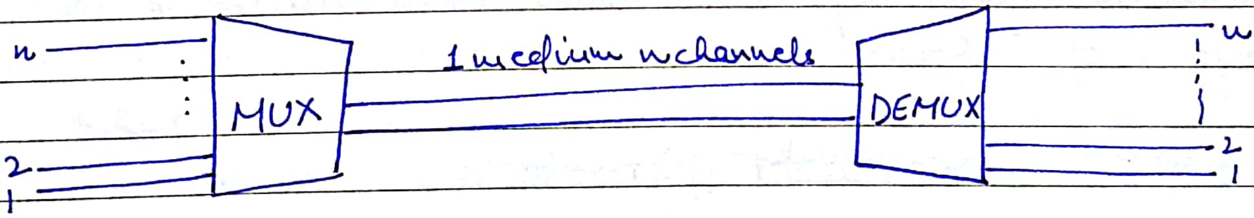
The advantage is speed. For this it is useful for high speed applications such as transmission of data from one computer to another. Byte synchronis" is accomplished in data link layer.

⇒ Multiplexing
When the bandwidth of a medium is greater than individual signals to be transmitted thru channel, a medium can be shared by more than one channel of signals. This process of making the most effective use of available channel capacity is called multiplexing.
- A technique that allows simultaneous transmission of multiple signals across a single data link.



Types

1. Frequency Division Multiplexing (FDM):
The available bandwidth of single physical medium is subdivided into several independent frequency channels. Independent msg signals are translated

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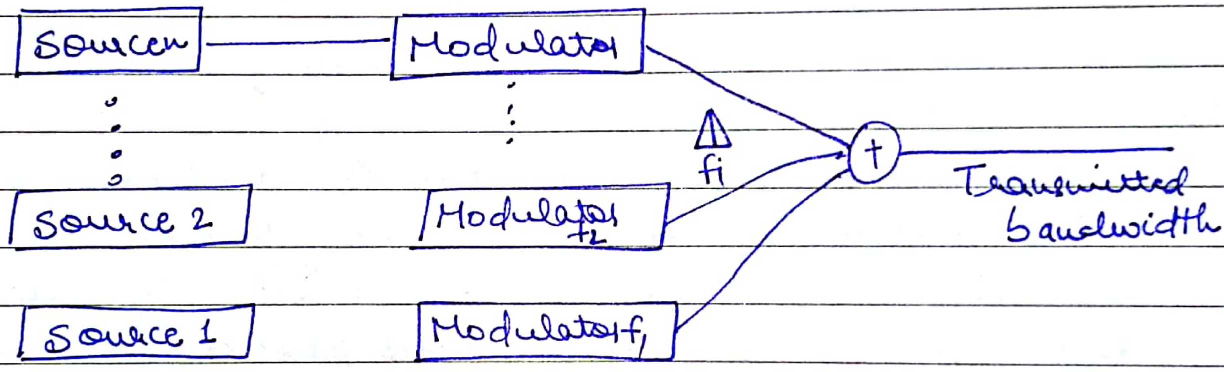
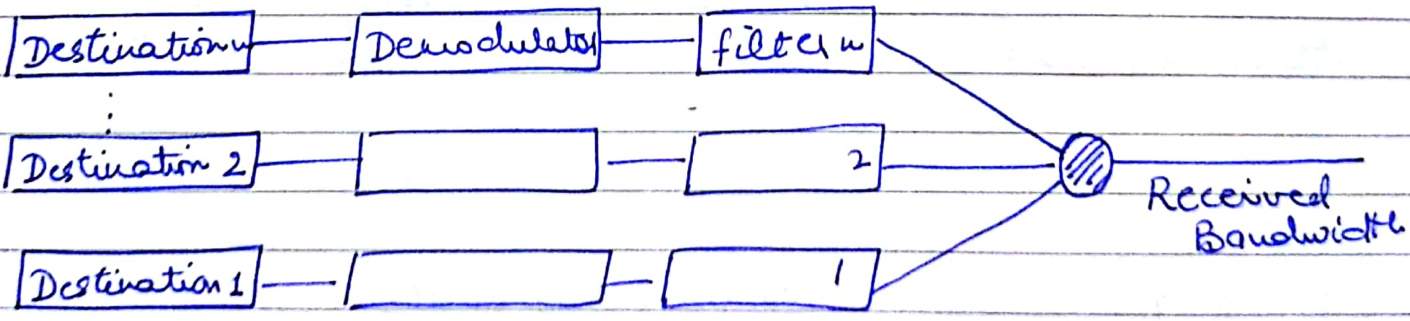
into diff. frequency bands using modulation tech. which are combined by linear summing circuit in multiplexer to composite signal. The carriers used to modulate individual msg signals are called sub-carriers.



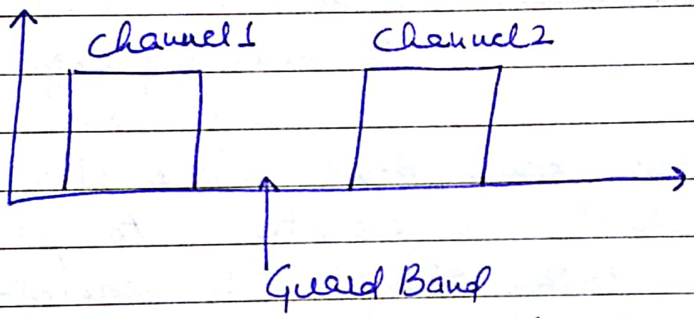
FDM Multiplexing Process

At receiving end the signals is applied to bank of bandpass filter which seperates individual frequency channels. The bandpass filter o/p are then demodulated & distributed to diff. o/p channels.



FDM Demultiplexing Process

If channels are very close to one another, it leads to inter-channel cross talk. Channels must be seperated by strips of unused bandwidth to prevent cross talk. These unused channel b/w each successive channel are known as guard bands.



- Frequently used in radio broadcast & TV n/ws.
- AMPS cellular phone uses FDM
- Since it involves analog use signaling it is more susceptible to noise.

Ques 5 channels each w/h 100KHz BW are to be multiplexed. What is the minimum BW of link if there is need for guard band of 10KHz b/w channels.

Sol^n $5 \times 100 + 4 \times 10$

$= \underline{\underline{540 KHz}}$.

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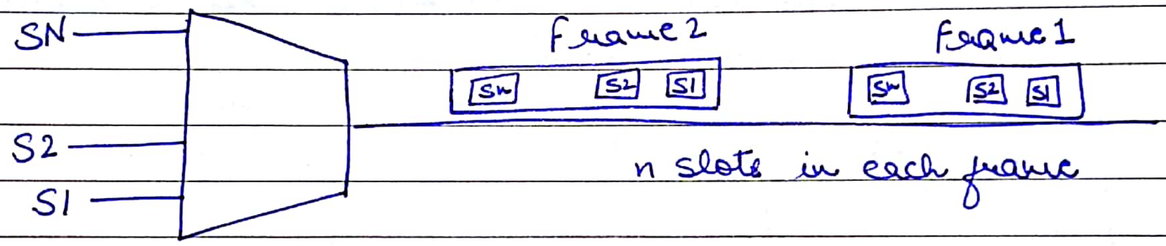
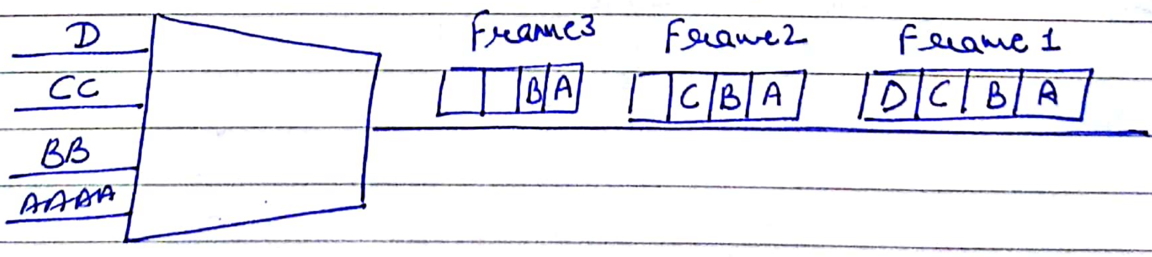
⇒ TDM (Time Division Multiplexing) [Digital signal]
All signals operate w/h same frequency at diff. times.



Composite signal has some dead space b/w successive sampled pulses, which is essential to prevent interchannel cross talk. Along w/h sampled pulse, one synchronizing pulse is sent in each cycle. These data pulses along w/h control infoⁿ form a frame.

Synchronous TDM : Each time slot is pre assigned to a fixed source. The time slot are transmitted irrespective of whether source have any data to send or not. Channel capacity is wasted.



T-1 & ISDN telephone lines are common examples.

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Statistical TDM / Asynchronous TDM : Dynamically allocates the time slots on demand to seperate i/p channels thus saving channel capacity.

Time slots are fully utilised leading to smaller time for transmission & better utilization of bandwidth. Data in each slot must have an address part which identifies source of data.

- Used for LANs

→ Wave Division Multiplexing (WDM)

- Conceptually same as FDM, except that multiplexing & demultiplexing involves light signals transmitted thru fibre optic channels.
- Multiplexing & demultiplexing of light signals can be done w/h the help of prism.
- Used for very high frequencies signal.

→ Interleaving

The process of taking a group of bits from each i/p line for multiplexing.

TDM can be visualized as two fast rotating switches one on multiplexing side & other on demultiplexing side. The switches are synchronized & rotate at same speed but in opposite directions.

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→ Bit stuffing | Bit Padding

When speed of two devices are not integer multiple of each other, they can be made to behave as if they were by a technique called bit padding.

In this, multiplexer adds extra bit to a device source stream to force the speed relationships among various devices in to integer multiples of each other.

Ques 4 sources, each creating 250 characters per second. If interleaved unit is a char. & 1 syn. bit is added to each frame. Find

(i) Data rate of each source = 250 X 8 = 2000bps

(ii) duration of each char. - 1/250 s = 4ms

Frame rate - 250 Frames/s

Duration of each frame - 1/250 s = 4ms

no. of bits in each frame - 4 X 8+1 = 33bits

data rate of link. 250 X 33 = 8250bps

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⇒ Error Detection & Correction

Data can be corrupted during transmission. For reliable commⁿ, errors must be detected & corrected.

Types of Error

- **Single bit**
  - one ~~unit~~ bit of data unit has changed
  - occur in Parallel Transmission
- **Burst error**
  - 2 or more bits in data unit has changed.
  - Serial Transmission

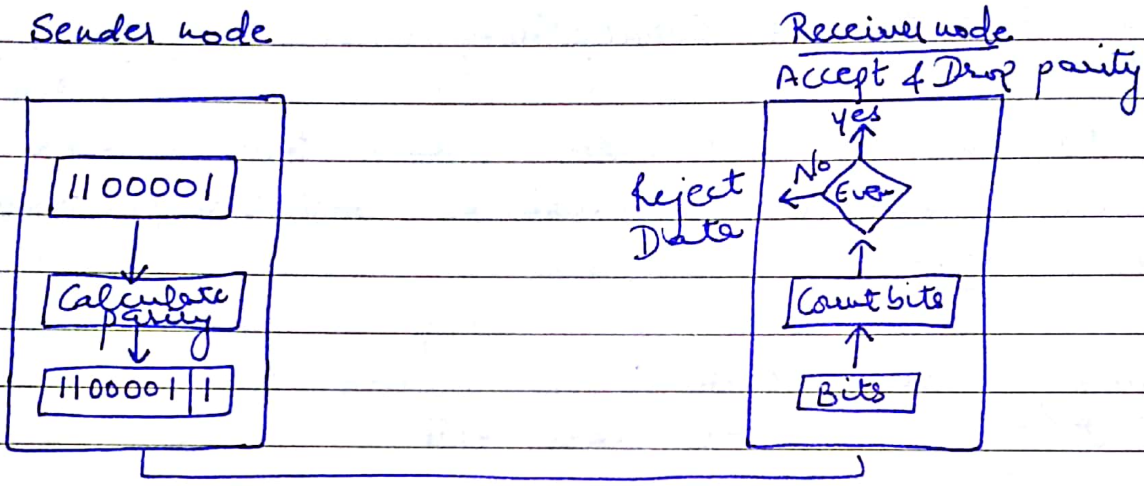
→ **Redundancy** : Error detection uses the concept of redundancy, which means adding extra bits for detecting errors at destination.

Detection Methods

- Simple Parity
- CRC
- Checksum

→ **Parity Check**

- Most common & least expensive mechanism
- A redundant bit called parity bit is added to every data unit so that total no. of 1s in the unit becomes even.



- Detect all single bit errors
- Detect burst error only if total no. of errors in each data unit is odd.

→ Two - Dimensional Parity check
- Block of bits is organized in a table.

1	1	0	0	1	1	1	1
1	0	1	1	1	0	1	1
0	1	1	1	0	0	1	0
0	1	0	1	0	0	1	1
0	1	0	1	0	1	0	1

← 1100111$\boxed{1}$ 1011101$\boxed{1}$ 0111001$\boxed{0}$ 0101001$\boxed{1}$ 01010101

Data + parity bits

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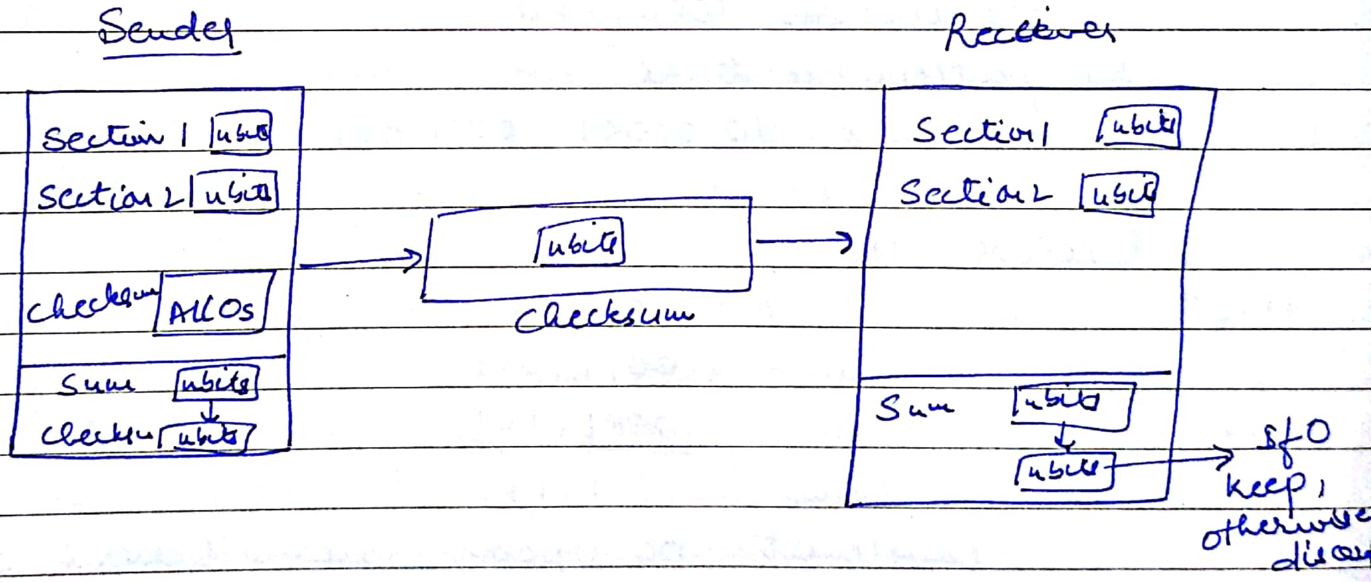
- It increases the likelihood of detecting burst error
- If 2 bits in one data unit are damaged & two bits in exactly same position in another data unit are damaged, error is not detected.

→ Checksum

- Generator subdivides the data unit into equal segments of n bits (usually 16)
- These segments are added using ones complement arithmatic.



Sender side

1. The unit is divided into k sections, each of n bits
2. All sections are added using ones complement
3. The sum is complemented & becomes checksum
4. The checksum is send with data.

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Checksum Checker / Receiver

1. Unit is divided into k sections
2. All sections are added using one's complement
3. Sum is complemented
4. If result is zero, data accepted otherwise rejected.

e.g. 10101001 00111001

10101001
00111001

Sum 11100010

Checksum 00011101

The pattern sent is

← 10101001 00111001 00011101

Checksum

Receiver Side

10101001
00111001
00011101

Sum 11111111

Complement 00000000 means pattern is OK.

Ques 10101111 11111001 00011101

* Checksum detects all errors involving an odd no. of bits as well as most errors involving even no. of bits.

ATM → Asynchronous Transfer Mode

DDCMP → Digital Data Communⁿ Msg. Protocol

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⇒ Framing

Header	Packet (Data)	Trailer

Header ↓ usually contains addressing infoⁿ

Trailer ↓ contains redundancy bits for error detection

Fixed-Size Framing

- No need for defining boundaries of frames
- Size itself can be used as a delimiter
- Easy to manage for reciever
- Eg is ATM wide area n/w which uses 53 byte frames called cells.

Variable-Size Framing e.g. DECNet, DDCMP

- Prevalent in local area n/ws
- End & start of frame has to be defined.

Two approaches are used :

1. Character oriented approach
2. Bit oriented approach

Character oriented approach : Data to be carried are 8 bit characters from a coding system such as ASCII. To seperate one frame from next 8-bit flag is added to the start

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and end of a frame.
Any pattern used for flag could be part of info^n. To fix this problem, a byte stuffing strategy was added.
↳ a special byte is added to data section of frame when there is a character w/R same pattern as flag. The data section is stuffed w/h an extra byte. This byte is usually called ESC character. When reciever encounters ESC character it removes from data section & treat next character as data & not flag.

Bit oriented Protocol :

01111110	Header	Data	Trailer	01111110
Flag				Flag

Bit Stuffing → if a 0 & five consecutive 1 bits are encountered, an extra 0 is added. Note that extra bit is added after one 0 followed by five 1s regardless of the value of next bit.

Clock based Protocol : SONET
↳ Synchronous Optical Network

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Logical Link Control (LLC)
- Interface to upper layers
- flow & error control
- Mgmt. functions

Medium Access Control (MAC)
- Construct header & trailer
- Assemble frames
- Address & error check
- Access the medium

LLC Frame Format

DSAP	SSAP	Control	Data
←1 byte→	←1 byte→		

Control field employs 3 diff. formats
Infoⁿ (I) frame → carries upper layer infoⁿ & some control infoⁿ.
Supervisory (S) frame → provides control infoⁿ. An S frame can request & suspend transmission, report on status & acknowledge receipt of I frames.
Unnumbered frame (U) → Used for control purposes.

MAC Frame Format

Control Header	Source Addr	Destination Addr	LLC Data	CRC

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⇒ Flow Control

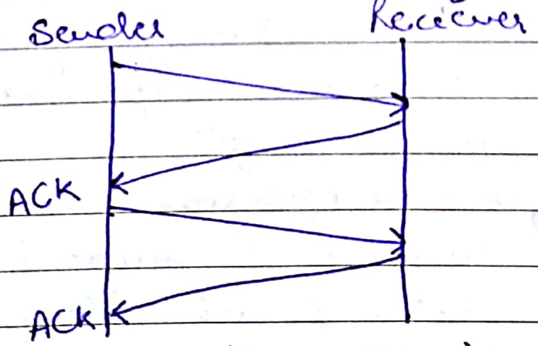
↳ refers to the set of procedures used to restrict the amount of data the transmitter can send before waiting for acknowledgement.

Methods used are :

1. Stop-and-wait (Request/Reply) : requires each data packet to be acknowledged by the remote host before next packet is sent.
2. Sliding window : used by TCP, permit multiple data packets to be in simultaneous transit, making more efficient use of n/w bandwidth.

→ Stop-and-wait

This is simplest form of flow control where sender transmits a data frame.



The sender must wait until it recieves ACK frame before sending next data frame. This is referred as ping pong behaviour, simple to understand & easy to implement, but not very efficient.

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Major drawback is that only one frame can be in transmission at a time, this leads to inefficiency if propogation delay is much longer than transmission delay.

e.g. RPC (Remote Procedure Call) require stop-and-wait behaviour.

Let us assume following

Transmission time : The time it takes for a station to transmit a frame.

Propogation time : Time it take to travel a bit from sender to reciever.

$$\text{Link Utilization} = \frac{1}{(1+2a)}$$

$a \rightarrow$ Propogation time / Transmission time.

When propogation time is small, link utilization is good but in case of long propogation delays as in satellite commⁿ, utilization can be very poor.

→ Sliding Window

Sender station sends sequentially numbered frames. If header of frame allows K bits, the sequence no. ranges from 0 to 2^k-1. Reciever also maintains a window of size 2^k-1. The reciever acknowledges frame by sending ACK frame that includes sequence no. of next frame expected.

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Sliding Window : Sender

Maintain three state variables:

- Send window size (SWS)
- last ack reciever (LAR)
- Last frame sent (LFS)

~~LES~~ $\boxed{LFS - LAR <= SWS}$

- Advance LAR whene ack arrives.

Sliding Window : Reciever

- recieve window size (RWS)
- Largest frame acceptable (LFA)
- Last frame recieved (LFR)

$LFA - LFR <= RWS$

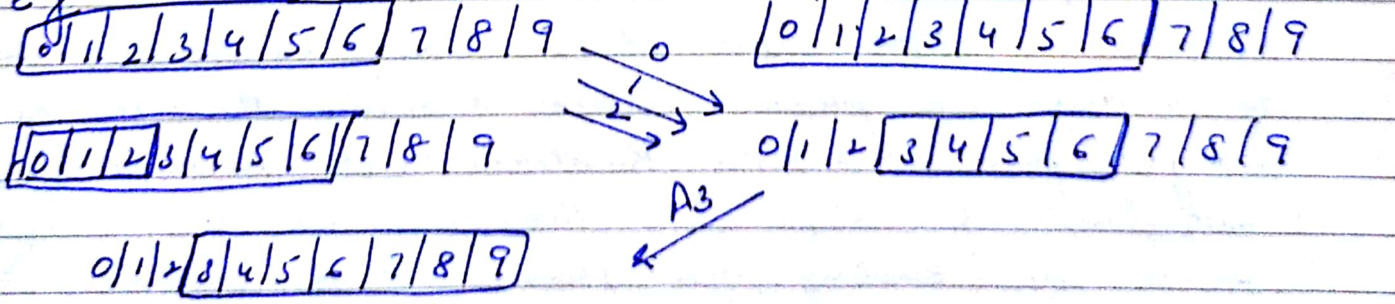
- Frame SeqNum arrives:

if $LFR < SeqNum <= LFA$ — accept

if $SeqNum <= LFR$ or $SeqNum > LFA$ - discarded

- Send cumulative ACKs - send ACK for largest frame such that all frames less than this have been recieved.

eg:



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Link Utilization

$U = 1$ for $N > 2a+1$

$= N/(1+2a)$ for $N < 2a+1$

where $N \rightarrow$ window size

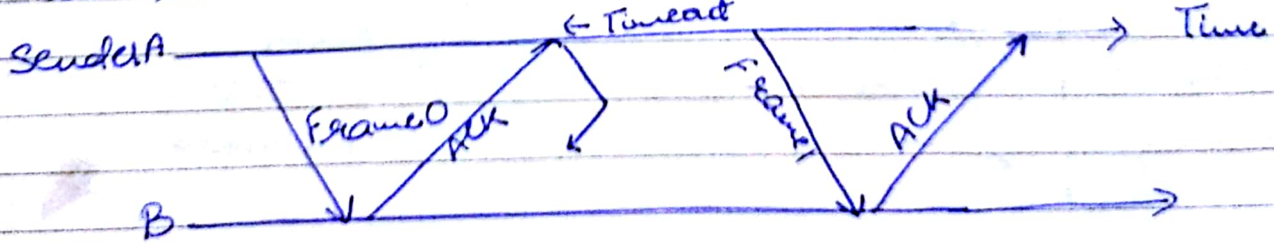
$a \rightarrow$ Propagation time / Transmission time.

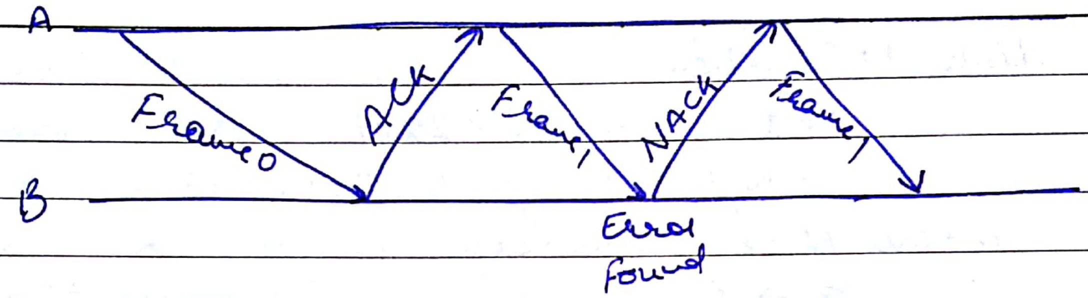
⇒ Error Control Techniques

When error is detected, reciever request to re-transmit the msg. The most popular retransmission scheme is Automatic-Repeat-Request (ARQ). Such scheme, where reciever asks transmitter to re-transmit packet if error is detected is known as Reverse Error Correction technique.

→ Stop-and-wait ARQ :

Simplest among all protocols, the sender transmit a frame, wait till it recieves positive ack. or negative ack. (NACK) from reciever. Station B sends an ACK if frame is recieved correctly, otherwise it sends NACK.

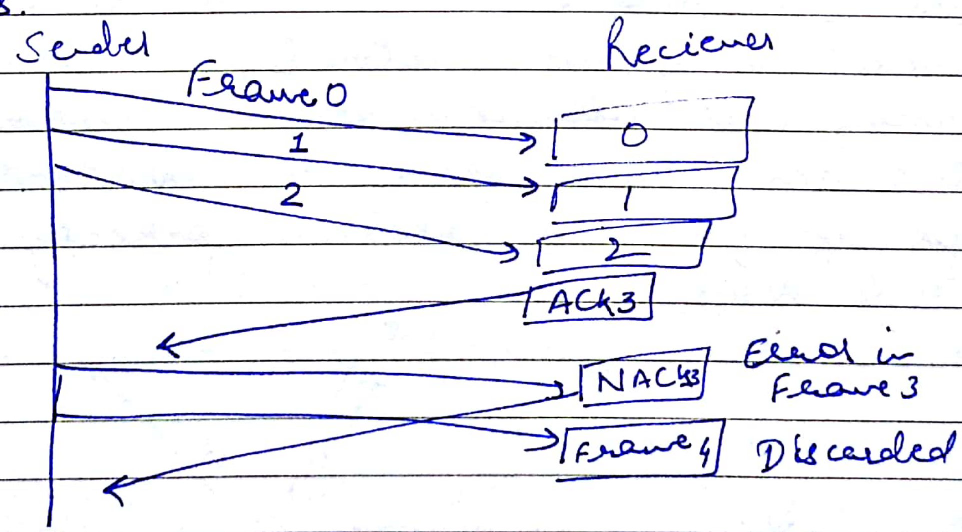




The main advantage of stop-and-wait ARQ is its simplicity.

→ Go-back-N ARQ

The sender sends frame continously w/out waiting for acknowledgement. That is why it is also called as continous ARQ. As reciever recieves the frames, it keeps on sending ACKs or NACK, in case frame is incorrectly recieved. When sender recieves NACK, it retransmits the frame in error plus all succeeding frames.



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→ Selective Repeat

- Retransmits only those for which NAKs are recieved or for which timer has expired. This is the most efficient ARQ.

Ques Consider use of 10K-bit size frames on 10Mbps channel w/h 270ms delay. What is link utilization for stop-and-wait ARQ assuming $P = 10^{-3}$

Soln

Link utilization = $(1-P)/(1+2a)$

Propogation Time = 270

Transmission Time = Frame length / data rate

= 10/10

= 1 msec

$a = 270/1 = 270$

Link Utilisation = $0.999/1+2*270$

= 0.18%

Ques What is channel utilization for go-back-N w/h window size 7

Soln Link Utilization = $N(1-P)/(1+2a)(1-P+NP)$

= 1.285%

Ques What is Piggybacking? What are its advantages?

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⇒ MAC Techniques

Random/Contention based	Round Robin	Reservation	Channelization
- Aloha (Pure, Slotted)	- Polling	- Centralized	- FDMA
- CSMA	- Token passing	- Distributed	- CDMA
- CSMA/CD			- TDMA
- CSMA/CA			

→ Contention Based Approaches → Media access method that is used to share broadcast medium

- Suitable for bursty nature of traffic
- There is no centralized control & when a node has data to send, it contends for gaining control of the medium.
- Principal advantage is simplicity.

Basic idea behind ALOHA

Hub | Outbound → / Medium / ← Inbound | Client 1, Client 2, Client 3

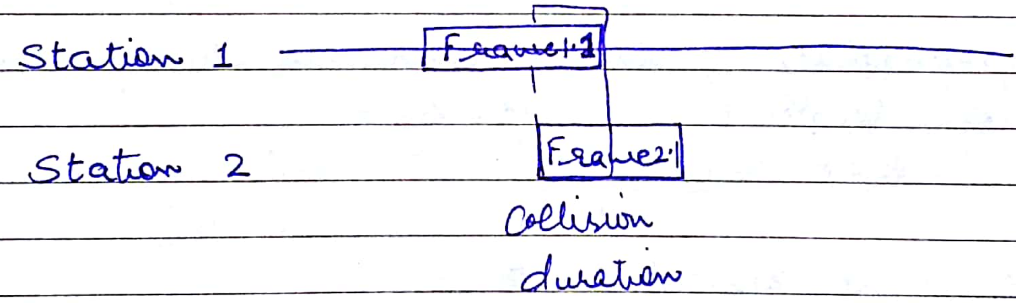
- Use of 2 diff. frequencies in hub/star conf.
- Hub broadcast packets to everyone on outbound channel
- Various client m/cs sending data packets to hub on inbound channel.

If data was recieved correctly at hub, ack. is send to the client.

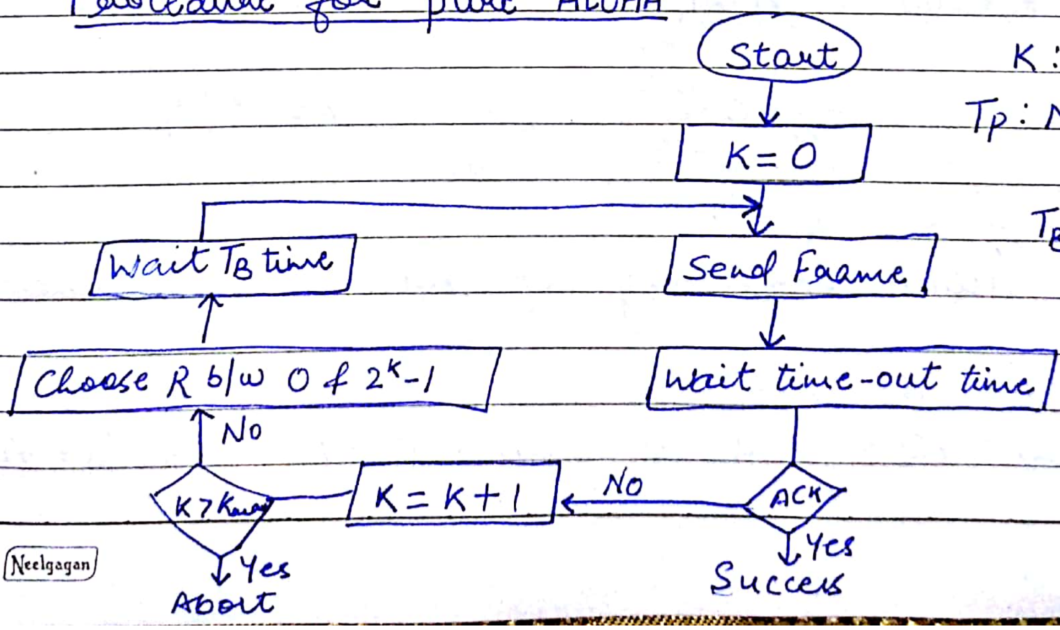
Pure ALOHA

- Whenever a station has data, it transmits.
- Sender finds out whether transmission was successful or experienced collision by listening to broadcast from destination station.
- Sender retransmits if there is a collision.

Frames in Pure ALOHA n/w



Procedure for pure ALOHA



K : No. of attempts
T_p : Max^m Propogation Time
T_B : Back-off time

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Analysis of Pure ALOHA

We will make following assumptions
- All frames are of constant length
- The channel is noise-free
- Frames donot queue at individual stations.

S represents no. of "good" transmissions per frame time & G represents total no. of attempted transmission per frame time

$$S = G * (\text{Probability of good transmissions})$$

The probability of having k arrivals during time interval of length t is given by

$$P_k(t) = \frac{(\lambda t)^k e^{-\lambda t}}{k!}$$

where λ is arrival rate

Set $t = 2T_f$ & $k = 0$, we get   Vulnerable Time $= 2T_f$

$$P_0(2T_f) = \frac{(\lambda \cdot 2T_f)^0 e^{-\lambda 2T_f}}{0!}$$

$$= e^{-\lambda 2T_f}$$ $\lambda = G/T_f$

$$= e^{-2G}$$

$$\Rightarrow S = G \cdot e^{-2G}$$

For pure ALOHA probability of successful transmission is e^{-2G}

Throughput $S = G \times e^{-2G}$

Max^n throughput $= S_{max} = 0.184$ when $(G = 1/2)$

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→ Slotted ALOHA

- invented to improve the efficiency of pure ALOHA as chances of collision is very high in pure ALOHA.
- In Slotted ALOHA there is still possibility of collision if two stations try to send at beginning of same time.
- Time is divided into slots
- Nodes start to transmit frames only at beginning of slots.

Procedure for slotted ALOHA

1. Send frame A at slot boundary & wait for ack
2. If ack recieved successful transmission.
3. If there is collision node detects collision before end of slot
4. wait for random amt. of time & go to 1.

The node retransmits frame in each subsequent slot w/h probability p until frame is transmitted w/hout collision.

* These protocols works efficiently when there are less active nodes.

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⇒ Carrier Sense Multiple Access (CSMA)

In this, a node having data to transmit first listens to the medium to check whether another transmission is in progress or not. The node starts sending only when channel is free. This scheme is also known as listen before talk.

There are 3 variations as follows:

(i) 1-persistent CSMA: If node having data to send, start sending if channel is sensed free. If medium is busy, node continues to monitor until channel is idle. Then it starts sending data.

(ii) Non-persistent CSMA: If channel is sensed free, node starts sending packet otherwise node waits a random amt. of time & then monitors the channel.

(iii) p-persistent CSMA: If channel is busy node continues to monitor until the channel is free & then it sends w/h probability p.

→ CSMA/CD: CSMA/Collision Detection

The wastage of channel capacity is reduced if nodes continue to monitor channel while transmitting a packet & immediately cease transmission when collision is detected. This scheme is also known as Listen-While-Talk.

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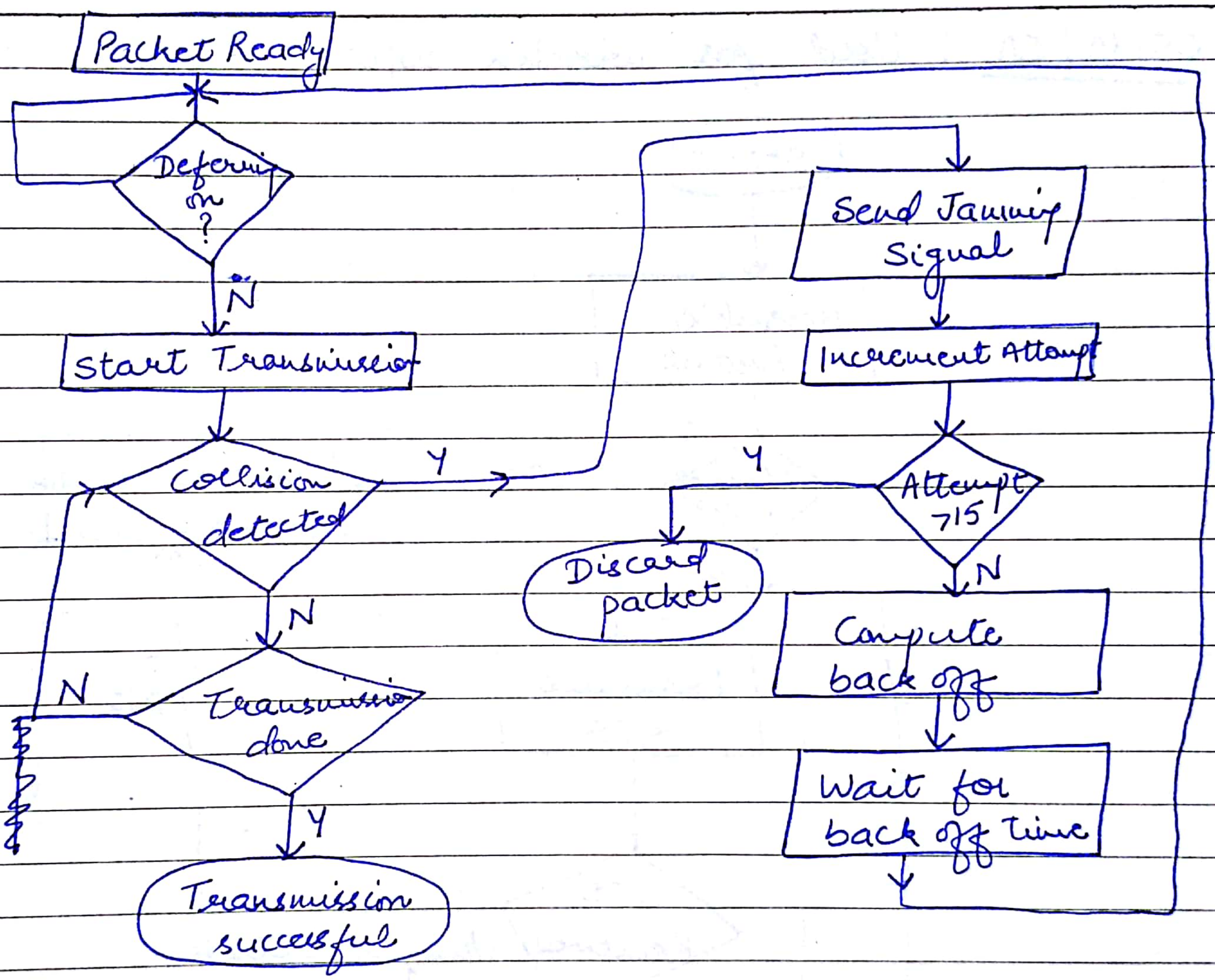

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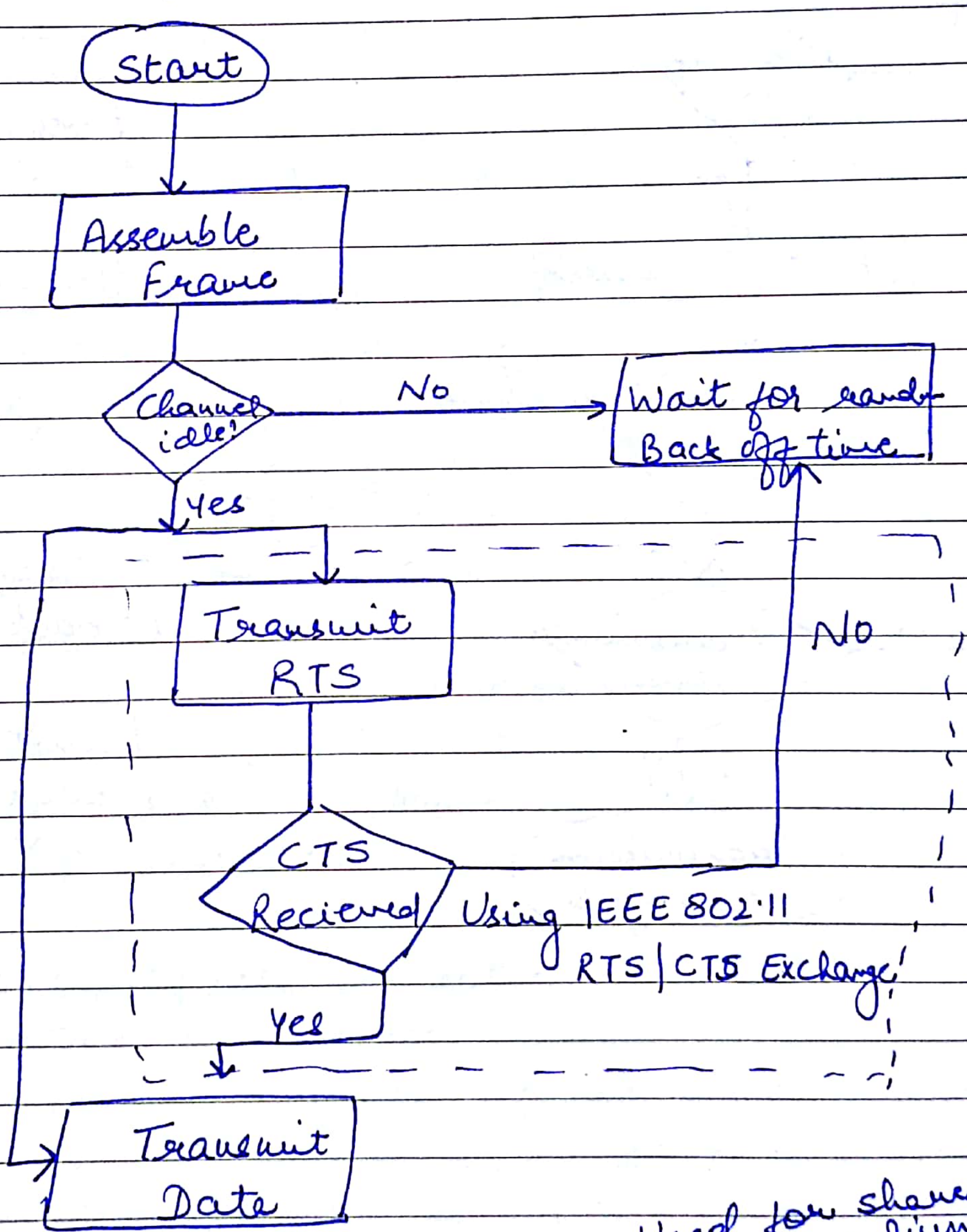
CSMA / CA : Used for wireless n/w.



Hidden node problem ?

↳ Use RTS | CTS → Clear To Send

RTS → Request To Send

RTS | CTS → Used for shared medium

⟹ Hamming Code

K parity bits are added to n-bit data word, forming a new word of n+k bits. The bit positions are numbered in sequence from 1 to n+K. Those positions numbered w/h powers of two are reserved for parity bits. The remaining bits are data bits.

Consider for example 8 bit data word 11000100. We include 4 parity bits w/h this word & arrange 12 bits as follows:

Bit position	1	2	3	4	5	6	7	8	9	10	11	12
	P_1	P_2	1	P_4	1	0	0	P_8	0	1	0	0

Each parity bit is calculated as follows:

P_1 = XOR of bits (3, 5, 7, 9, 11) = $1 \oplus 1 \oplus 0 \oplus 0 \oplus 0 = 0$

P_2 = XOR of bits (3, 6, 7, 10, 11) = 0

P_4 = XOR of bits (5, 6, 7, 12) = 1

P_8 = XOR of bits (9, 10, 11, 12) = 1

When 12 bits are read from memory, they are checked again for errors. The parity of word is checked over same groups of bits, including their parity bits.

C_1 = XOR of bits (1, 3, 5, 7, 9, 11)

C_2 = XOR of bits (2, 3, 6, 7, 10, 11)

C_4 = XOR of bits (4, 5, 6, 7, 12)

C_8 = XOR of bits (8, 9, 10, 11, 12)

Since bits were written w/h even parity, the result, $C = C_8 C_4 C_2 C_1 = 0000$ indicates that no error has occurred.

Bit Position	1	2	3	4	5	6	7	8	9	10	11	12
	~~0~~	~~0~~	~~0~~	~~0~~	~~0~~	~~0~~	~~0~~	~~0~~	~~0~~	~~0~~		
No Error	0	0	1	1	1	0	0	1	0	1	0	0
Error in bit 1	1	0	0									

Evaluating the XOR of corresponding bits, we determine the four check bits to be as follows:

	C_8	C_4	C_2	C_1
No error	0	0	0	0
Error in bit 1	0	0	0	1
Error in bit 5	0	1	0	1

The decimal value of C gives the posn of bit in error. The error can be corrected by complementing corresponding bit.

For k check bits & n data bits, total no. of bits, n+k that can be in coded word is at most 2^k-1. In other words, $n+k \leq 2^k-1$ must hold. ~~Bo~~ 2^k-1-k gives the no. of bits for data word.

The basic Hamming code can detect & correct an error in only a single bit. ~~Bone~~ By adding another parity bit to coded word, Hamming code can be used to correct single error & detect double errors. If we include additional parity bit previous 12 coded word becomes $001110010100P_{13}$, where P_{13} is evaluated from XOR of other 12 bits. The following four cases can occur:

If $C=0$ and $P=0$	No error occurred
If $C\neq0$ and $P=1$	A single error occurred that can be corrected
If $C\neq0$ and $P=0$	A double error occurred that is detected but cannot corrected
If $C=0$ & $P=1$	An error occurred in P_{13} bit.

A modified Hamming code, to generate & check parity bit for single error correction & double error detection scheme is most often used in real systems.

⇒ <u>Hamming Distance</u> : No. of differences b/w corresponding bits.

eg $d(000, 011)$ is 2.

The minimum Hamming distance is smallest Hamming distance b/w all possible pairs in set of words.

eg 000, 011, 10~~1~~, 110.

$d_{min} = 2$

* To guarantee detection of upto s errors in all cases, min. Hamming distance in block code must be $d_{min} \geq s+1$

* To guarantee correction of up to t errors in all cases, min. Hamming distance in block code must be $d_{min} \geq 2t+1$.