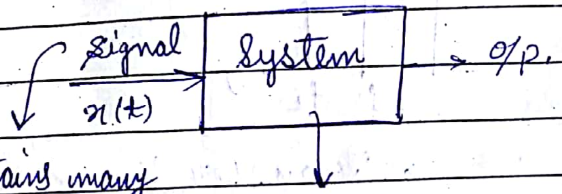
S.C.

The Physical Layer

The characteristics of different communication media are different but all of them ~~should~~ show bandpass behaviour.



contains many frequency components.

biased to certain frequencies.

Hence, to know the output, we must know the frequency components present in the signal and the selective character of the system.

$$\sin \omega t = a_0 + a_1 \sin \omega t + a_2 \sin 2\omega t + \ldots$$
$$b_1 \cos \omega t + b_2 \cos 2\omega t \ldots$$

If a signal $x(t)$ is periodic with periodicity T,

$f = 1/T$, $\omega = 2\pi f$

$$x(t) = a_0 + a_1 \cos \omega t + a_2 \cos 2\omega t + \ldots$$
$$b_1 \sin \omega t + b_2 \sin 2\omega t + \ldots$$

$$\int_0^T \cos m\omega t \cdot \cos n\omega t = 0 \qquad \int_0^T \cos n\omega t \cdot \sin m\omega t = 0$$

Variations in signals due to $\rightarrow a_0, a_1, a_2, b_0 \ldots$

If a signal is periodic with period $\rightarrow \infty$, then

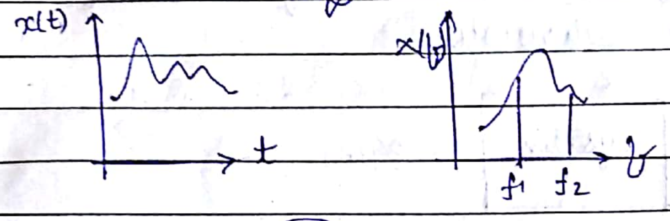
$\omega = 2\pi \frac{1}{T}$ $\qquad$ $\omega \rightarrow 0$.

In case of aperiodic signals:-

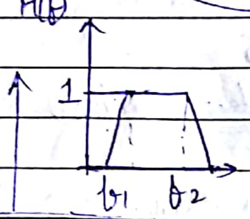
Fourier series $\rightarrow$ Fourier transformation

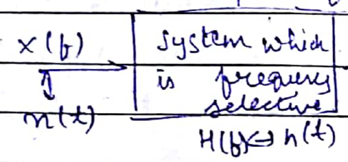
If a signal is $x(t)$, then in frequency it can be represented as a function $X(f)$, where

$$X(f) = \int_{-\infty}^{+\infty} x(t)\, e^{-j\omega t}\, dt$$



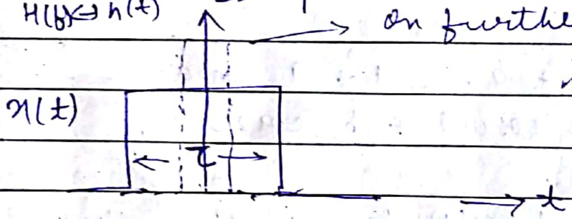
H(f) → Transfer function of the system



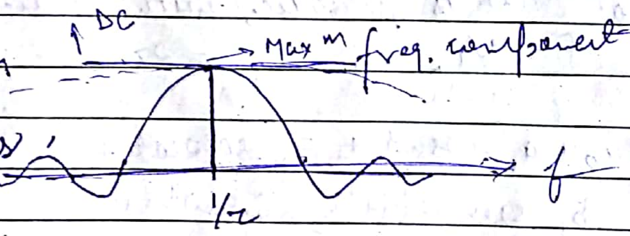


→ $Y(f) \Leftrightarrow y(t)$ $\quad Y(f) = X(f) \cdot H(f)$

→ Impulse



→ on further compressing it becomes an impulse.



on compression higher frequencies

→ sinc function

equitable distribution of frequencies

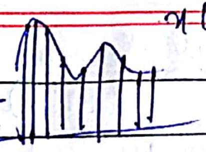
White Spectrum.

$x(t) \to$ Impulse (all freq. components) $\qquad$ O/p : $h(t) \rightleftharpoons H(f)$.

O/p → frequency selection i.e impulse response which is $H(f)$.

$x(t)$

made of impulses



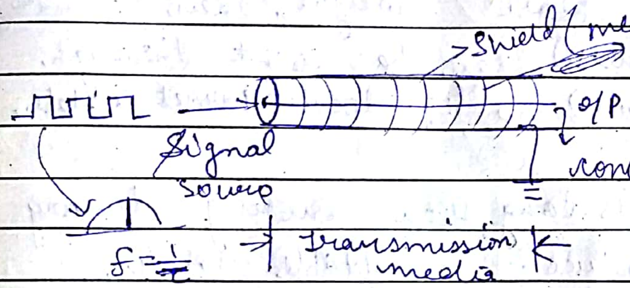
Impact of any ~~impulse~~ phenomenon will remain ~~as long~~ in case not all the energy is dissipated.

$$\int_{-\infty}^{\infty} x(t) \cdot h(t-\tau)\, d\tau$$

↓

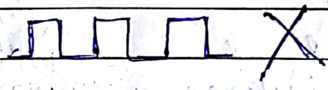
Summing up all the impacts of the phenomena at different τ's.

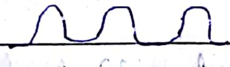
$$y(t) = x(t) \circledast h(t)$$



Cable shows bandpass characteristics. (very high frequency components won't be carried w/o sufficient reduction).

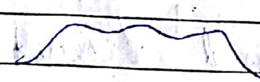
o/p →





(edges will be rounded off as edges contain high frequency components).

In case of long cable, excessive rounding off takes place.



(reduction in amplitude)

Receiving side: on the basis of some threshold value.

(Wrong)

Probability of error = Bit Error Rate (BER).

10^3 10^3

(Out of 10^3 bits, 1 is erroneous).

According to the standards set by different communication authorities, the BER (prob.) should be less than 10^{-6}

10^{-3} to 10^{-2} (wireless)

We observe that –

1) If the cable is short enough, then binary signals (sharp pulses) bits) can be sent through the cable. e.g: local ethernet cable.

2) But if the cable is long, then sending binary signals will introduce unacceptable error.

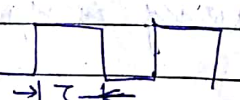
Modem → used for modulation and demodulation, required in case of long cables.

e.g. of Lan card specification: 10/100/1000
↓
100MBPS

interface

Switch specification: 10/100 } Common maxima

Max^m available speed = 100 MBps bit rate.

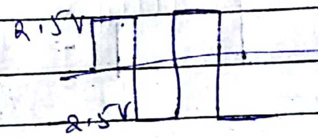


$$\tau = \frac{1}{100 \times 10^6}$$

Transmitter and receiver performs Bit Synchronisation.

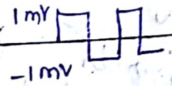
There will be an average DC value in this case, which isn't good for performance.

So, instead of taking 1 and 0, we take:-



pulses like this,

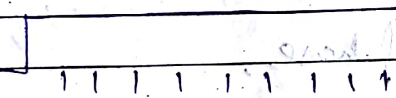
Receiver's end:



∴ Avg. dc = 0

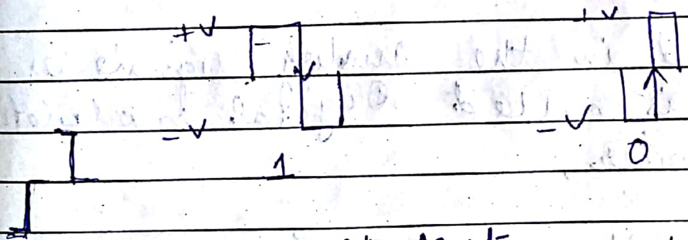
Good info content = equally likely 1 and 0,
∴ Avg. DC = 0.

Synchronisation is necessary at regular intervals due to temperature differences in switch's and sender's sides.

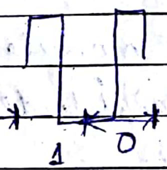


(In this case, synch. isn't possible)

∴ We send in the Manchester code way:-



It ensures at least one clock tick is available in each bit being received.



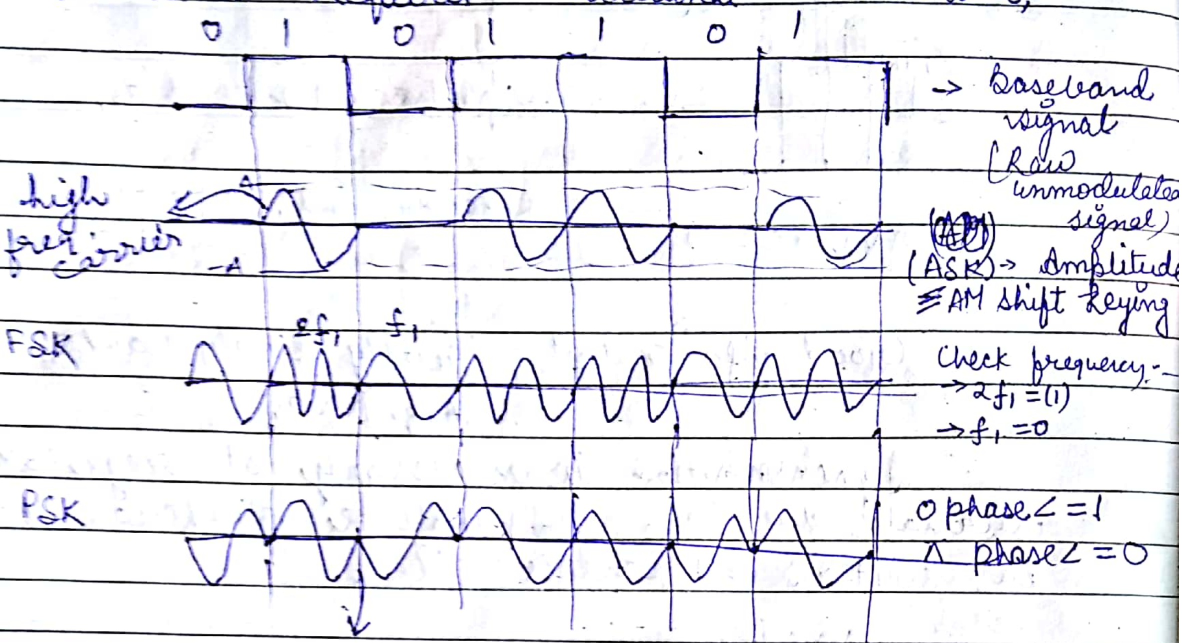
Sending through transmission lines → Line coding

1) Bipolar (both +ve and -ve) (no DC)
2) Ensuring time synchronisation at every bit slot.

available in Manchester coding.

Digital (Binary) Modulation

Disadv :- Requires additional bandwidth.



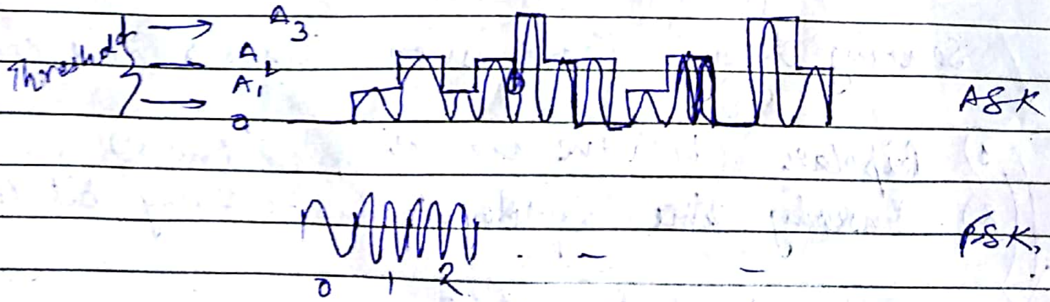
change in phase.

What is the value of the signal → Analog
Which signal is it? → Digital

The info contained in the analog signals is digital, ∴ It is called Digital modulation of analog carrier.

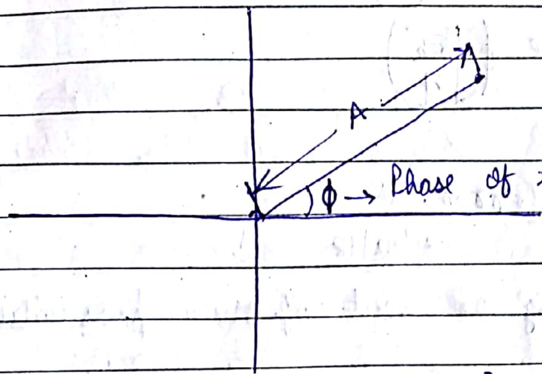
M-ary Modulation

M discrete levels.
Let M be 4
If we apply amplitude modulation then we can use 4 distinct amplitudes to represent 4 values.

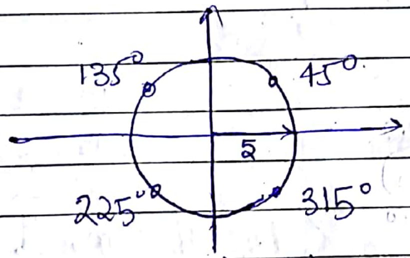


ϕ @ $0°, \pi/2, \pi, 3\pi/2$ → PSK.

Representation of M-ary modulation in polar system



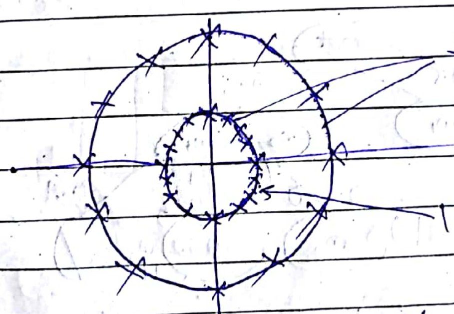
4 ary phase modulation –



Wide gap b/w phases ⇒ lesser impact of error

More impact of ~~eto~~ noise in analog than digital.

32 array modulation ; a certain minm distance b/w phases ∴ another dimension req.



$\int_a^{\infty} e^{x^2} dx = erfc(a)$

It is called constellation diagram of M-ary Modulation.

$Pe|_{AM}$ = complementary error f^n · $Pe|_{FM}$ = $Pe|_{PM}$ =

$$\boxed{\int_a^{\infty} e^{x^2} dx \rightarrow erfc(a)}$$

$P_{E|AM} = erfc\left(\sqrt{\frac{E_b}{\eta}}\right)$ → noise density f^n.

$P_{E|FM} = erfc\left(\sqrt{\frac{E_b}{\eta}}\right)$

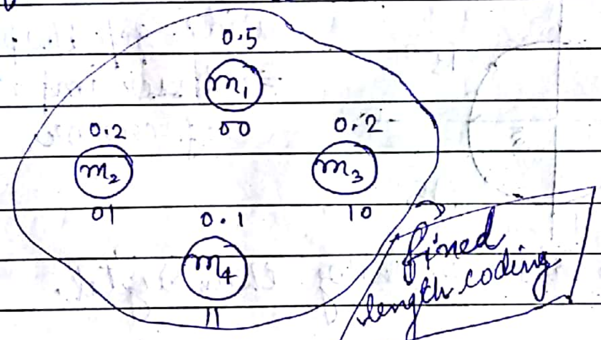
$P_{E|PM} = erfc\left(\sqrt{\frac{2E_b}{\eta}}\right)$

↓ less prob. of error.

21/08/18

By sending one out of two possibilities
A or $\bar{A}$

one bit of information: yes → 1, no → 0] two possibilities



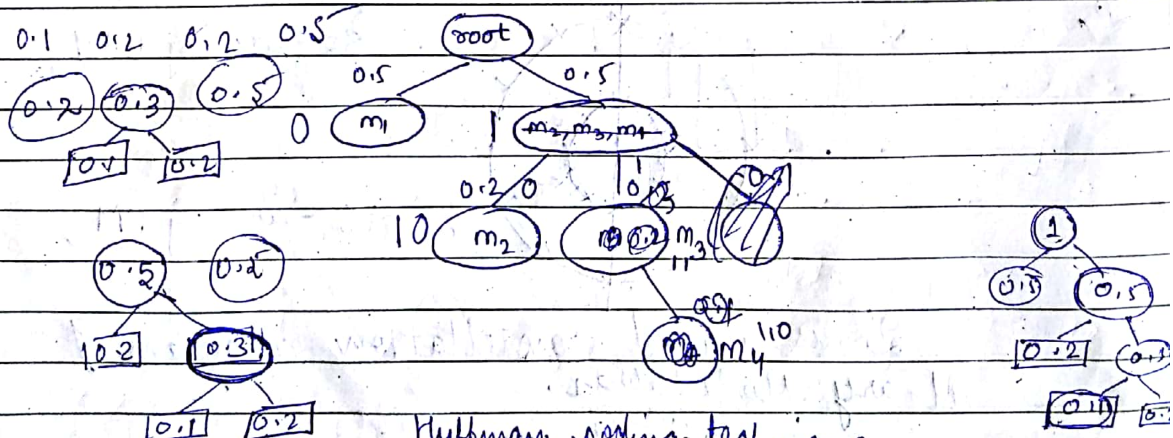
$m_1 \rightarrow 0$
$m_2 \rightarrow 10$
$m_3 \rightarrow 11$
$m_4 \rightarrow 101$
} variable length code
↓

$2 \times 1000 = 2000$ bits

$0.5 \times 1000 \times 1 + 0.2 \times 1000 \times 2 + 0.2 \times 1000 \times 2 + 0.1 \times 1000 \ldots$

$= 1000(0.5 + 0.4 + 0.4 + 0.3)$

$= 1000 \times 1.6 = 1600$ bits



Huffman coding technique
↓
used for generation of optimum variable length code.

$0.1 \rightarrow 3$
$0.2 \rightarrow 2$
$0.5 \rightarrow 1$

$0.3 + 0.8 + 0.5$
1.6

bit of information
 > different
bit of data (Binary digits - Binits).

Fixed length :-
2000 bits of data contains 1600 bits of info

Variable length :- (Huffmann)
1600 bits of data contain 1600 bits of info.

Data may or may not contain information.

$$\text{Information} = \log_2\left(\frac{1}{\text{Probability}}\right).$$

$$\text{Info carrying Capacity} = B \log_2\left(\frac{S}{N}\right)$$

We try to Maximise information carried by ~~for~~ 1 bit.

Shanon's information theory

20Hz - 20kHz] human ear can sense
But in practice, the highest voice frequency is limited to 4kHz.

In voice transmission this is used and a sampling frequency of 8 kbps. (8 kilosamples per second).

error $\propto s^2$ (step size)

8 ksamples per s → 8 × 8 kbits per s
64 kbps.

Human speech ≈ 250 Hz.

Adaptive coding ⇒ Sampling rate changes ~~aft~~ according to the frequency used.

Jpeg → Spatial correlation.

21/08/18 – II

1) Bit of info ≠ Binary digit

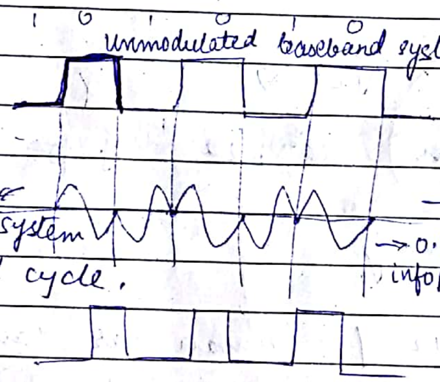
At best, one binit can represent one bit of info.

2) We can perform 'source coding' to ensure that each binary digit can carry close to 1 bit of info.

If through source coding, we can make '1' and '0' equally likely to occur, then we've achieved optimum source coding.

1 0 1 0 0

unmodulated baseband system



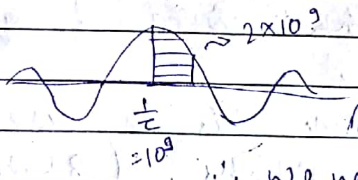
→ 1 GBPS $\tau = 10^{-9}$

→ 1 bit info per Hz.

phase modulated system with full cycle.

→ For this, we need 2 GHz because for 1 bit, entire one cycle is needed #

→ 0.5 bit info/Hz



$\approx 2\times10^9$

$\frac{1}{\tau} = 10^9$

Almost 90% energy

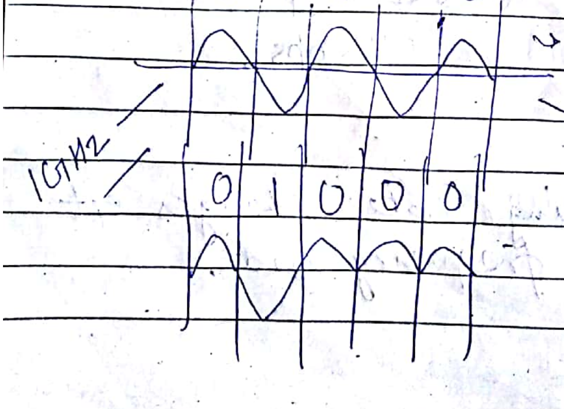
$10^9 - 2\times10^9$

Bandwidth $= 10^9$

∴ we need a bandwidth of 1×10^9 Hz $= 1$ GHz.

∴ To counter this, if we only use half of the cycle, we only need 1 GHz. (PSK)

0 1 0 1 0



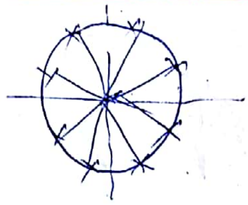
1 GHz

0 1 0 0 0

→ phase modulated system

→ using half cycle

1 bit info/Hz.

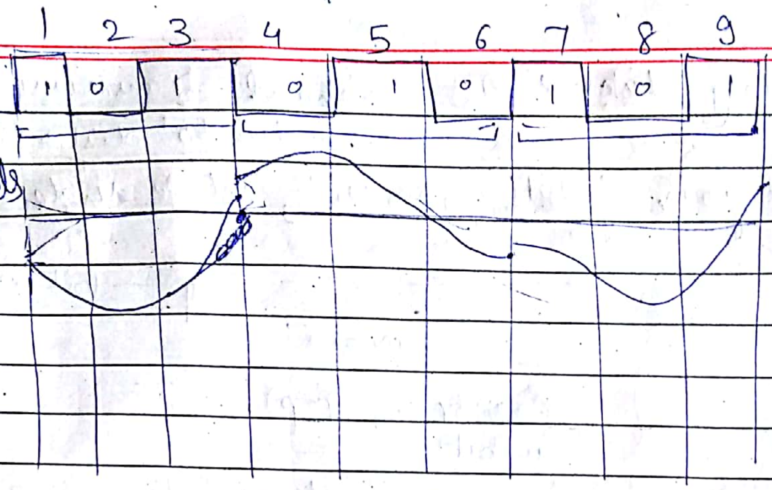


101 → 5
010 → 2
101 → 5

2(B)

5
101 → 8 levels
010 2
101 5

111
101 → 4
100 → 3
011 → 2
010 → 1
001 → 0
000



→ 8 ary phase modulation

3 giga bits per second   Bandwidth = $3/3$ GHz
= 1 GHz,

Channel allows 2.4 GHz
then $2.4 \times 3 = 7.2$ gbps can be sent.

Disadvantage : Increases probability of error.

1) a) A telephone cable can transmit 4K symbols (bauds) per second. If you are using 64-array phase modulation, then what is the capacity of the cable in bits (of information) per second ?

~~4K symbols/s.~~
~~$\log_2 64 = 6$~~

$4 \times 10^3 = \dfrac{x}{\log_2 64}$

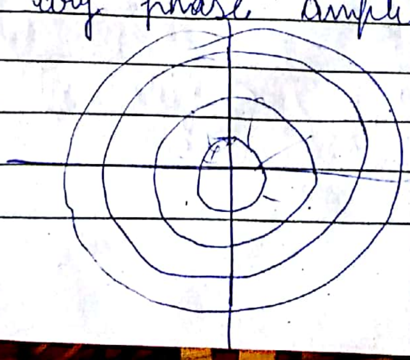
$\log_2 64 \times 4 \times 10^3$
24×10^3 bits/s.

Symbols ps = 4K.

Bits per second = $4K \times \log_2 64$

= 24 KBps.

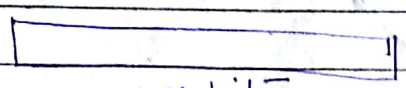
b) 64 ary phase amplitude Shift Keying.



16 phases
4 Amp.

For long distance ⇒ baseband transmission ✗
(due to distortion)

A group of bits are sent, not a single bit.


→ Bit Error Rate = p

m bits

No error in 1 bit $= (1-p)$.

No error in all m bits $= (1-p)^m$

P (No error in consecutive m bits) $= (1-p)^m$

04/09/18 — I

Data bits

$D_3 \quad D_2 \quad D_1 \quad D_0 \quad C_2 \quad C_1 \quad C_0$ 1010

Check bits

$C_2 = f(D_3, D_2, D_1) \rightarrow D_3 \oplus D_2 \oplus D_1$

$C_1 = f(D_3, D_2, D_0)$

$C_0 = f(D_2, D_1, D_0)$

$C_2 = 0 \qquad C_1 = 1 \qquad C_0 = 1$

At receiver's side → checkbits are regenerated.

$C_R = (C_2, C_1, C_0) \oplus C_g = (C_2', C_1', C_0)$

↓

If $R = 0$ accept the data.

4-bit word has been converted to a 7-bit word

4 bits → 16 possible combinations.

7 bits → 128 ,, → receiver is receiving, out of which only 16 are valid.

Only single bit error can be detected by even parity check.

0 → 000   1 → 111   Received : 001101

error correcting capability

can be detected and corrected to 000111

$$
\begin{array}{r}
1010 \\
1101 \\
\hline
0111
\end{array}
$$

XOR

{differ in these bit positions}

∴ Hamming Distance = 3

16 → 32 bit ⇒ min^m H.D. = 2. It shows that a single bit error can't convert one valid code word into another valid code word.

Actual data	Sent data
000	0000
001	0011
010	0101
011	0110
100	1001
101	1010
110	1100
111	1111

(Pairs of sent codewords bracketed with 2.) even parity

Min^m H.D = 2

H.D = 1 { 0000
1000 X g Valid codeword

If $(H.D)_{min} = d$ bits
Errors that can be detected = (d-1) bits

To correct an error of d bits, we need a ~~H.D~~) min^m H.D. of (2d+1) bits.

CRC : 1) has hardwares which implements it very fastly, (stable).
2) error detection.
3) 32 bit data, 31 erroneous bits can be detected.
4) optimized Hamming code.

Packet size = 1KB, link bit rate = 10Mbps

transmission time $(t_t) = \frac{10^3}{10^7} = 10^{-4}$ second per bit

(time taken to put the packet into link)

propagation time $(t_p) = \frac{\text{length of the link}}{\text{velocity of the packet}}$

Say length = 1000 km.
velocity (fibre optics) = 2×10^5 km/s.

$= \frac{10^3}{2\times10^5} = 0.5\times10^{-2}$ s
$= 5\times10^{-3}$ s.

$= 5 \text{ ms}$.

$t_t = 0.1 \text{ ms}$ $\quad t_p = 5 \text{ ms}$

total time taken to send a packet (send + acknowledgement)

= round trip time (~~RTT~~) (RTT) $= t_t + t_p + t_p$

$= 2t_p + t_t$

(processing time ≈ 0). $= 10.1 \text{ ms}$.

Efficiency of a channel $= \dfrac{t_t}{2t_t + t_p} = \dfrac{t_t}{RTT}$

$= \dfrac{0.1}{10.1} \approx \dfrac{0.1}{10}$

$= 0.01$

1% efficient

If W no. of packets are (allowed to be) sent to increase the efficiency w/o receiving the acknowledgement

$W = 100$ efficiency $= 100\%$.

$$\boxed{W_{max} \simeq \frac{RTT}{t_t}}$$

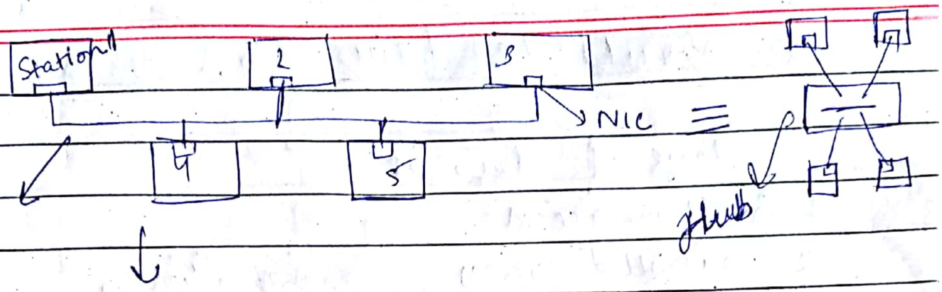
SOF		S No.	CRC	EOF

sequence number in current transmission window.

LAN ⇒ 100 m dist. allowed $\rightsquigarrow t_t >> t_p$.

$t_t << t_p$ (WAN).

18|09|18 → I



10 Mbps
100
1000

While station 1 is transmitting, no other station can.

If we make an equiprobable time ~~d~~ for transmission, each station gets 2 Mbps.

Broadcast ⇒ one station to all others

1	2	3	4	5
	×	×		

~~Uta~~ Unicast ⇒ one to one.
Multicast → one to many
anycast → one to any

wrong because data sent by stations are random, not equiprobable.

Even though 2 and 3 ~~and 1~~ are sleeping and 1 wants to send at 6 mbps, it can't.
This type of system provides strict discipline.

Self organisation :- devices themselves decide bandwidth allocation.

NArq → no rule.

Medium Access Control (MAC)

When devices are to use a common medium, then what mechanism should be followed to access the common medium so that the resources (bandwidth) is maximally utilised.

$\frac{1.5}{100 \times 10^6}$
1.5×10^{-8} s.

It should be fair too,

Ways of doing it –
1. Random access
2. Controlled access → inefficient

Earlier devices used to be connected by hub now by switch.

Max^m frame size allowed in Ethernet cable = 1.5kB

$t_t = \frac{10^4}{10^8} = 10^{-4} = 0.1$ ms, 10000 bits (max^m frame size)

$t_p = \frac{0.100}{2 \times 10^5} = 0.5 \times 10^{-6}$ s,
$= 5 \times 10^{-7}$ s.
$= 0.0005$ ms

$t_t >> t_p$

Before the transmission is completed, all the stations have already received the data, and corruption

Mixing of data due to simultaneous sending of data packets is called collision of data.

Carrier Sense multiple access (CSMA)

1) Before transmitting your frame, listen to the channel. If it is busy then keep listening until it is free. (sense freq.)

2. If the channel is free then transmit.

Reduces the probability of collision,

Improvement :- CSMA/CD (Collision Detection).
CSMA/CA (Collision avoidance).

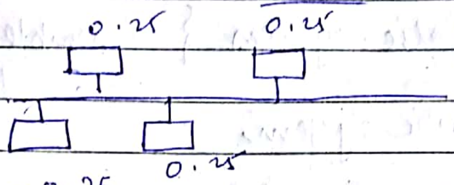
Promo – 0.005 s (3 senses channel as free)

$7 \times 10^8 \times 60 \times 60 \times 24 \times 365$

On detecting collision the rest of the frame won't be sent.

To visualize collision, actually $2t_p$.

25/09/18 – I



access prob. (p) = 0.25

$$D = \sum_{i=1}^{4} p_i$$

Load – (p) = $\frac{\text{traffic demand}}{\text{capacity of the channel}}$

If access probability is p, then probability that exactly j no. of stations send simultaneously (n no. of total stations),

$$P_j = {}^{N}C_j \times p^j (1-p)^{N-j}$$

$$P_{idle} = P_0 = {}^{N}C_0 \times p^0 (1-p)^N$$
$$= (1-p)^N \quad \{\text{no one sends}\}$$

$\cancel{P_{collision}} = P_{\substack{\text{successful}\\\text{transmission}}} = P_1 = {}^{N}C_1\, p (1-p)^{N-1}$

Total probability $= P_0 + P_1 + P_{collision}$

$$\Rightarrow 1 = (1-p)^N + {}^{N}C_1\, p (1-p)^{N-1} + P_{collision}$$

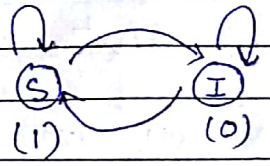
$$P_{collision} = 1 - (1-p)^N - {}^{N}C_1\, p (1-p)^{N-1}$$

Efficiency $(\eta) = P_1$

If $N \to \infty$, $p \to 0$ so that load is below 1. (Np)

Then binomial distribution turns into Poisson's distribution.

~~In Poisso~~ each node has 2 states: send and idle.

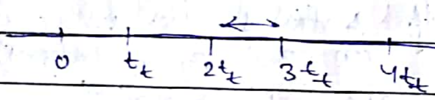


nodes → random variables.

Stationary Argolic system { ensemble moments = time moments)

Stoichastic system

In Poisson's process, (probability varies with time, keeping average same.)



Unit of time = t_t

In case 2 packets are sent, collision will occur.

Probability that n no. of arrivals in 't' duration of time.

$$P_n(t) = \frac{(\lambda t)^n}{(\lambda t)!} e^{-\lambda t}$$

{ λ → represents the average traffic arrival rate.

$$P_1(1) = \frac{1}{1} e^{-1} = \frac{1}{e} = 0.36$$

ALOHA	← 1980 → (if any station wants to send, it can send anytime.)
Slotted - ALOHA	
CSMA/CD →	80-90%
p-CSMA/CD	98%
p-CSMA/CA (wireless)	← Wi-fi

cooperative

⇓

for successful transmission $2t_t$ time is required as a collision can occur when one packet ends, another starts.

$$\therefore P_1(2) = \frac{2}{2!} e^{-2} = 0.18$$

Slotted ALOHA — each packet can be sent at the start of a clock. ~~tsy~~ (synchronisation)

$\therefore$ 36% efficiency. $\rightarrow e^{-G}$

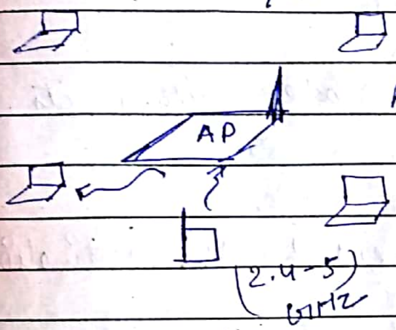
Aloha $\Rightarrow e^{-2G}$

Frequency is allocated on demand.

GSM → time slot and frequency spectrum.

Common channels → anyone can send anytime, similar to slotted - aloha.

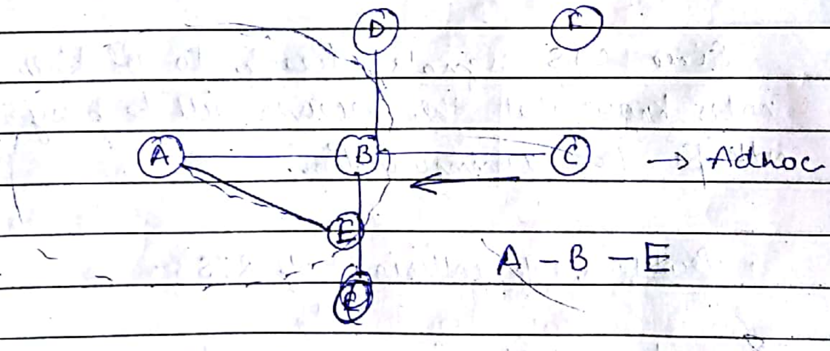
CSMA/CD → useful for small networks.



ADHOC network (no access pt), AP → Access Point.

all transmit in same frequency.

CSMA/CA



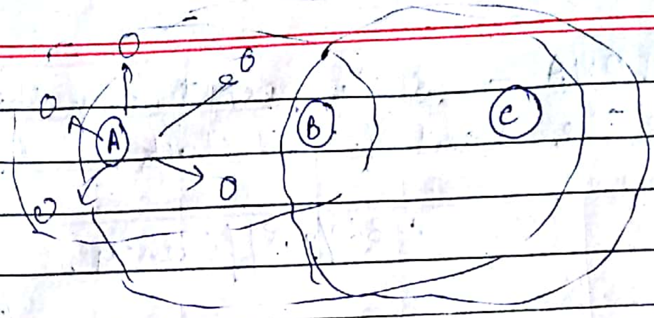
C → B

A wants to send to B, A won't be able to sense that B is busy, receiving signal from C, ∴ Collision.

Here, CSMA/CD is failing.

This is called hidden node problem.

30/10/18 — I



→ Medium Access Control for this, CSMA/CD fails.

CSMA/CA :-
A will send a message RTS (Request to Send) within its range. RTS = (dest. add., duration of time

8 bits msg id	dest, add. 32 bits	duration 32 bits

RTS is broadcasted to all the nodes within its range.

CTS (Clear to ~~transmit~~ Send) :- sent by the destination, ↳ sent to all nodes.

Since CTS signals reach to all the nodes, the neighbouring nodes know that the receiver will be busy, so they wouldn't attempt for communication.

• Problem of collision of RTS :-

Since RTS's size is very less, the collision doesn't cause much loss.

Wi-fi MAC Protocol

1). If a station wants to transmit, it senses the channel and if the channel is found free (for ~~two~~ a predefined duration of time, known as DIFS), it ~~sends~~ sends the RTS message.

p-persistence CSMA

2) Once the receiver is ready to receive, it sends a CTS message and then communication can start.

All the neighbours of both the senders and receiver are aware that communication is already on b/w 2 nodes for a known duration.

So, collision is avoided.
But RTSs may collide.
RTS collision can be avoided by p-persistence.

RTS can be sent according to p-persistence CSMA/CD.
Draw a random no. from collision window, wait for those many no. of slots and then send RTS.

BER = P.
Prob. of error-free = $(1-P)^n$ {n → no. of bits in a frame}

If n is very high {higher frame size}, then $(1-P)^n$ will be less than 1.
So, higher frame size isn't desirable.

∴ error correction techniques should be implemented here.

If data is divided into packets □□□□, b/w each packet there is free intermittent time in which ~~any other~~ a new node can send RTS which can cause collision.
SIFS → Short Interface Spacing.

DIFS > SIFS [Before sending an RTS, ~~it has~~ the node has to sense the channel free for DIFS time]

30|10|18 → II

Switches have interface cards.

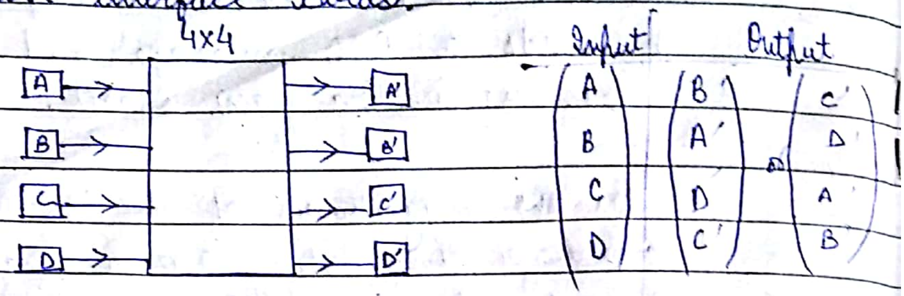
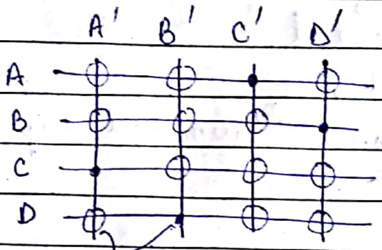


Fig. Switch

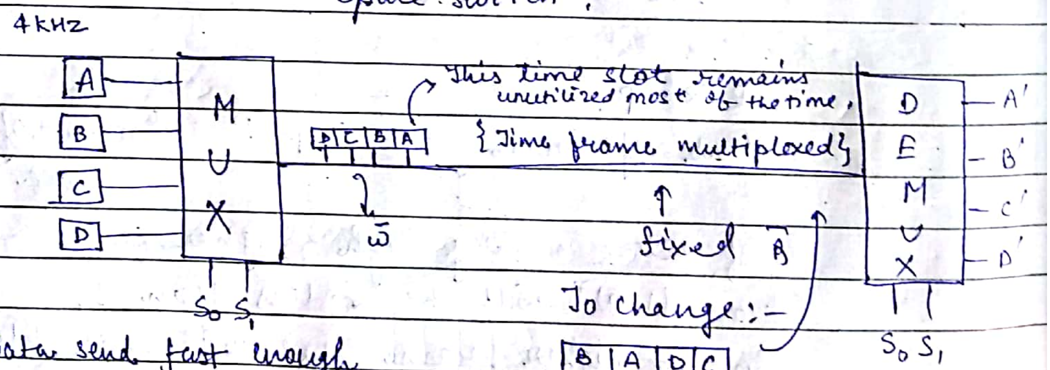
We should be able to obtain any i/p – o/p config.



$$\begin{array}{c|cccc} & A' & B' & C' & D' \\ \hline A & 0 & 0 & 1 & 0 \\ B & 0 & 0 & 0 & 1 \\ C & 1 & 0 & 0 & 0 \\ D & 0 & 1 & 0 & 0 \end{array}$$

Here, we can put a transistor with –ve voltage.
" +ve "

This is called a Space switch.

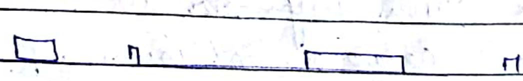


Data send fast enough to achieve Nyquist rate
∴ 8 ksamples/sec.
1 sample = 8 bits
∴ Bandwidth = 64 kB
No. of devices = 4
∴ Total Bandwidth = 4 × 64

(Time Switch) / Asynchronous time div. multiplexing

Combination of space and time division multiplexing ✓

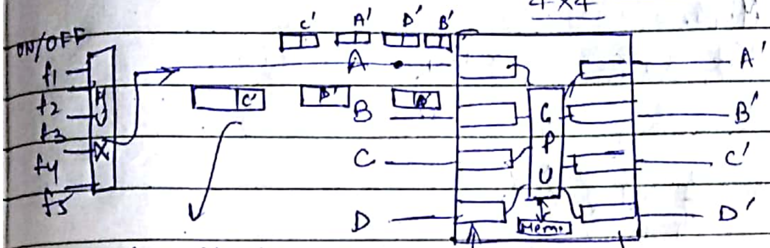
ON/OFF



$\frac{\text{ON}}{\text{Total}} < 2\%$

We can add more devices to achieve efficiency. But the problem is that the other 99 devices connected may not want to send data to C'. This is because 'when and where' are strongly coupled in time space switch.

For this, we need Packet Switch (Asynchronous).



Till 3G → Time switch

4G ↑ → Packet switch.

Where it will go, that info is in the data itself.

I/P Buffers

→ o/p Buffers.

Interrupt service → Every time a packet comes, it generates an interrupt and is put into buffer.

Length of buffers is random.

Rate of arr. > Rate of dep. Buffer will grow.

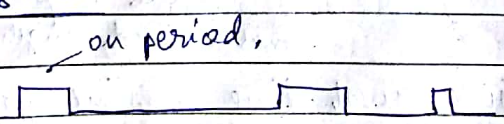
" < " buffer will shrink.

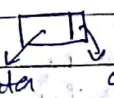
This is called statistical multiplexing.

Getting stored in buffer ⇒ causes random delay to the data.

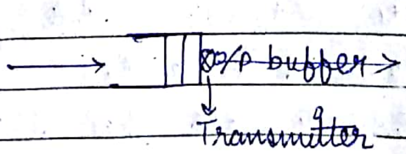
06/11/18 – I

Time switch:-





flows from diff^n i/p buffers.



Say prob of packet being ON = 0.1

No. of packets that can be multiplexed = 10

Source characteristics -

1) $P_{ON} = 0.1$

2) Peak Bit Rate (p) = The bit rate at which the source transmits data if it is ON.

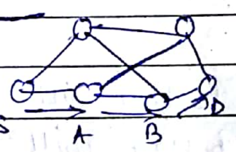
Let p be 10 Mbps.
Then average bit rate $= p \times P_{ON} = \cancel{0.1} 10 \times 0.1$
$= 1$ Mbps.

$n \times \hat{a} = C$ → capacity of link
(average)

$n \times 1 = 10$

$\therefore n = 10$.

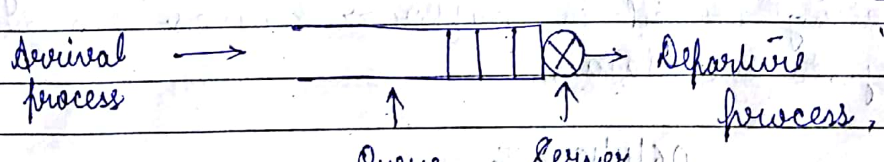
use of i/p buffer → when more than 1 flow is simultaneously switched on.



$T_{S \to D} \neq T_{S \to A} + T_{A \to B} + T_{B \to D}$
{additional buffer ~~time~~ time delays are there}

Problem - Random delay of packets.

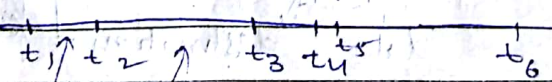
'μ' no. of customers served / time.



'λ' no. of arrivals per unit time.

(has a fixed length [0, ∞) and a discipline like FCFS, LCFS, priority, SJF.

Inter arrival time : Time gap between 2 consecutive arrivals.



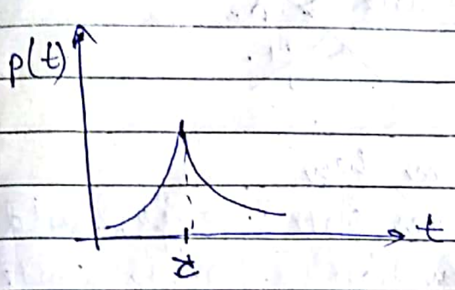
I.A.T $= t_2 - t_1$, $t_3 - t_2$ ... We can find the average inter arrival time, τ.

Hence, we can state that the avg. rate of arrival

$$\boxed{\lambda = \frac{1}{\tau}}$$

Poisson's Process with the average rate = λ,

In a Poisson's process, the inter arrival time is exponentially distributed and hence, it looks naturally justifiable.



The prob. that any random value will be very diff" from average is very low.

$$P_n(\tau) = \frac{(\lambda t)^n}{n!} e^{-\lambda t}$$ Probability of 'n' no. of arrivals within a time of duration 'τ'.

A queue is characterized as follows :-

(arrival process)/(departure process)/(no. of servers)/(length of the queue).

e.g : Poisson's / Poissons / 1 / ∞.
(M) (M)

M/M/1/∞ queue.

$\lambda \rightarrow$ $\boxed{\otimes} \rightarrow \mu$ For stability :- i) $\mu > \lambda$.

$\mu, \lambda \rightarrow$ avg. Instantaneous values may be > or <.

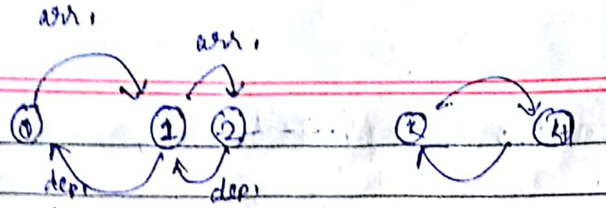
ii) The stationary probabilities (P_K) of 'state' of the queue shouldn't be a function of time. $P_K \neq f(t)$

State of the queue => No. of customers in the queue.

If there are 'k' customers (packets) in the queue, then the state of the queue is 'k'. Here, it can vary from 0 to ∞. Probability that the queue will be found in state 'k' is represented by P_K.

Markov chain Model of the Queue

Birth death chain



Time slice → so small that only 1 event can occur.

~~Rate of transition from 0 to 1st state ⇒ λ.~~
~~1 to 0 ⇒ μ.~~

If the queue is in equilibrium then
Rate ~~No.~~ of transitions from state i to j should be equal to the rate of transition from state j to state i.

∴ ~~Lo x p~~ Rate of transition from state 0 to state 1
= Rate of transition from state 1 to state 0.

$\Rightarrow P_0 \times (\lambda) = P_1 \times \mu$ → No. of arrivals/departures.

$\therefore P_1 = \left(\frac{\lambda}{\mu}\right) P_0$ — (1) P_i - Probability that state of the queue is i.

Hence, expected state of the queue $= \sum_{i=0}^{\infty} i P_i$

Let $\rho = \frac{\lambda}{\mu}$ (Load). Hence, from (1) :-

$P_1 = \rho P_0$ Similarly $P_1 \lambda = P_2 \mu$

$P_2 = \rho^2 P_0$

$\therefore P_k = \rho^k P_0$

The stationary probabilities that the queue is in state k is $P_k = \rho^k P_0$

Relation b/w P_0 and ρ :-

We know that : $\sum_{k=0}^{\infty} P_k = 1$

$\Rightarrow \sum \rho^k P_0 = 1$

$\Rightarrow \dfrac{P_0 \times 1}{1-\rho} = 1$

$\Rightarrow P_0 = 1-\rho \qquad \Rightarrow \rho = 1 - P_0$

The probability that the queue is not empty.

$\therefore$ The average no. of customers in the queue

i.e, $N = \sum_{k=0}^{\infty} k P_k$

$= \sum k \rho^k P_0 = P_0 \sum k \rho^k$

$= \dfrac{P_0 \rho}{(1-\rho)^2} = \dfrac{(1-\rho)\rho}{(1-\rho)^2} = \dfrac{\rho}{1-\rho}.$

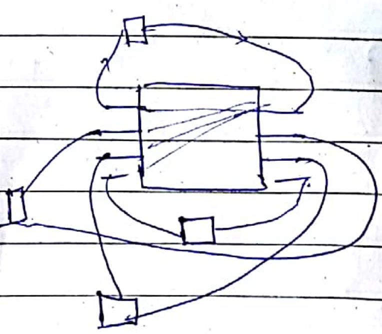
Replace ρ by $\frac{\lambda}{\mu}$

$$\boxed{N = \frac{\lambda/\mu}{1-\lambda/\mu} = \frac{\lambda}{\mu-\lambda}}$$

Eg: For a bank, $\lambda = 8$, $\mu = 10$

$N = \dfrac{8}{10-8} = 4$

Eg: 8 Mbps $\rightarrow$ O $\rightarrow$ 10 Mbps



* Little's formula :-

$N = \lambda T$ where (waiting time + service time)

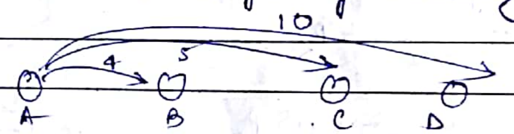
$T \rightarrow$ avg. time spent by a customer in the queue.

It shows the relationship b/w avg. no. of customers, average amount of time spent and the arrival rate.

Delay at the queue $T = \frac{N}{\lambda} = \frac{\lambda}{(\mu - \lambda)\lambda} = \frac{1}{\mu - \lambda}$

At Bank counter, time spent by customer. (W.T + S.T)

Uses:- performance and design of Routing Algorithms.



Traffic rate in A – B = 5 + 4 + 10 = 19

Capacity of A–B link = 20

$\therefore$ Delay $= \frac{1}{20-19} = 1\ s.$

It shows the relationship b/w avg. no. of customers, average amount of time spent and the arrival rate.

Delay at the queue $T = \frac{N}{\lambda} = \frac{\lambda}{(\mu-\lambda)\lambda} = \frac{1}{\mu-\lambda}$

At Bank counter, time spent by customer. (W.T + S.T)

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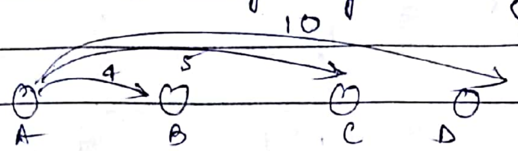
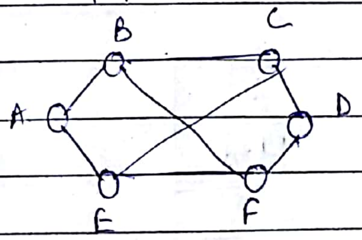


Traffic rate in A-B = 5+4+10 = 19

Capacity of A-B link = 20

$\therefore$ Delay = $\frac{1}{20-19}$ = 1 s.

13/11/18 - I



Source \ Dest.	A	B	C	D	E	F
A	X					
B		X				
C			X			
D				X		
E					X	
F						X

Throughput = $\sum_{i=1}^{N} (s_i, d_i)$

Objective : maximise the throughput, satisfying the delay constraints of flow.

Global optimisation problem → Routing
↓
all the links should be maximally utilized.

There is no diffn b/w switch and a router.
L_3 switch — Router
↓
implemented for network of networks.

For performing :-
Network layer activity, a node runs 2 processes.
1. Packet forwarding.
2. Gather routing info.

Every node has a routing table.

Dest.	Next hop	Interface	delay
B	B	1	
C	~~B~~	2	
D	E	2	
E	E	2	
F	B	1	

network id ← (B)

all the buffers, links are interfaces (local context)

Destination address
↓
Network address
(Net masking)

Routing Table.

Finding the net mask :— trial and error (from ~~B~~ 32 to 1)

Small routing Table : less memory
less search time.

Internet → hierarchial
ordered set of links

When end to end route (set of links to be traversed) is ~~not~~ ~~decid~~ rigidly decided by the source itself, then this is called Source Routing.

When routing decision is independently modified by each subsequent nodes, it's called per-hop routing.

When routing table changes, it's called dynamic routing.
It can be made dynamic by exchanging info b/w nodes.

Echo packet : Test packets are broadcasted. These packets are given the highest priority.

t_0 ; $t_0 + \tau$ returned   Delay $= \tau/2$.

	F Delay
B	15
D	20
E	13

Link state packet prepared by nodes
To every other node (flooded).
except for the ar

In some cases, instead of delay, we measure the remaining energy.

From D to

A	B	C	D	E	F
2	5	9	0	7	8

Distance vectors:
(contains delay to all nodes),
shared with all the neighbouring nodes.

Link State : knows abt few, shares with all.
Distance vector : knows abt all, shares with few.

Link state > Dist. vector.

Routing info should be sent as frequently as possible, keeping in mind that ~~the~~ ~~not~~ a bandwidth for user traffic and routing traffic is ~~equally~~ opti-mall distributed.

Greedily
~~Always~~ using shortest path creates congestion and increases delay.
∴ Shortest Path → Game Theory