3rd Jan, 2024

Computer Networks

Textbook: Computer Networks by Tanenbaum.

Midterm, Final (40/60) ⟶ No attendance

Class Hours.

Monday	10-11
Wednes	8-10

Thurs 10-11.

Century of information processing.

Communication → Broadcast.
Communication → Point to point.

→ To contact particular device in network, we need IP address.

→ For communication, we need channel.

OSI Layers ⟶ Tomorrow.

Page rank algorithm?

Math

→ Eigenvalues, characteristic matrix.

→ Probability.

4th Jan, 2023

Internet

Laptop

Desktop

Phones

Tablets

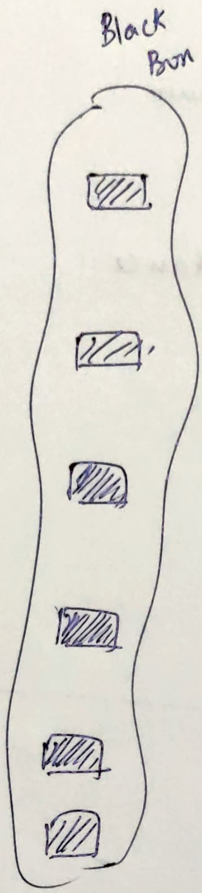
Smartwatches

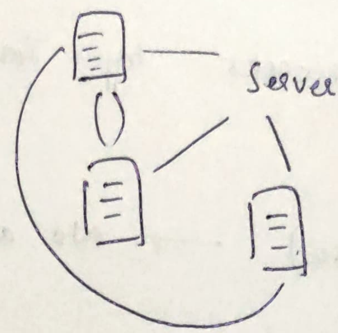
Printers

Speaker

Matress

Cars





Internet network of networks.

Why?

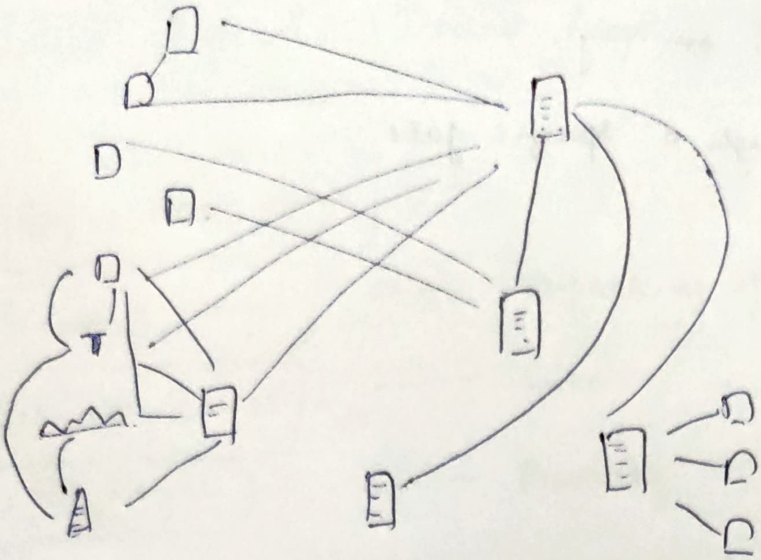
We want network to be something that follows particular rules of communication (Protocols).

Rules governing a network.

↑

Protocol.

Internet is governed by several protocols. (http being one of them)



Internet

Computer Network
(graph)

A network whose nodes are computing devices (computers, computerised cars, printers, phones, ...) & a link b/w two nodes indicates possibility of communication.

Airline Communication

1. Ticket of a flight from A1 to A2.
2. Luggage
   - No luggage → Security
   - Person + Carry on
   - Person + Check in
   - Person + carry on + Check in

P

L gets tag

Luggage store

Breaking info as 2 types of data can't be together.

3. Go to the particular gate
4. Airplane on a fixed runway.
5. Airplane routing.

Runway 24

6. Landing on a specific runway.

7. Exit from plane through a specific gate.

8. Luggage

9. Ticket enquiring.

Same steps in a different way.

1. Entry pass.
2. Luggage.
3. Gate Management
4. Runway.
5. Routing – Routing – Routing.
   5½ 6.
7. Runway.
8. Gate.
9. Luggage.
10. Exit assurance

10. Exit assurance.
9. Luggaae.
8. Gate
7. Runw ay

5 Layer Protocol (Internet Layering Protocol)

enter

Application Layer —

Transport Layer — Unpacking of message

page 68

Network Layer — Gate

Link Layer — Runway

Physical Layer

OSI Layers

Open systems interconnection

Application

Presentation

Session

2 extra layers

Transport

Network

Link

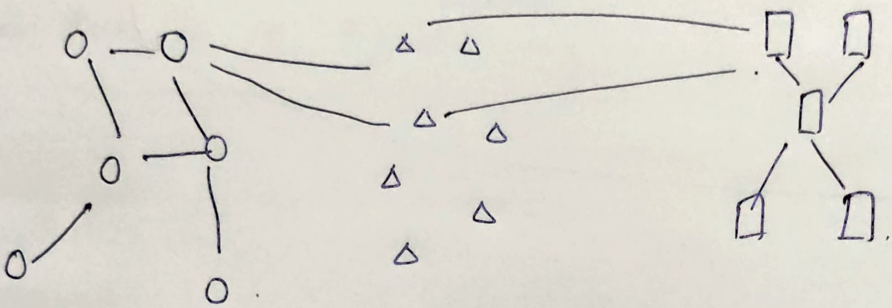
Physical

8th Jan, 2023

How does Google work?

Google Servers → has links to other webpages / servers.

Internet



Users / Clients.

Electronic devices/routers. (decides which message goes which path)

Servers.

Internet has several networks each having it's own protocols

Basic of network → electronic transmissions. (electromagnetic transmissions in case of wired / wireless transmission)

Networks started from radio (transmitter sends at certain freq, receiver tunes to that frequency to listen) → was also used for secure communication.

Internet Layering Protocol

Application
Transport
Network
Link
Physical

Application → Entry / Exit.
Transport. → Luggage
Network. → Gate.
Link. → Runway.
→ Routing
Physical.

Datagram?

Travelling Salesman Problem?

OSI Model (Open Systems Interconnection)

Application → Presentation (Data compression / data encryption)
→ Session (Data delimitation / security).
Transport.
Network.
Link.
Physical.

Presentation → Baggage management.
Session → Removal of banned objects

*. Internet doesn't have these 2 layers

Sort of combined with application or transport

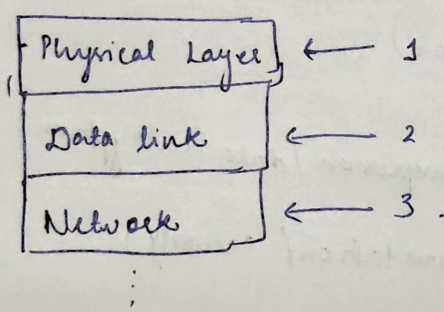
10th Jan, 2024

So till now we saw top to bottom approach of layers. Now we will discuss bottom to top approach.

We will discuss → Physical.
→ Data link
→ Network.

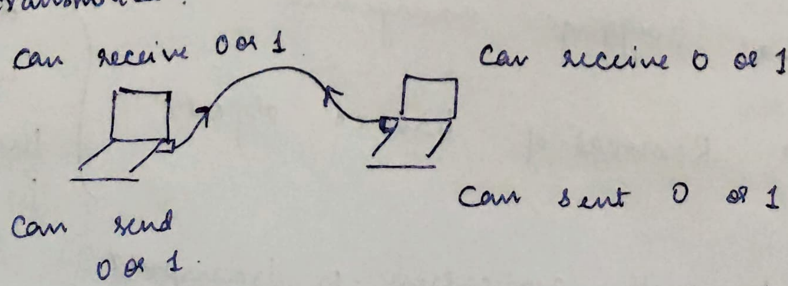
Each computer has an address unique to it → MAC Address

Bottom - Up View



Which layer is MAC address attached to? Data Link Layer

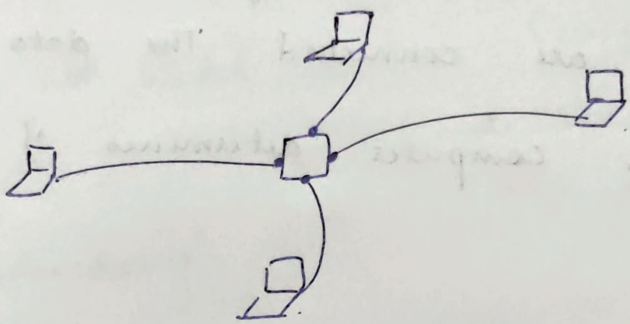
Physical Layer: Through this, raw data. (seq. of 0's and 1's) gets transmitted.



You and your brother are in same room, want to play a game against each other in your own systems. How?

→ Wire.

- Physical Layer has no media management.
- If both simultaneously send signals then they will collide.



Physical layer only detects connectivity (graph theorically connects). So basically sends message to any device connected. (will it just broadcast?)

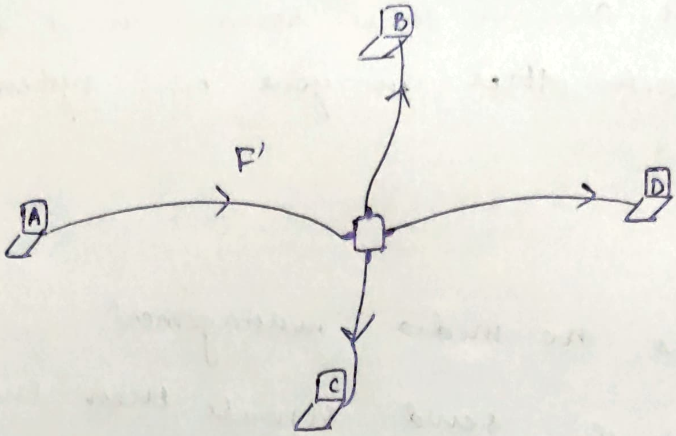
- If 2 computers simultaneously send signals there will be collision.

<u>Data Link Layer</u>

Mac Address: Unique manufacturing given code to every device.

$\underbrace{32e : ffc : 7xxf7 : \dots\dots}_{\text{Depend on manufacturer}} : \boxed{75}$ → One system

Datalink layer (DLL)



DLL check the sender, reciver & payload (data), sends to all systems that are connected. The data link layer of all the reciver computer determines if it's meant for it.

- Data link layer creates Frames.

Source MAC Address	Dest. MAC Address	...	Payload
A	C		

F

F ⟶ F' (has 0s and 1s)

- A sends F'. B, C, D all get F'.
- All push it to their DLL.
- DLL decide whether the message is meant for them or not. If yes, it reads, otherwise it junks.
- So only C reads the message.
- Collisions ?

Circuit Switching & Packet Switching

CS: A fixed communication channel is created between the two & that is used for continuous interaction

Advantages:

1. Consistency.
2. Routing not needed.
3. Faster.
4. Less redundancy.
5. More secure.

Disadvantages

1. Large no. of connections (complexity).
2. Adding a new user two way communication is tough.

P.S: Data is broken into small parts. potentially broadcasted.

If we pick up 2 points between 0 & 1, the probability they will be same is 0. So if the packets are very small, collisions can be minimized.

*Find MAC Address of your laptop and figure out what it means

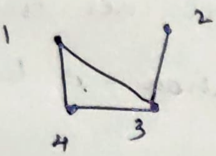
What is IP address? Network Layer.

Will discuss in next class

Basic Graph Theory

Graphs: Graphs are pairs $G = (V, E)$ where V is a set & E is a set of sized 2 subsets of V

$$G = (\underbrace{\{1,2,3,4\}}_{V}, \underbrace{\{\{1,3\}, \{2,3\}, \{1,4\}, \{3,4\}\}}_{E})$$

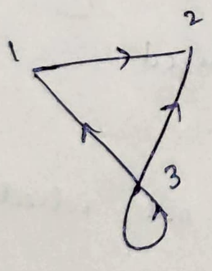


V : Nodes / Vertices

E : Links / Edges.

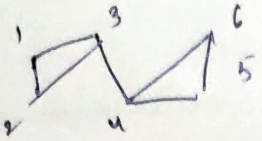
In other words, graphs are collection of nodes and edges.

A graph is directed if every edge has a source & a target (every edge is an arrow).

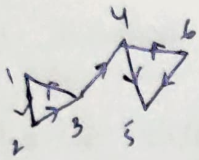


In a graph if a vertex is connected to itself by an edge then that edge is called a loop.

A path in a graph is a sequence of edges $e_1 \dots e_k$ such that $\forall i$ $e_i = xy$ $e_{i+1} = yz$ for some $x, y, z \in V$



$13, 34, 45, 56$ is a path from 1 to 6. If a graph is directed. then a **directed path** is a seq of edges $e_1 \dots e_n$ such that $\forall i$, $e_i = \overrightarrow{xy}$ $e_{i+1} = \overrightarrow{yz}$ $x, y, z \in V$

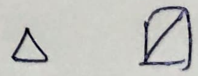


$\overrightarrow{12}, \overrightarrow{23}, \overrightarrow{34}, \overrightarrow{45}$ is a directed path from 1 to 5.

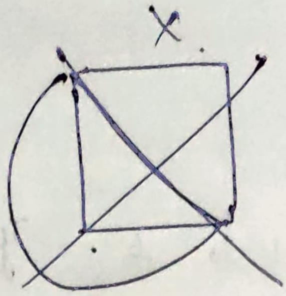
A **cycle** is a graph is a sequence of edges $e_1 \dots e_n$ such that $e_i = xy$ & $e_n = wx$ for some $x, y, w \in V$

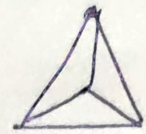
In graph ⊞ $12, 23, 31$ is a 3-cycle & $13, 34, 42, 21$ is a 5-cycle.

A graph is **connected** if for any $x, y, \in V$. $\exists$ a path from x to y.

A graph is **planar** if it can be drawn on a plane without vertices crossing each other 

A graph is **complete** if any 2 vertices are connected by an edge.





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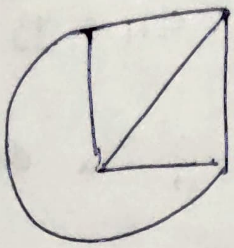


Complete graph on 4 vertices is plannar.

Complete on n vertices is K_n.

Q. What about K_5? Is it planar?

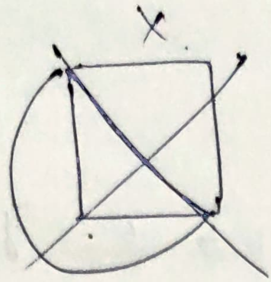
→ Putting 5 points on plane and connecting each pair.

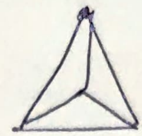
(TRY!!).

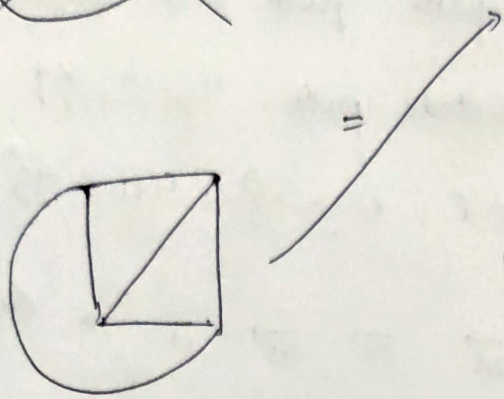
Let's take triangle.

Check by keeping other 2 points in the diff regions. All combinations should be tried.

We can not get K_5.







Complete graph on 4 vertices is plannar

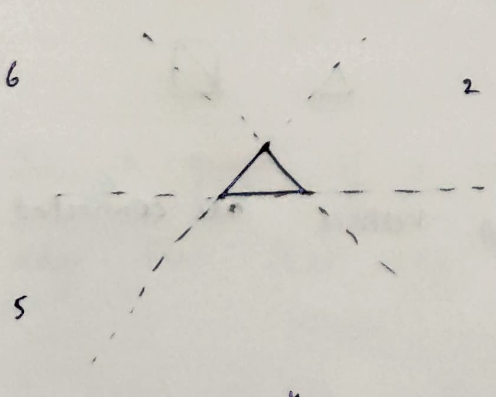
Complete on n vertices is K_n.

Q. What about $\underline{K_5}$? Is it planar?

→ Putting 5 points on plane and connecti-ng each pair.

 X

Let's take triangle



(TRY!!)

Check by keeping other 2 points in the diff regions. All combinations should be tried.

We can not get K_5.

15th Jan 2024

Communication in Shared Medium.

Assume, transmissions are heard over limited distance.

CSMA ?

Carrier Sense Multiple Access Protocols

① Let transmissions are heard over a distance of 50. A node at location 170 is transmitting for node at location 200. Node at location 240 starts transmission.

This is called Hidden Station Problem - I.

The idea "I will transmit when no one else will" fails.

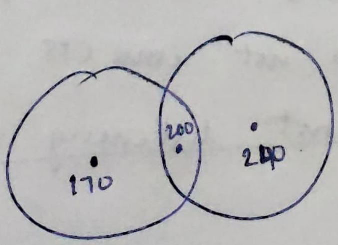
~~that~~ here 200 listens to both 170 & 240. But they cannot hear each other.

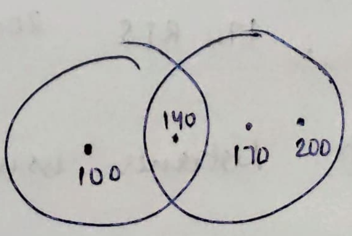
② A node at location 170 is transmitting for node at location 200. Node at location 100 starts transmission for node at location 140.

This is called Hidden Station Problem - II.

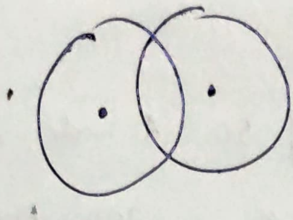
HSP 2

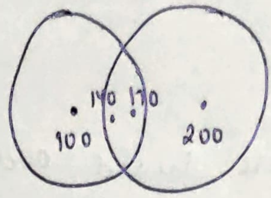
HSP 1



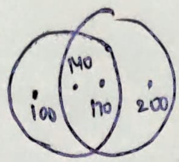


③ A node at location 170 is transmitting for node at location 200. A node at location 140 wants to transmit for node at 100.
(but does not)

 X



X wrong diagram



This is called. <u>Exposed Station Problem</u>.

<u>Solutions</u>: When node wants to transmit, it issues RTS. Listener issues CTS.

RTS : Request to Send.
CTS : Clear to Sent.

170 issues RTS. 200 issues CTS. 240 gets CTS, will not issue RTS.

Solution ①: 170 RTS 200 CTS 240 heard CTS hence no RTS

Solution ②: 170 RTS. 200 CTS 100 RTS. 140 listening 170 hence does not issue CTS.

Solution ③: Listener issues CTS <u>if not listening any.</u> ~~transmission~~.

170 RTS 200 CTS.	140 RTS. CTS of 200 not listened.	100 CTS. transmission of 170 doesn't reach 100

17th Jan, 2024

Books

1. Computer Networks - Andrew Tanenbaum.
2. Data Communication & Networking - Behrouz Forouzan

MSP, ESP $\longrightarrow$ belong to data link layer.

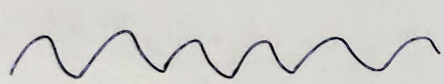
Encapsulating Security Payload

Physical Layer Basics

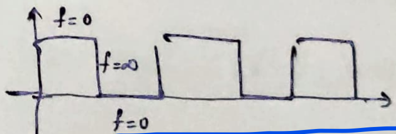
Sending signals.

Signals — Digital. (Discrete)
— Analog. (Continuous)

Analog



Digital



frequency changes between 0 and ∞

For signals we have.

→ Frequency.
→ Amplitude.
→ Phase. (Check def)
→ Wavelength.

$\text{Freq.} \propto \frac{1}{\text{Wavelength}}$

Bandwidth (of communication channel)

Range of frequencies that can go through that channel

* Bandwidth can be theoritically ∞ in optical fibre.

Types of Communication

1. Wired
2. Tereshial Wireless.
3. Satelite.

1. Wired } Classical Telephones.

Cu wire

Optic Fibre

2. Tereshial Wireless } Cellphones

3. Satelite } Satelite phone, Cable TVs.

Point to point

Broadcasting.

What is best form of communication?

Carrying information in hard disks (which has memory in terabytes) and taking a load of them to the location we need manually beats internet avg speed.

which is in Kbytes/sec

avg. speed of manual harddisk transport > avg. internet speed.

Still we prefer internet as it allows instaneous communication

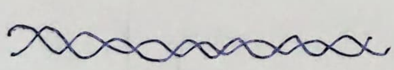
Point to Point.

1. Magnetic Media.

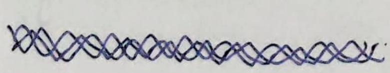
Hard disk
USB.
CD.
FLOPPY

On avg. perform best.

2. Twisted Pair Wires.

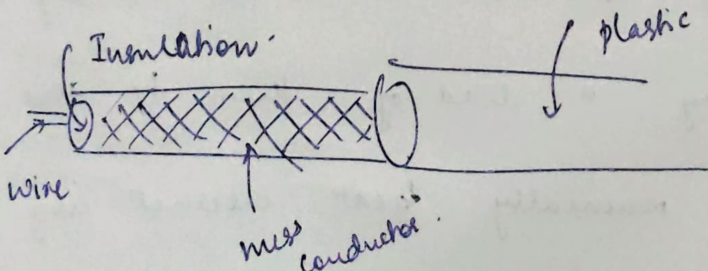


Category 3.



Category 5. more twists, higher bandwith and speed

3. Coaxial Cable.



4. Fibre optics

Processing Power : 4.8 MHz $\xrightarrow[\text{20 years}]{}$ 2 GHz

40 times

So increased 20 times for a decade.

Communication Rate : 56 Kbps $\xrightarrow[\text{20 years}]{}$ 1 Gbps

125 times / decade.

Communication tech was improving much more than processing power.

Fibre optics :

① More bandwidth.

② Must faster to build / install

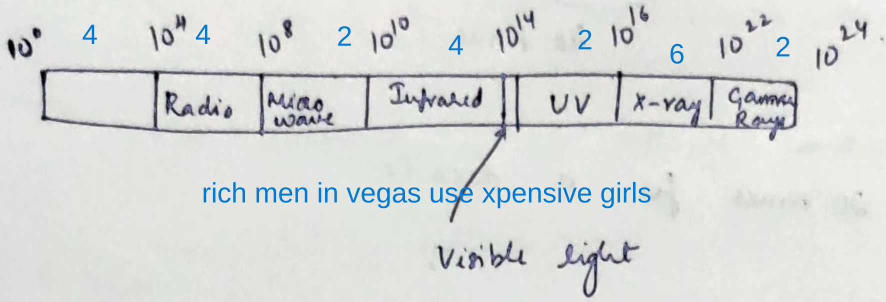
③ Works for longer range.

disadvantage.

① Needs more care.

Wireless Transmission

f (Hz).



Electromagnetic Spectrum

It consists of everything except sound (which isn't electromagnetic waves).

Radio: Used by radio.

① Small freq / High wavelength.

② Penetrates solids.

③ Travel longer.

$$\underbrace{\text{Radio} < \text{Microwave}}_{\text{danger}}$$

Microwave: Mobile phones, TV.

① All properties of radio hold.

Infrared: TV remotes

① Cannot penetrate solid.

Visible Light : Traffic lights

→ Networking using LAN (rare)

→ Easy to block.

Satelite Communication

1. Geostationary.

→ Farthest from the Earth.

→ Appears to stay fixed.

2. Medium Earth Orbiting Satelite.

→ Medium Height.

→ Moves slowly.

3. Low earth orbit.

→ Satelite (very close to earth).

2 Imp. Technologies to learn about Physical Layer.

1. Multiplexing

2. Switching.

A wave looks like,

$$g(t) = \frac{c}{2} + \sum_{n=0}^{\infty} a_n \sin(2\pi n f t) + \sum_{n=0}^{\infty} b_n \cos(2\pi n f t)$$

Question: If $g(t)$ is given then how do you find a_n, b_n & c ?

$$\int_0^T \sin(2\pi n f t) \cos(2\pi k f t)\, dt = 0 \quad \forall\, n, k$$

$$\int_0^T \sin(2\pi n f t) \sin(2\pi k f t)\, dt = \begin{cases} T/2 & n = k \\ 0 & \end{cases}$$

$$a_n = \frac{2}{T} \int_0^T g(t) \sin(2\pi n f t)\, dt$$

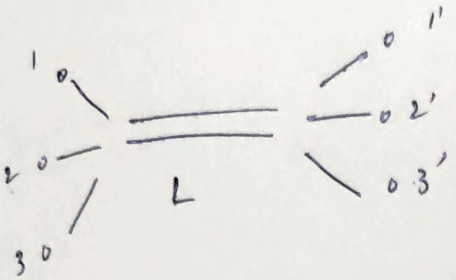
$$b_n = \frac{2}{T} \int_0^T g(t) \cos(2\pi n f t)\, dt$$

$$c = \frac{2}{T} \int_0^T g(t)\, dt$$

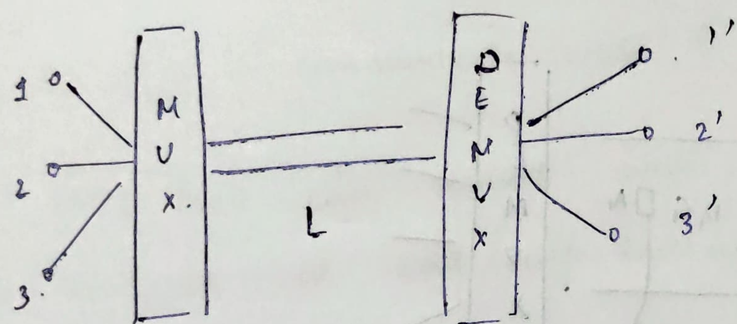
All wave extractions happens as following.

Communication through same link gives rise to multiplexing

Multiplexing



1, 2, 3 want to send a message to 1' 2' 3' simultaneously through L.



One way to do it, especially useful in analog is

Frequency Division Multiplexing.

- Each user is assigned seperate bandwidth
- Some space is kept between the bandwidths.

Note: There is a variant of this called Wavelength Division Multiplexing used for fibre optics mostly.

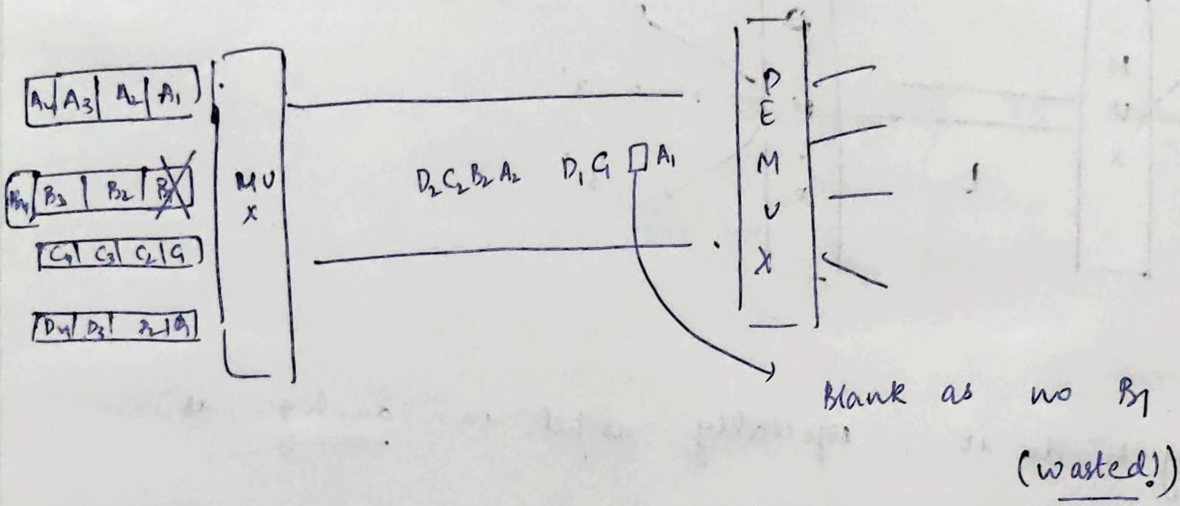
FDMA is bad for digital so

Time Division Multiplexing

→ Useful for digital.

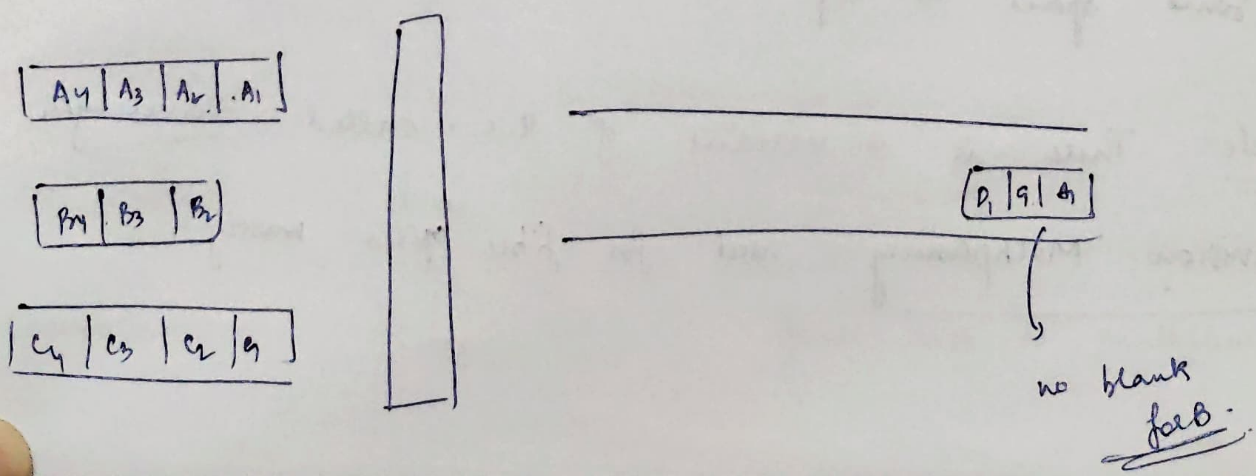
→ 2 types — Synchronous TDM.
  — Statistical TDM.

Sync TDM



Order of sending = Order of receiving.

Stat TDM



Saves slots but messages need address

24th Jan 2024

Switching.

Any communication channel has a limit (physically feasible)

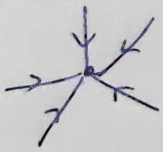
N points.

If A wants to communicate with B.

→ Every point can connect with every other point. But this increases cost and infrastructure. Giving bandwidth to everyone isn't possible.

Complete Graph also called. Mesh topology.

Star Topology.



Every node communicates via central node.

Circuit Switching

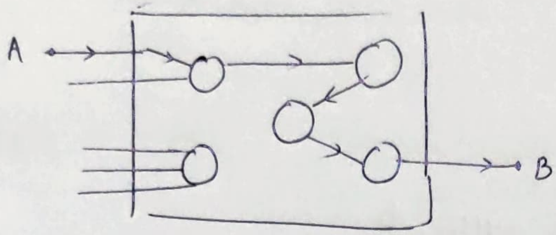
When fixed communication channel is created btw. (two) users before communication.

Stages of Circuit Switching

① Establishment of communication line

② Private Communication make communication

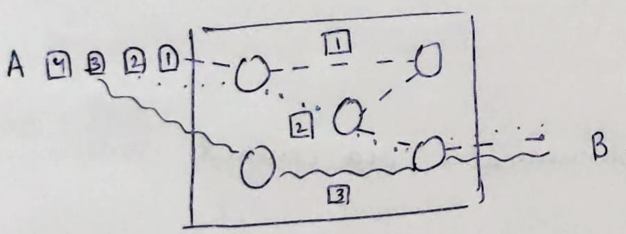
③ Ending the communication channel



Communication only starts only after the channel is created.

→ Bandwidth wasted but better from user perspective. Traditional telephones used this

Packet Switching:



Every packet chooses best path.

→ Data is broken into packets & packets are sent one by one

→ No fixed communication channel is created between users and packets are free to pick any available route.

→ This involves delay for queuing and reassembling

→ Needless to say, packets need destination address

*

Payload	Dest address

PACKET

* Routing Table helps choosing path for each packet.

Physical Layer of Communication

① Point to Point Wired. → Wired Telephone

② Terrestrial Wireless → Mobile Phone

③ Satellite → Cable TV

Mobile Phone.

Characteristics.

1G. → Analog voice.

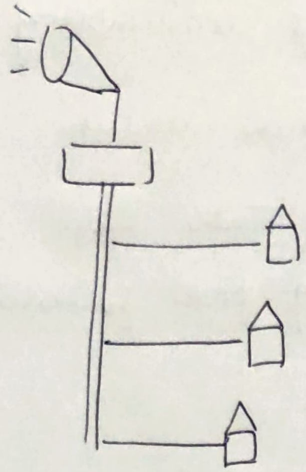
2G → Code Division Multiplexing, Digital Voice

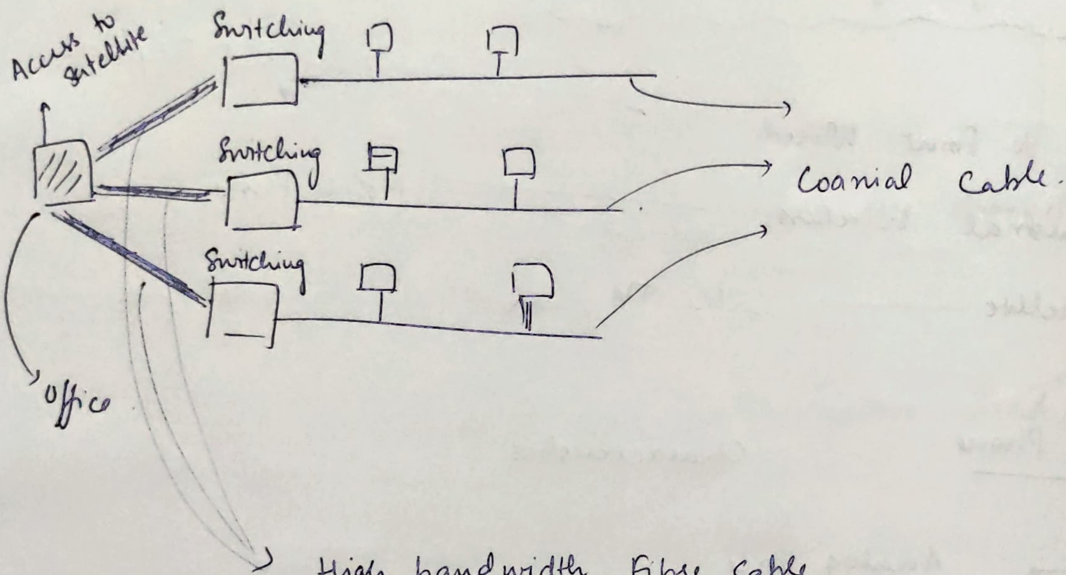
3G → Voice + Media Digital.

4G → ?

5G →

Cable TV





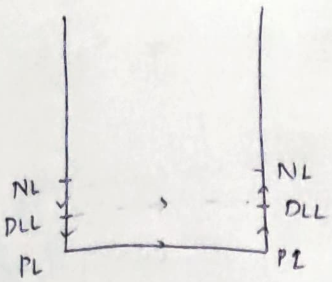
In circuit switching → cost depends on distance.

In packet switching → cost depends on amount of information

because in circuit switching, channel management is imp.

in packet switching, packet management is important.

Data Link Layer

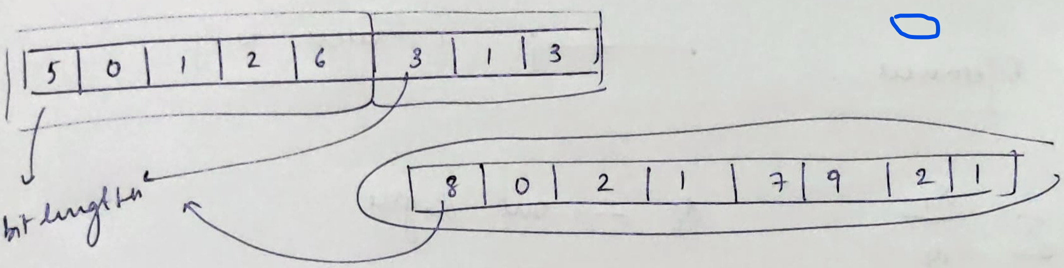


Network layer thinks DLL gets info from it and sends to DLL of receiver (it doesn't see the involvement of PL)

Physical Layer (PL) $\quad \boxed{}$ Packet.

Data link Layer (DLL) $\quad$ | H | PL | T | frames.

header payload trailer



| 5 0 1 2 6 | 3 1 3 | 8 0 2 1 7 9 2 1 |

But errors occurs if 3 changes to 6

| 5 0 1 2 6 | 6 1 3 8 0 2 | 1 | 7 9 2 1 ... error identified.

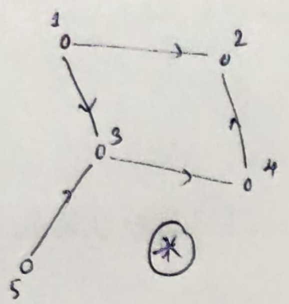
entire process ruined.

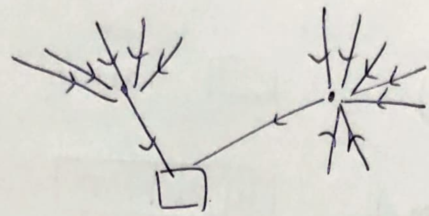
DLL will help us manage these things.

Google Search

How does google rank various website ?? (How are Page ranks given?)

given by Larry Page





No of referances.

$\longrightarrow j$ i refers to j.

$$r_j = \sum_{i \to j} \frac{r_i}{d_i}$$

$d_i \longrightarrow$ out degree

(no. of stems going out)

for *

$$\boxed{\begin{aligned} r_1 &= 0 \\ r_2 &= \frac{r_1}{2} + r_4 \\ r_3 &= \frac{r_1}{2} + r_5 \\ r_4 &= r_3 \\ r_5 &= 0 \end{aligned}}$$

1, 4 coming to 4

1 has 2 routes going out

4, 5, 3 have only 1 route going out.

solve these equations to get rank of each node

PROBLEM

→ These equations may not even have a solution

Many websites exist so number of variables very high

Storing such large matrix ⟶ computations are high.

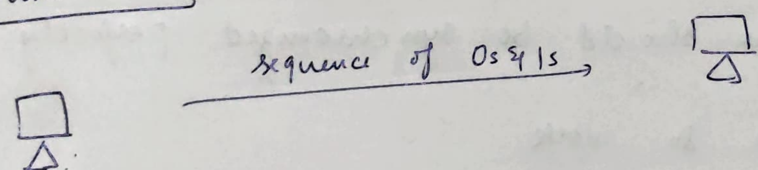
Search π such that $\boxed{P\pi = \pi}$ eigen values.

$$r_j = \frac{r_i}{d_j} + \frac{r_i'}{d_i'} + \frac{r_i''}{d''} \qquad \underset{n \times n}{\overset{P}{\begin{pmatrix} \frac{1}{d_i} & \frac{1}{d_i'} & \frac{1}{d_i''} \end{pmatrix}}}$$

?

this can be done without storing P

29th Jan, 2024.



Data Link Layer.

Digital Signal? Both sender and receiver has a clock. Receiver periodically measures the signal and analyses the pattern of increase and decrease and analyses which is 0 and which is one

Modulation

Data ⟶ Signal

Demodulation

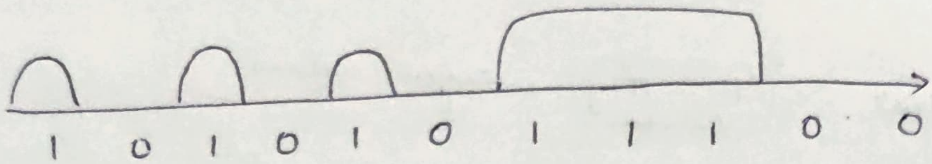
Signal ⟶ Data.

Modulation is done by varying nature of signals over a proper time intervals

Return to Zero (RZ)

Data

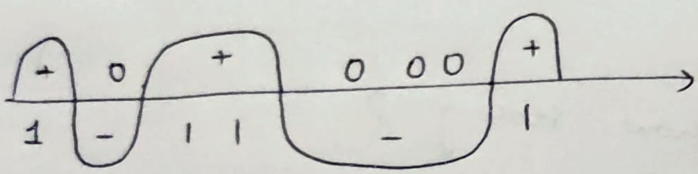
1 0 1 0 1 0 1 1 1 0 0.



Non return to Zero (NRZ)

Data

1 0 1 1 0 0 0 1



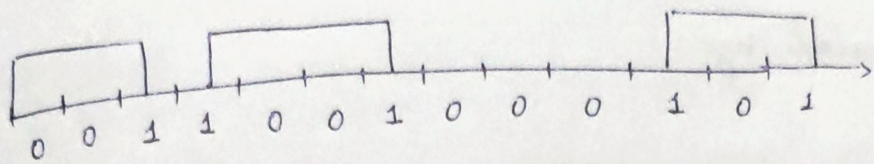
→ Clocks on both sides should be synchronized perfectly for these coding methologies to work.

↓

Problem

- Sequence of 0s or sequence of 1s can be hard to detect (Variations are easy to detect and help in synchronization of clock)
- Exact 0 is hard to get

Non - return to Zero Inverted (NRZI)

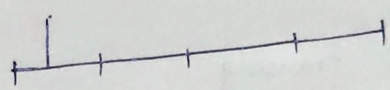


variation everytime 1 comes, otherwise stays the same

Solves the sequence of 1 problem

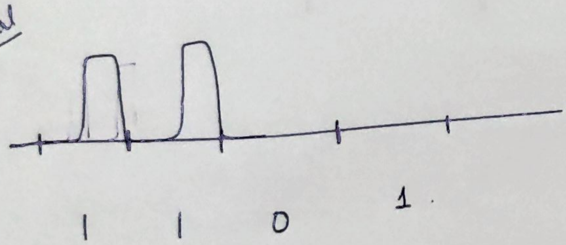
Sequence of 0s problem remains.

Manchester Coding

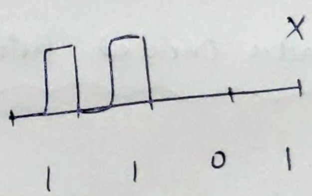


1 1 0 1

Trial



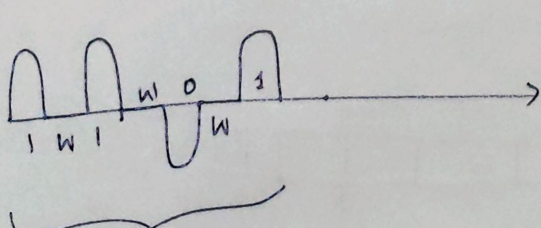
X



Homework.

Find a scheme that addresses both the weaknesses

W → wait.



half the time slots lost

Framing

Fixed Size

Variable size.

Flag	Header	Payload	Flag

Header → 1) Destination

2) Protocol

3) Error Detection Code

Variable Sized Framing

Character Oriented Protocol ⟶ Byte Setup

Character ⇝ ASCII Code

F	11	......	F.

Use ESC character to denote beginning of a text used in the flag in the original body

Text ⟶ Text contains Flag

	F			ESC	

↓

Frame sent

F	H		ESC	F			Esc	Esc			F

ERROR

- → Single Bit Error
- → Burst Error.

Single bit errors are rare. Why?

Errors mostly occur in higher layers and not physical layer

01101001 ⟶ 01$\boxed{0}$01001

Sent Received.

Wrong.

Single bit error.

01101001 ⟶ 010001101

Wrong.

Burst Error.

Data link layer has the following purposes ⟶ 1) Framing
2) Error Correction/ Detection

Suppose data is being sent at 1Mbps ⟶ 10^6 bits per second
↳ very slow.

So if any physical variation that causes error occurs, it's very unlikely that it happens to only 1 bit thus error can occur for more than 1 4 sec.

- Error detection
- Error correction

Forward Error Correction

(Receiver tries to guess the correct message)

↓

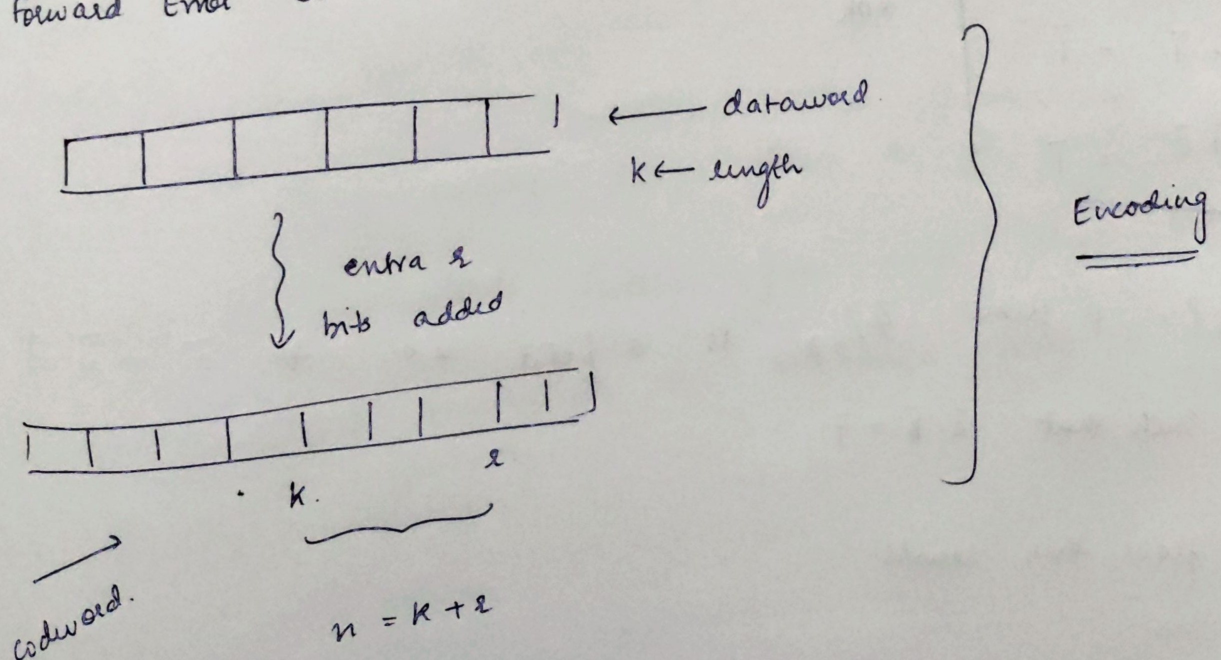
Unpredictable but fast

Retransmission (Send back)

↓

More accurate.

Only if error is less, few bits only affected, only then is Forward Error Correction used.



Remainder classes when number divided by n

$$\mathbb{Z}/_{n\mathbb{Z}} = \{ \bar{0}, \bar{1}, \quad , \overline{n-1} \}$$

$$\left\{ \begin{array}{l} \bar{a} + \bar{b} = \overline{a+b} \\ \bar{a} \cdot \bar{b} = \overline{ab} \end{array} \right.$$

$x = qn + a \qquad 0 \leq a \lneq n$

$y = q'n + b \qquad 0 \leq b \lneq n$

Then

$(x+y) = q''n + c \qquad 0 \leq c \lneq n$

where $a + b = ln + c$

$\underline{\underline{n=2}}$

$$\left. \begin{array}{l} \bar{0} + \bar{0} = \bar{0} \\ \bar{1} + \bar{1} = \bar{0} \\ \bar{0} + \bar{1} = \bar{1} \\ \bar{1} + \bar{0} = \bar{1} \end{array} \right\} \text{XOR}.$$

$n = p$, p prime $\mathbb{Z}/_{p\mathbb{Z}}$ is a field i.e. $\forall\ \bar{a} \neq \bar{0}\ \exists$
$\bar{b}$ such that $\bar{a} \cdot \bar{b} = \bar{1}$

prove this result

$$\boxed{\begin{aligned} 6b &= 4x + 1 \\ \frac{6b-1}{4} &= x \end{aligned}}$$

Rough.

$$\left.\begin{aligned} \bar{0} - \bar{0} &= \bar{0} \\ \bar{0} - \bar{1} &= \bar{1} \\ \bar{1} - \bar{0} &= \bar{1} \\ \bar{1} - \bar{1} &= \bar{0} \end{aligned}\right\}$$ even subtraction gives you XOR.

<u>We mostly study block codes</u> :

Generally, if data words are of size r and codewords of size n then encoding scheme is denoted by $C(n, r)$

How many size r frames are there? 2^r

Encoding is one to one.

If n is sufficiently larger than r. It gives us legrooms to make the codewords further from each other. But there is a practical limitation on how much more n can be than r.

Example

$n = 3$, $r = 2$

Dataword	Codeword
00	000
01	011
10	101
11	110

Observation

1. If 1 bit is corrupted , can receiver detect ?

Yes , as it will no longer be on the list.

2. But it cannot be correct.

3 Can receiver detect 2 bit error ?

Nope.

Example $r = 2$ $n = 5$.

00	00000
01	01011
10	10101
11	11110

1. Can detect 1 bit error
2. Can detect 2 bit error } all errors can be detected.

3. All code words have atleast 3 difference from each other so 1 bit errors can be corrected.

4. 2 bit errors can not be corrected.

01010 is transmitted, could be 00000
11110.
~~01000~~

Hamming Distance.

Hamming distance between 2 bit strings X, Y of same size is defined by $d(X, Y)$ = # of positions that they differ

= # of 1^s in X XOR Y

Minimum Hamming distance of an encoding scheme is the minimum Hamming distance between 2 code words

$C(s, n) \longrightarrow$ possibility of n errors.

How to encode such that atleast s errors can be detected?

Key the hanning distance btw any 2 codewords as minimum $s+1$.

Theorem: If Hamming distance between any 2 codewords is atleast $s+1$ then upto s-bit error gets detected

How to encode such that s bit error gets corrected?

Hamming distance should be $2s+1$.

Theorem: If Hamming distance between any 2 code words is atleast $2s+1$ then receiver can detect & correct upto s bit errors.

Linear Block Code

A block code is called a linear block code if XOR of any 2 codewords is a codeword.

One special type of Linear Block code is :-

Simple Parity Check

$n = k+1$

Add one extra bit at the end to make sure # of 1s is even.

Exercise: Show that this is Linear Block Code.

1st Feb 2024.

Problem 1: Why is a simple parity check code a LBC?

Problem 2: Give an example of a non-linear block code.

Soln 1

	Codeword.
00	000
01	011
10	101
11	110

Use induction and develope from 1 bit.

Simple Parity Check code is set of all strings with even number of 1s. We need to prove that by XORing 2 such strings we get a string with even number of 1s.

1 bit Simple Parity Check code $\longrightarrow$ 0

$\underbrace{0 \text{ XOR } 0 = 0}_{\text{Base case done}}$

n-1 bits induction.

0s of 1st codeword cancle 0s of 2nd codeword. $\longrightarrow$ $2x$.

1s of 1st codeword " 1s " " ". $\longrightarrow$ $2y$.

$\left.\begin{array}{l} 0 \text{ XOR } 1 \\ 1 \text{ XOR } 0 \end{array}\right\}$ 1. so only remaining 1s in XOR's.

result is as follows.

$$\frac{2(2n-1) - 2x - 2y}{2} = (2n-1) - x - y$$

Prove # of 1s in S_1 XOR S_2 (S_1 and S_2 same length)

$\#$(of 1s in S_1) + $\#$(of 1s in S_2)

- 2. ($\#$ of positions where S_1 & S_2 has 1's)

$$\begin{array}{r} 11011 \\ 10100 \\ \hline 21111 \end{array}$$

Solution 2

Given an r and an n for every data word of r bits give a codeword of n bits.

Dataword	Codeword	
00	~~000~~ 001	010 not a codeword.
01	~~001~~ 011	
10	~~010~~ 100	
11	111	

Example:

Can you produce a non-linear code of r = something, n = something such that it can always detect 2 errors.

b

Problem 3. Can you find a LBC with $k = 3$ & $n = 7$ that always detect 2 errors.

$k = 3$	$n = 7$
000	0000000
001	0010011
010	0100101
011	0110110
100	1001001
101	1011010
110	1101100
111	1111111

3, 6, 9, ... 24.

is this linear?

linear?

* Simple Parity check can detect odd number of errors but it can not tell how many places it happened.

detects 1 error is simple → make 4th bit parity and keep everything else 0.

<u>Homework</u> → turn it into a theorem.

$n = 2k + 1$. theorem for this?

$\underbrace{7 = 2(3) + 1.}$

then if codewords in this.

data word	codewords
S_1.	S_1 S_1 (XOR of all bits of S_1).
S_2	S_2 S_2 (XOR of all bits of S_2).
⋮	⋮

prove distance of such codewords ≥ 3