10/01/2020

Data Communication

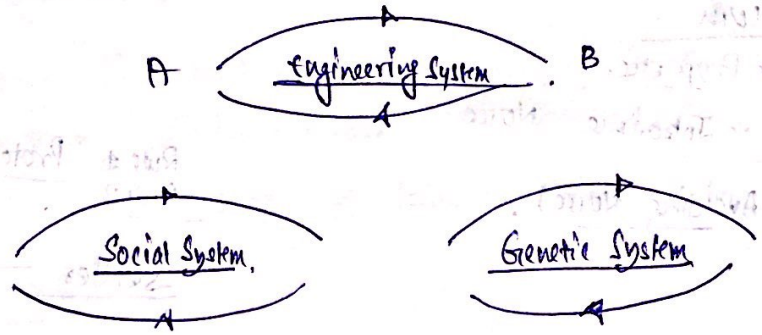
Prof. Sarbani Roy

(1)

Books

Data & Computer Communications, William Stallings, Behrouz A Ferouzan

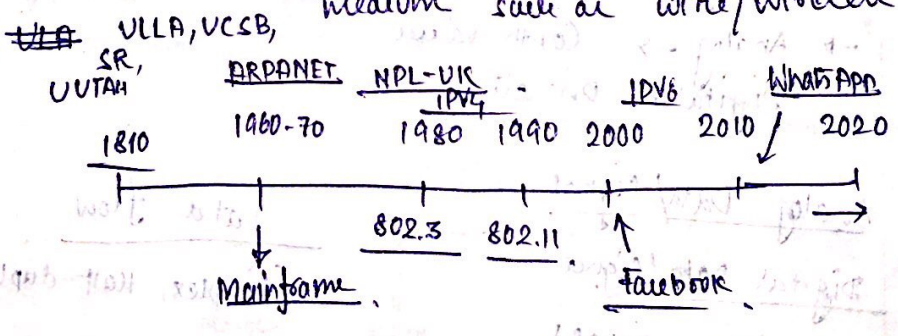
Communication System



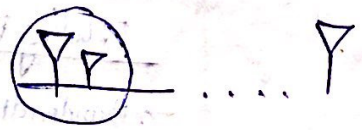
Data Communication

Telecommunication → Communication at a distance.

Data communication → Exchange of data b/w 2 devices via some form of transmission medium such as wire/wireless.



Source. Destination.



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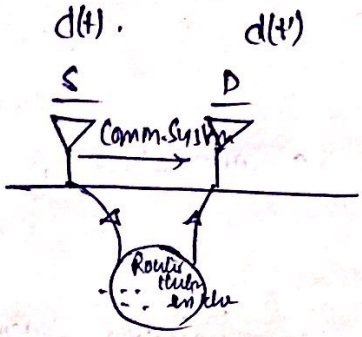

Appln.

Medium
→ Properties.
→ Introduce Noise
(Avoiding Noise).

Rule 1 Protocol
Rule 2.

Protocol Rule 1
Rule 2
...

Sender —— Message → Medium —— Receiver

Source → Transmitter → Comm. system
Destination ← Receiver ←

Signal.
→ fn of data
→ Analog → Contn values
Digital → Discrete.

Analog Data/Signal
Digital Data/Signal
Noise (also a signal)

Data flow
(Simplex, Half-duplex, Full duplex)

Transmission Media.

Deciding Factors.
→ Bandwidth
→ Radiation
→ Noise Absorption
→ Attenuation

Broad Categories

Different types of Cables.

Wired v/s Wireless.

Wireless

$c = f \times \lambda$. Higher f ↑ Higher energy photon.

Electromagnetic Wave.

Radio-frequency

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Data Communication

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Networks

- set of devices connected by communication links.
- node can be a computer/printer or any other device capable of sending/receiving data.

Network Criteria

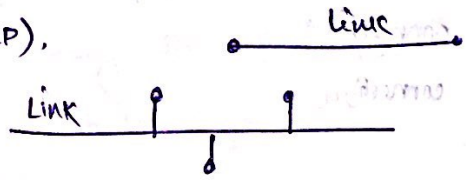
		Minimise	Maximise
Performance	① Depends on Network Element	② Delay	& Throughput
Reliability →	① Failure rate	② Robustness.	
Security →	① Error	② Malicious ~~Errors~~ Users	

Physical Structure

Type of connection

→ Point to point (P2P).

→ Multipoint

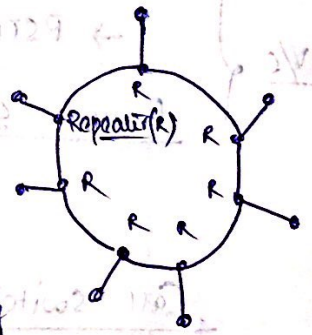


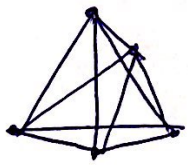
Physical Topology

→ Connection of devices

→ Type of transmission → multicast, unicast, broadcast.

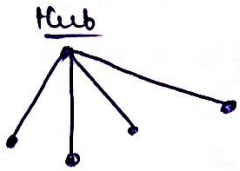
Topology → Mesh, Star, Bus, Ring



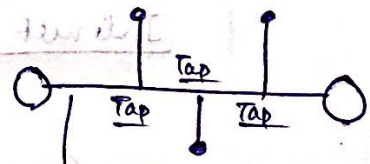


Mesh

Fully connected



Star



Drop Line

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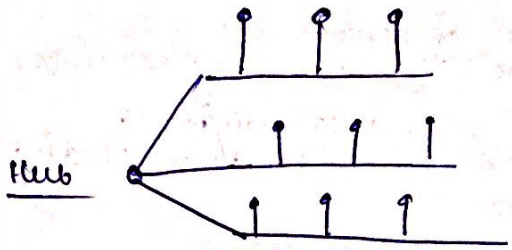
A hybrid topology :- A star backbone with 3 bus network



Categories of Networks

1. LAN (short distance)
2. WAN (Long distance)
3. MAN (Metropolitan Area Network).

WAN Technology

→ Dedicated connection
→ Switched connection

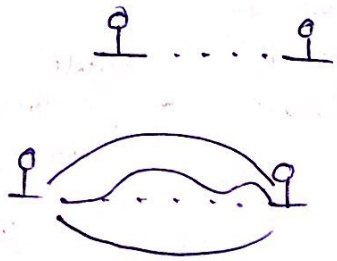
Switched WAN, P2P WAN

Circuit Switching

→ PSTN concept

V/S

Packet Switching



Cell Switching

(Asynchronous transmission media)
ATM.

Internet.

NAP (Network Allocation Protocol).

Protocol.

→ Synonymous with rule.

Elements of Protocol.

Network layer.

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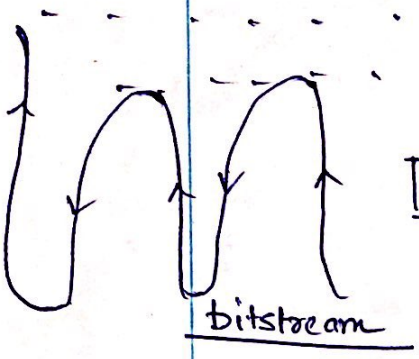

Appln

Session Layer & Synchronization

Transport Layer

Network Layer

Data Link Layer → Logical Link Control, Media Access Control

Physical Layer

01 1

TCP/IP

OSI Model . ISO ~~Model~~

Organization

Interaction b/w layer in the OSI Model.

An exchange using the OSI Model.

Physical & Data Link Layer.

top to top delivery.

Network Layer — Source 2 destination.

Transport Layer

Session, Presentation & Appln Layer.

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Addressing :- Physical Address → Phys L, DLL
Logical Address
Port Address
Specific Address.

Transmission → Phys.
Log.

Spec → google.com

port addr → which process.

Appln → Google Chrome → Multiple Threads.

LA & PA → help data to reach.

* Defn of Layers & address in TCP/IP

* Physical Addresses.
  ↓ Trailer → Redundant bits
  07:01:02:01:2C:4B.

* I.P addresses :- ~~A part of an internet with 2 routers~~

Data Communication

Signals & Signal Analysis

Data → Signals.

Waves
- Mechanical
- EM waves
  ~~Sector~~ Electro-magnetic field
  $\vec{z}$ along $\vec{E} \times \vec{B}$

~~Tran~~ Transmission media
- → Guided (wired)
- → Wireless

Propagation of an EM
~~Ap~~ Amplitude can change but freq. remains same.

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- Analog signals

- Periodic signals < Periodic Fn.

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

freq → rate of change wrt time

sine-wave in time-domain & freq. domain.

- Composite periodic signal.
- Decomposition of a composite periodic signal in time & freq. domains.
- Phase difference due to distortion.

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Data Communication

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Composite Signals & Periodicity

① Periodic signal is decomposed into 5 sine waves with 100, 300, 500, 700 Hz & 900 Hz. What is its bandwidth? Draw the spectrum assuming all components have max. amplitude 10V.

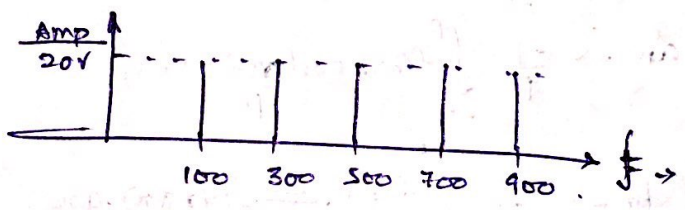
② A periodic signal has a bandwidth of 20 Hz. Avg. frequency 50 Hz. Draw the spectrum.

③ A non-periodic composite signal has a bandwidth of 200 KHz with a middle frequency of 140 KHz & peak amplitude of 20V. The 2 frequencies have an amplitude of 0V. Draw the frequency domain

Solution

① Bandwidth = Highest frequency − Lowest frequency
= 900 − 100
= 800 Hz.

Spectrum



② $H_f - L_f = 20$

$H_f + L_f = 50 \times 2 = 100$

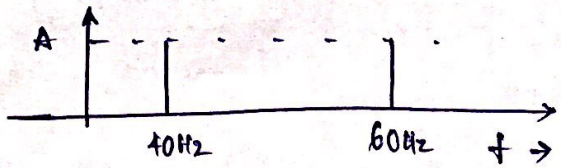
$2H_f = 120$

$\Rightarrow H_f = 60$ Hz

$2L_f = 80$

$\Rightarrow L_f = 40$ Hz

Assuming amplitude = A V,



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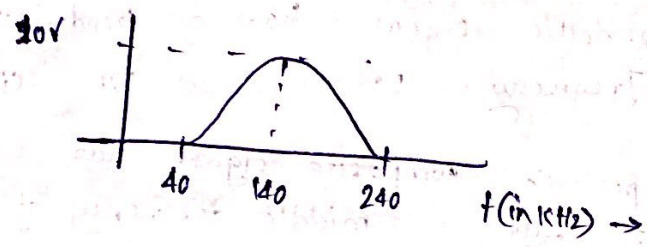
3

max = x min = y.

$$x - y = 200 \text{ KHz}$$

$$\frac{x+y}{2} = 140 \text{ KHz}$$

$$x = 240 \text{ KHz}$$
$$y = 40 \text{ KHz}.$$



Discrete freq. (Periodic)

$$s(t) = A_1 \sin(2\pi f t + W_1) + A_2 \sin(2\pi f t + W_2).$$

$$f(x) = \frac{a_0}{2} + \sum_{n=1}^{\infty} a_n \cos\left(\frac{n\pi x}{p}\right) + \sum_{n=1}^{\infty} b_n \sin\left(\frac{n\pi x}{p}\right).$$

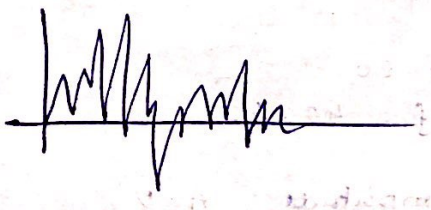
Fourier coefficient

$$a_0 \rightarrow \frac{1}{p}\int_{-p}^{p} f(x).dx.$$

$$a_n \rightarrow \frac{1}{p}\int_{-p}^{p} f(x).\cos\left(\frac{n\pi x}{p}\right).dx.$$

$$b_n \rightarrow \frac{1}{p}\int_{-p}^{p} f(x).\cancel{to}\sin\left(\frac{n\pi x}{p}\right).dx.$$

Non-periodic (Continuous)



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Fourier Analysis

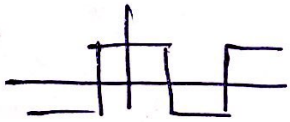
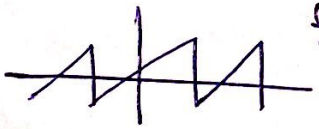
- $f(-x) = f(x)$. (Even fn).
- $f(-x) = -f(x)$. (odd fn).

Even symmetrical, odd, Neither.

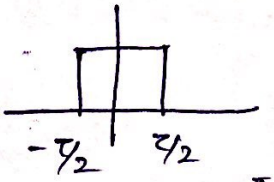
$$\int_{-p}^{p} \underbrace{f(x)}_{\text{odd fn}} \cdot dx = 0$$

$f(x)$ is odd.

$a_0 = 0 = a_n$.

-  Square signal.
-  Sawtooth signal.

Fourier Transform



Period & Scale.

Fourier Tranform $\rightarrow$ $S(f) = \int_{-\infty}^{\infty} s(t) \cdot e^{-j2\pi f t} \cdot dt$

$\rightarrow$ Inverse Fourier Transform $s(t) = \int_{-\infty}^{\infty} S(f) \cdot e^{j2\pi f t} \cdot dt$.

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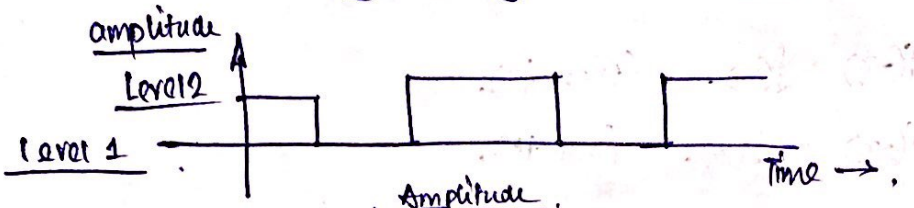
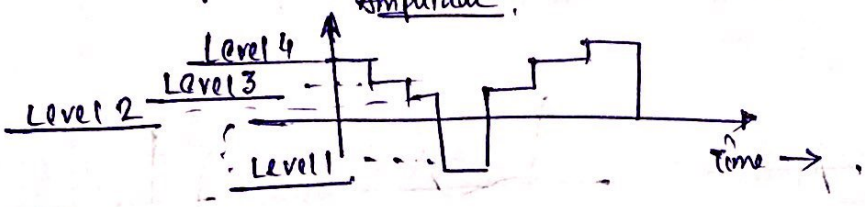
Digital Signal.





Bitrate → Capacity to transfer information.

Bits :- $\log_2(\text{Levels})$

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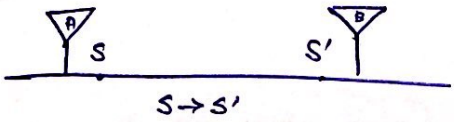
Impairments

→ Signal at the beginning of the medium is not the same as the signal at the end of the medium.

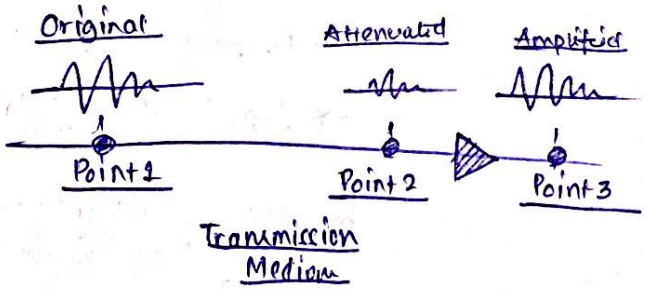
3 causes :-
1. Attenuation
2. Distortion
3. Noise.



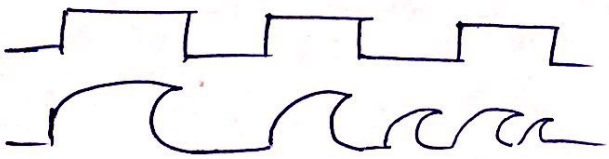
Attenuation : signal strength falls off with distance.

→ Means loss of energy → weaker signal.

Attenuation Distortion



Attenuation of Digital Signals



loss/gain of energy

$$dB = 10 \log_{10}\left(\frac{P_2}{P_1}\right)$$

$P_1 \rightarrow$ input signal

$P_2 \rightarrow$ output signal.

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Distortion

→ Signal changes form/shape.

Delay Distortion

↳ Has an impact on the performance of data communication.

↳ Maximum Bit rate affected

↳ Loss of component (distinguishable)

→ Intersymbol interference may occur.

Noise

→ Another signal clubbed with another signal. (unwanted addn)

Four Categories

1. Thermal
2. Induced
3. Crosstalk
4. Impulse

Signal to Noise Ratio (SNR).

→ Ratio b/w two power.

Performance

→ Bandwidth

→ Throughput

→ Latency (Delay)

→ Bandwidth - Delay Product.

Latency = Propagation Delay + Transmission Delay + Queuing time + Processing time.

Channel Capacity.

$n \rightarrow$ no. of bits

$L \rightarrow$ # of levels.

$L = 2^n$

$$\boxed{C = 2 \times B \times \log_2 L}$$

↳ assumed that channel is noiseless.

Shannon's Theorem

$$\boxed{C = B \log_2 (1 + SNR)}$$

↳ in presence of noise

$B \rightarrow$ Bandwidth.

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Digital Signals.

Analog signal.

Frequency → bit rate per second

Wavelength → bitlength → the channel occupied the bit.

$\log_2 L = b$

L → no. of level. b → no. of bits required per s.

Q. (1) Assume that you need to download, a text document books at the speed of 500 page/min

arg. no. of line of page = 25 (assume)

∴ total no. of line, $500 \times 25 = 12500$.

arg. no of character = 75/line.

total character = 12500×75
$= 937500$.

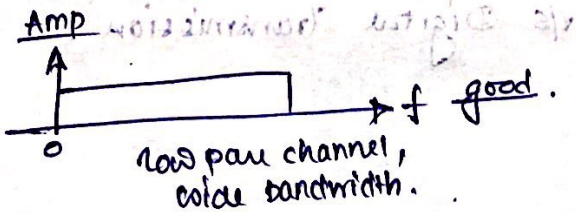
$\frac{937500}{60} = 15625$

∴ $(15625 \times 8) = 125000$ bit.

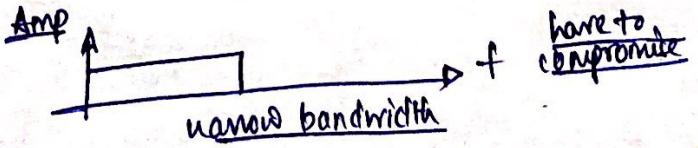
Time & Frequency domains of periodic & non-periodic digital signal.

~~Bank~~ Baseband & Broadband transmission.

Baseband → low pass channel.
It has some bound.



Baseband transmission using a dedicated medium.



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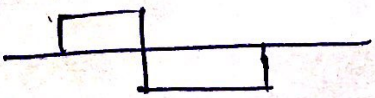
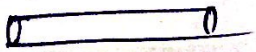
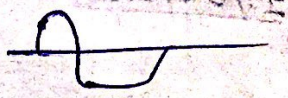


input





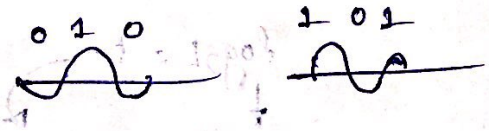
output.

It will not allow multiplexing.

Low pass channel with limited bandwidth.

Rough approximation of digital signal using the first harmonic for worst case.

Worst situation →



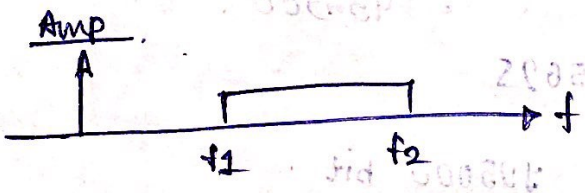
Simulating a digital signal with first three harmonics →

Bandwidth requirements

more harmonic → better signal → high bandwidth
↓
more cost

Broadband transmission
↓
modem

Modulation.



bandpass channel

Modulation of a digital signal for transmission on a bandpass channel.

Modem → Digital cellular telephone.

Analog signal carrying analog & digital data.

Analog v/s Digital Transmission.

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2 A digitized voice channel is made by digitizing a 4 KHz ~~broad~~ bandwidth analog voice signal. We need to sample the signal at 2x the highest frequency 2 sample/s. We assume that each signal requires 8 bits, what is the required bits & how many levels we need? What is the bit rate?

Soln. ~~$x = 4 \times 10^3$ Hz~~ $f = 4 \times 10^3$ Hz

$2 \times 4 \times 8 = 64$ Kbps.

$\log_2 64 = b$

$\Rightarrow \underline{b = 6}$ (Levels).

What is the Bit rate for Full HDTV?

Soln. 1 pixel = 24 bits

Full HD = 1920×1080.

$1920 \times 1080 \times 24 \times 60$

$= 2,98,59,84,000$.

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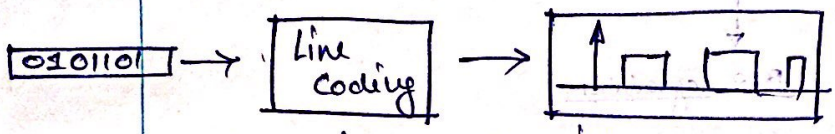
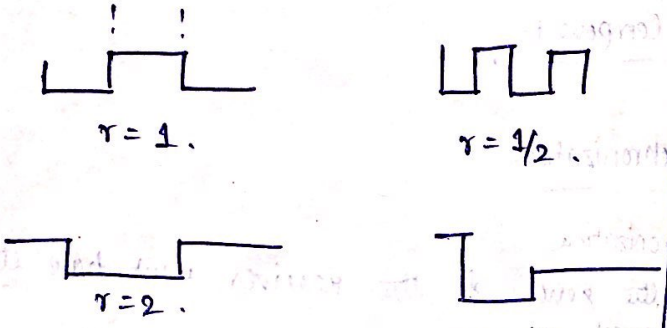
①

Digital Transmission



Converting string 1's and 0's into a sequence of digital signal.

Signal level v/s Data level.



End to End System: Line Decoding & coding

Mapping Data Symbol onto Signal level

$r = \frac{\text{No. of data element}}{\text{No. of signal element}}$

Relationship b/w data rate & signal rate

↓ bps Bitrate

↓ baud modular rate

Data rate & Baud Rate

Baud/Signal Rate.

$S = c \times N \times \frac{1}{r}$ bauds.

N is the data rate

c is the case factor (worst, best, avg).

r is the data element & signal element.

B_{min} & N_{max}.

$r = \log_2 L$.

$B_{min} = \frac{1}{2} \times N \times \frac{1}{r}$.

$\boxed{N_{max} = 2 \times B_{min} \times r}$

Note :- The actual bandwidth of a digital signal is infinite, effective bandwidth is not.

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Issues

→ Baseline Wandering

→ Effects of Baseline Wander.

↓ Jitter

↓ BER degradation.

→ Jitter.

→ Line Encoding :- DC Component

Effect of lack of synchronization

→ Self synchronization

→ Clocks at the sender & the receiver must have the same bit interval.

→ If the receiver clock is fast/slower, it will misinterpret the incoming bit stream.

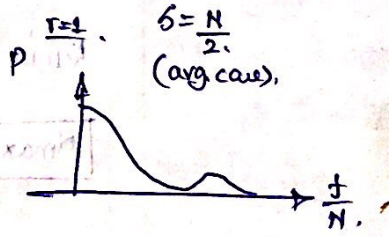
~~Line Code~~.

→ Errors. → They can happen during transmission.

→ ~~Some codes~~

→ Noise & Interference.

→ Complexity



Line Coding Schemes

- Unipolar
- Polar
- Bipolar.

Unipolar → Only one-polarity of voltage level.
→ Bit rate = Data rate
(Non-Return to Zero Scheme).

Polar → One positive & one negative
NRZ, RZ, Manchester, Differential Manchester

↓
① NRZ-L (NRZ-Level)
② NRZ-I (NRZ-Inversion).

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During transmission of spf bit there is no returning to zero in between transmission.

Unipolar.

Polar encoding.

V(1), -V(0).

→ NRZ-L → The level of the voltage determines the value of the bit

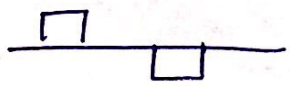
→ NRZ-I → The inversion ~~of or the~~ determines the value of bit.

Spectrum of NRZ-L & NRZ-I.

→ The main limitations are the presence of a dc component & ....

Polar RZ.

→ Each symbol has transmission in the middle.



$r = 1/2$.

$S = C \times N \times \frac{1}{r}$.

→ $r = 1/2$

$C = 1/2$ ∴ $S = N$.

high bandwidth cost.

Advantages & Limitations.

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Polar Biphase

→ Manchester :- consists of NRZ-L & RZ scheme

→ Differential Manchester :- ~~Combination~~

Polar Biphase : Manchester & Diff. Manchester

→ Advantages

→ Limitations

Note. None of them have error-detection.

→ Key Features

Bipolar-AMI & Pseudoternary

→ Advantages & Disadvantages.

Finite freq. spectrum of different encoding techniques.

Summary of Line Coding Schemes

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Capable to Error detection .

Consist 3 steps → division , substitution , combination

m bits replaced by n bit to maintain ~~extra~~ equal chunk , add extra 0 bit

padding → adding missing no. of bits in term of 0.

Block Coding .

& Block Coding Concept .

01001 . . .

↓ mB division .

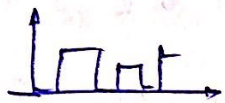
→ 010..1 . . . . 000..1 110..0

m-bits

↓ mB to nB substitution

010..1 0..1 0...1

nbits .

Line Coding . → 

4B/5B in combination with NRZ-1

→ NRZ-1 .

→ One solution is to change the bit stream , prior to encoding with NRZ-I . so that we do not have long stream of zeros .

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4B/5B enc. → NRZ-I enc. → ⊔⊓ → NRZ-I dec. → 4B/5B dec.

Substitution in 4B/5B block coding

4B/5B encoding

4B/5B solving the synchronization issue.

8B/10 encoding.

→ Key Features

Scrambling Techniques.

→ Issues. long sequence of 0s.

→ Bipolar (AMI) encoding can be used.

AMI → Alternate Mark Inversion.

filling sequences.

AMI used with scrambling.

→ Bipolar with 8-zero substitution (B8ZS).
→ High density Bipolar 3-zero. (HDB3).

B8ZS.

0 0 0 0 0 0 0 0

→ 0 0 0 V B 0 V B

HDB3.

→ substitutes 4 consecutive zeros with 000V / B00V depending on the number of non-zero pulses after the last substitution.

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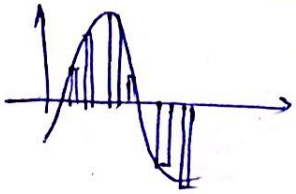
Analog to Digital.

Delta Modulation.

& Pulse Code Modulation.

Analog Signal → [Sampling] → [Quantization] → [Encoding] → Digital Signal.

Sampling. → Ideal
→ Natural
→ Flattop



Sample Rate & Nyquist Theorem

Low pass & Bandpass

Example:- Recovery of a sampled sine wave for different sampling rate

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Analog to Digital Conversion

→ Digital signal is superior than analog.
→ More robust to noise.

Pulse code Modulation (PCM) .

1. Sampling
2. Quantization
3. Binary encoding.

Components of PCM encoder .

Sampling Theorem

→ at least 2x highest signal freq.
→ Pulse Amplitude Modulated (PAM) sampler.

Compline .

→ Ideal
→ Natural
→ Flattop.

Sampling Rate .

Δ Lowpass & Bandpass

Nyquist sampling rate for lowpass & bandpass signals .

Recovery of sampled sine wave for different sampling rates.

Quantization .

A = (max - min) / L → No. of zones .

Quantization & encoding of a sampled signal.

Tradeoff b/w accuracy & bitrate.

Max. Data Rate of a channel

PCM Bandwidth

Quantization Error . Bitrate . PCM Decoder .

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→ Delta Modulation (DM).

DM Modulation Components.

→ Delta PCM (DPCM)

Differential PCM.

28/2/2020.

→ Transmission Mode
→ Asynchronous Transmission
→ Synchronous "
→ Isochronous "

Analog Transmission.

→ Why D-A conv? → If transmission medium → only transmit analog. The medium/channel is band pass, and/or multiple users need to share the medium.

→ DAC.

Modulation & Demodulation
$f_c \gg f_m$

AM concept → modulating or info signal
→ modulated carrier.

AM Basics

→ AM signal ($c(t)$) =
→ mod. signal → $m(t)$ =
→ carrier signal → $c(t)$

- Sidebands & the frequency domain
→ Relationship b/w time & freq.
→ AM.
→ Modn index
→ % of modulation
→ Single sideband modulation → Freq. domain exp. of FM
→ Double sideband suppressed carrier
→ SSB → benefits → WBFM & NBFM.
→ Disadv. → SSB &. → Freq. modulation

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①

A → Application

T → Transport

N → Network

Datalink ← DL → LLC / MAC

P → Physical

concept of data packet → Frame
packet

Network

↓

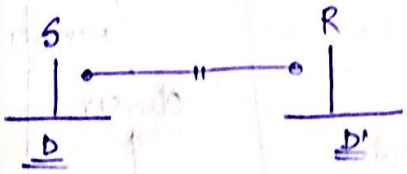
Frame

| H | Data | T |

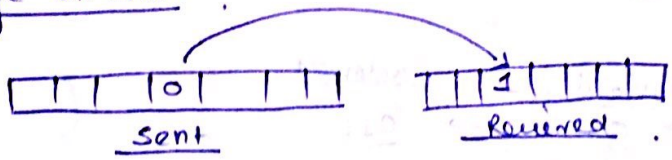
↓

Physical

Datalink also takes care of error detection & correction techniques.



→ Single bit error



→ Burst error

>2 bits in the data unit

Redundancy

Sender

Encoder

Message

↓

Generator

↓

Message & Redundancy

Unreliable transmission →

Receiver

Decoder

Message

Correct / Discard

Checker

↑

Received Info.

Approaches

1. XORing
2. Block coding. (Data words $\longrightarrow$ Code words).

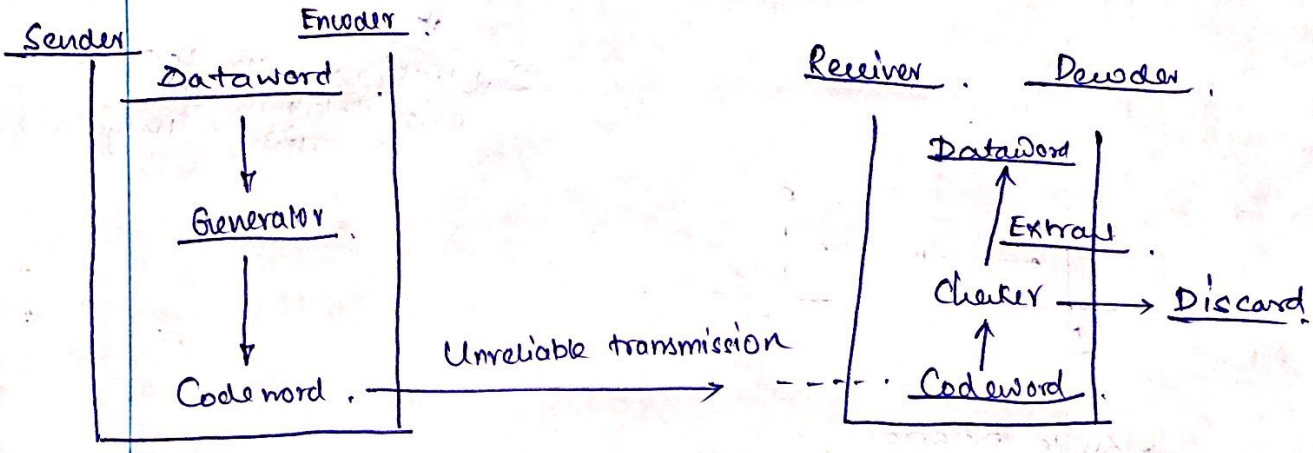
$n = k + r$

2^k Datawords $\longrightarrow$ 2^n Codewords.

2^n Codewords

(only 2^k are valid).

if valid becomes another valid word then error cannot be detected.



Dataword		Codeword
01	$\longrightarrow$	011

011 $\longrightarrow$ ✓

111 $\longrightarrow$ ✗

000 $\longrightarrow$ ✓ (Error)

but still valid code-word.

Redundant bits

$k=2, n=5$.

Dataword	Codeword
00	00 000
01	01 011.

Difference $\rightarrow$

$$\begin{array}{cc} & \begin{bmatrix} 00000 \\ 10101 \\ 00101 \end{bmatrix} \\ 3 & \\ & 2 \end{array}$$

eg.

Hamming Distance

$d(000, 011) = 2$.

(XOR operation)

$000 \oplus 011 = 2$.

Minm hamming distance $= 2$

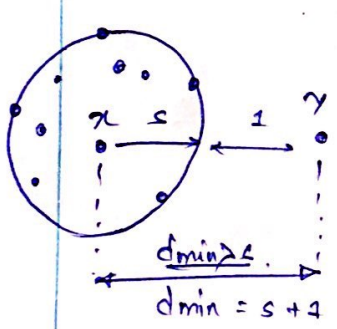
00	000
01	011
10	101
11	110

$d = (\text{Error})_{max} + 1$

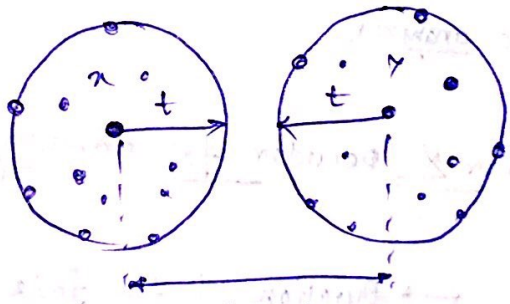
$\Rightarrow d = 2 \Rightarrow \epsilon_{max} + 1 = 2$

$\Rightarrow \boxed{\epsilon_{max} = 1}$

Geometric



Detection.



$d_{min} = 2t + 1$

Correction

$d_{min} \in \{2x + 1\}$ (odd)

Linear Block

Single parity checker

(1 redundant bit) is added.

Encoder & Decoder.

Transmission Scenarios. Datarword 1011. Codeword 10111

① No error occurs. ✓

② a_1. → 10011 ✗

③ r_0 → 10010 ✗

④ r_0 & a_3. → 00110 ✓ (Error) → Wrongly created,

⑤ a_3, a_2 & a_1 → 01011 ✗

$n = 2^r - 1$ $K = n - r$.

2D parity check code.

~~Hamming~~.

C(7,4). $n = 7, K = 4$,

Logic analyzer.

Encoder & Decoder for Hamming.

→ Duration of the fade (first & last).

Burst Error.

→ Burst error detection using Hamming Code.

CRC → Cyclic Redundancy Check.

0001011 → 0010110

Division in CRC encoder.

Divisor → decided by the system (known to both parties)

→ Encoder & Decoder.

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→ Polynomial Checker.

↳ polynomial to represent a binary word,

CRC division using polynomials.

Syndrome $\neq 0$ → One or more bits is corrupted,

$S = 0$ (No bits corrupted / decoder failed).

$$\frac{c(x) + e(x)}{g(x)} = \frac{c(x)}{g(x)} + \frac{e(x)}{g(x)}.$$

Standard polynomials.

CRC,

→ Checksum

↓ (negative sum of all data bits

Example.

Soln: Re-transmission.

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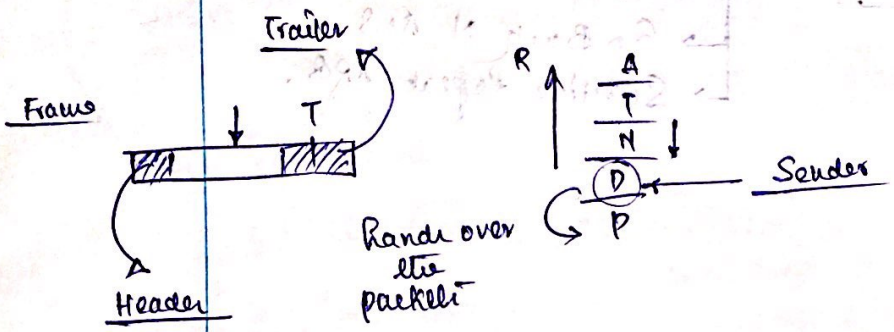
(1)

Framing

→ Data Link Layer ⟶ Frames

↓

Makes it distinguishable from one another.



Frame

① Character oriented protocol
② Bit oriented protocol

* Data from upper layer

Flag	Header		Trailer	Flag

Byte stuffing ⟷ unstuffing

Adding 1 extra byte for flag & escape (Esc)

⇓

gets removed @ the receiver end

Bit oriented protocol

Added 0 (whenever 5 1s, follow a 0)

Flow & Error Control → Retransmission of packets

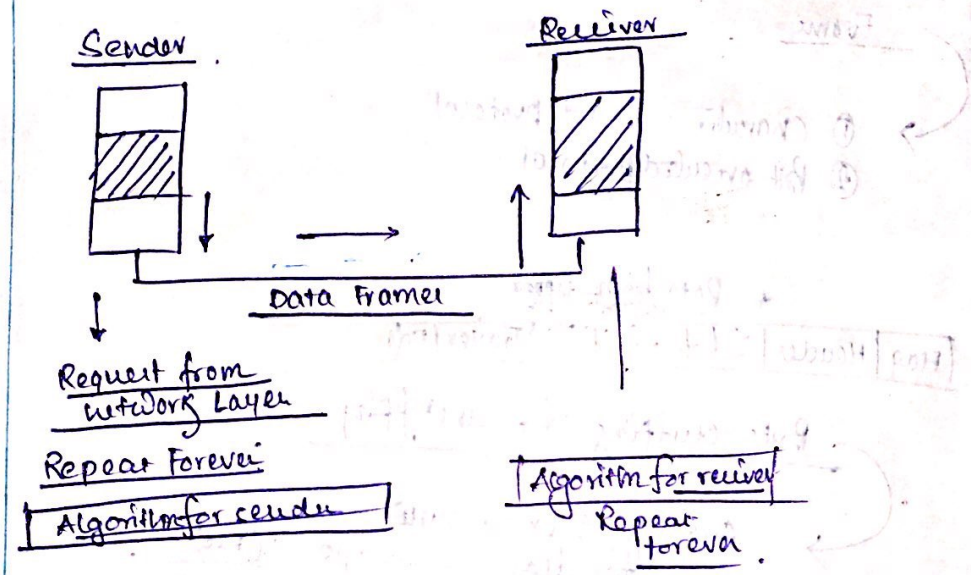
⇓

Restrict the amt. of data before waiting for acknowledgement

Taxonomy of protocols

Protocols

- For noiseless channel
  - Simplex
  - Stop & Wait
- For noisy channel
  - Stop & Wait ARQ
  - Go Back N ARQ
  - Selective Repeat ARQ.



Design of Stop & Wait protocol

Use of ← ACK frame
Acknowledgement

Use of time out.

ARQ protocol → seqno.

Go-Back-N.

→ 2^m sequence number

→ sliding Window.

→ sent sequentially.

Receive Window - sent one by one

→ Window size can cause issue

0 2 3 0 can cause issue

Algorithm.

Selective Repeat ARQ

→ keeping ~~the~~ track of frame already received.

Window size > 2m-1

→ Piggyback

→ HDLC.

→ PPP.

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