Data communication

fundamental characteristics

- delivery (correct destination)
- accuracy (accurately data transfer)
- timeliness (timely manner / no delay)
- jitter (variation in packet arrival time)

components

- Message (data)
- Sender
- Receiver
- Transmission medium (physical path)
- protocol (rules on how tha data is transfered/ recieved)

Data Flow

- Simplex – one way
- Half duplex – both way not at same time
- duplex – both way ~~a~~at same time

Distributed processing.

- most networks uses this
- a task is devided among many computers

Network Criteria

- Performance (transit time/response time)
  (depends on no. of users, hardware, transmission medium, softwere) evaluation → throughput, → delay
- Reliability measurement → freqn. of failure, → recover time, → robustness in catastrophe
- Security

Type of connection

i. point to point

↳ dedicated link between 2 device.

↳

ii. Multipoint

Topology

Mesh

↳ total nodes/links : $n(n-1)/2 \rightarrow$ [duplex]

$n(n-1)$ [simplex]

protocols key ~~[illegible]~~ elements

i. Syntax → format of data.
which part of bits means what.
Ensures data arrangement.

ii. Semantics → meaning of data.

if there is a adrees what does that mean is this the route or reciver.

iii. timing → when and how fast

Standards

De facto
↳ adopted as standard through widespread use

De jure
↳ standards legislated by officially recognize body.

*) Standards are necessary to ensure that products from different manufacturers can work together.

Open Systems Interconnection (OSI) model

*) not a protocol but a model to design network architecture. (by ISO → organization)

*) Layered framework

7 Application
6 Presentation → user support layers
5 Session

4 Transport

3 Network
2 Data link → Network support layers
1 Physical

commonly a trailer is added ← 2

one layer uses services of the layer below.

Same layer communicate with same layer in a dif. machine

In Each layer sending device add it's own info. to the message it receives from above and pass it below.

And reverse happens in receiver device.

pear to pear protocol → one layer gives data to the next layer.

Encapsulation → lower level (N) encapsulates all the data from the level above (N-1).

physical layer

*) responsible for movements of individual bits from one hop to the next.

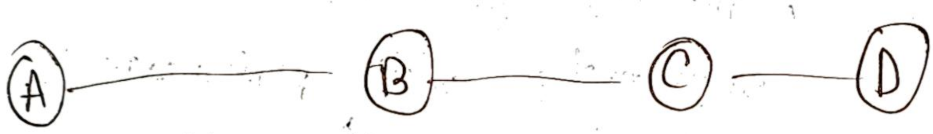
- encoding of bits
- transmission rate/media
- Synchronization of bits
  - ↓ sender & reciver must use same bit rate and must be syncrohronized at bit lvl.

Data link layer

- divides bits received from network layer into managable units (frame).
- physical addressing (adds header to find sender/receiver)
  (local)
- flow control (mechanism to avoid overwhelming the receiver.)
- Error control (dectect, retransmit lost frames, recognize duplicate frames) works with trailer

+ Access control (determine wich device has the control on the link at any given time)

hop to hop delivery



going from A to D data hops ~~from~~ between multiple device.

Network layer

- Individual packet → datagram
- makes sure data goes from origin to destination
- logical addressing (when passing network a header is added to the packet)
- Routing

Transport layer

- deliver message from one process to another
- service point address (port address)
- segmentation and reassembly
  A message gets divided into segments with port address and gets re assembled on arrival

Network layer takes each packet to destination device
Transport layer takes the whole message to the correct process on the destination device

- connection control
  connectionless - each segment is sent without creating connection

connection oriented → create connection with transporlayer, data transmit, connection termination.

→ flow control

→ Error control

Transport	data link	
regulates transmission betwen two device across a network	through to directly connected device	flow Con.
sender to receiving transport layer Bigger picture	across a single link Instant	Error Con.

Session layer

- Dialogue control & synchronization
  - ↓ communication between two process.
  - ↳ adding checkpoint to process

presentation layer

- Translation (changes infromation to bit and vice versa)
- Encryption/Decryption
- compression

Application layer

- → user interface and support
- → Network virtual terminal
- → file transfer access mangement
- → access network resources

source to destination delivery

- → Adds address to identify ~~sed~~ sender/receiver
- → choses path

Application → access to network resources
(data)

presentation → translate, En/decryption, compression
(data)

session → establish, manage and terminate session
(data)

Transport → proces to proces delivery, error recovery
(segments)

Network → move packet from source to destination
(packets)

Data link → bits to frames, hop to hop
(Frames)

physical → transfer bits over medium.
(Bits)

TCP/IP

OSI	TCP/IP
Application presentation session	Application (Specific Address)
Transport	Transport (port)
Network	Network/Internet (Logical Address) IP
Data link physical	Network Access (physical Address) MAC

~~MAC~~ Physical Address (MAC)

- 48bit
- recognize device in same network
- Stricted to Local Network
- Data link layer

Logical Address

- → IP
- → Network layer
- → Ipv4 – 32 bit, IpV6 – 128 bit
- → connects devices across internet

Port Address

- Numerical Identifier
- Transport layer
- 16 bit
- ensures data reached correct Application
- http, https, smtp

Specific Address

- readable
- Application Layer
- Domain name, resourcepath, etc.

Chapter 3

Data & Signals

Analog Data → continuous information (sound wave)

Digital Data → discrete information (binary data)

* they take discrete/continuous values

Analog Signal → can have infinite values in a range.

Digital Signal → limited number of values

periodic Analog Signals

*) A simple PAS is a sinewave which can not be decomposed into simpler signals. A composite PAS is composed of multiple sinewaves.

Sine waves

most fundamental form of periodic analog signal.

- peak amplitude (Volt)
  Intensity
- frequency
- phase

period – time(s) needed to complete 1 cycle.

frequency – Number of periods in One (1) second.

$$T = \frac{1}{f}$$

$T \rightarrow s$

$f \rightarrow Hz$

Phase

↳ measured in degrees or radians

$$1^\circ = \frac{\pi}{180} \text{ rad}$$

wavelength

↳ distance in on period.

↳ depends on frequency and medium.

$$\lambda = cT = \frac{c}{f}$$

Bandwidth

$$B = f_h - f_l$$

difference of frequency in a composite signal.

Fouriero analysis → a composite signal is a combination of simple sine waves with differeent frequencies, amplitudes and phases.

Digital Signals

Number of bits per level (L) = $\log_2 L$

if number of bpL is 3.17 it will be rounded up to 4.
this number has to be an intger and a power of 2.

bit rate → number of bits send in 1 second (bps)

bit length
↳ similar to wavelength
↳ the distance one bit occupies on transmision medium

bit length = propagation speed × bit duration

A digital signal is a composite analog signal with a infinite bandwidth.

baseband transmission

↳ sending digital signal over a channel without changing it to analog.

↳ lowpass channel

low frequency = 0

high pass channel

high frequency = ∞

broad band transmission

↳ convert digital signal to an analog signal before transmission.

Transmission Impairment

- Attenuation
- Distortion
- Noise

Attenuation

↳ loss of energy during travelling through a medium.

$$dB = 10\log_{10}\frac{P_2}{P_1} = 20\log_{10}\frac{V_2}{V_1}$$

W V

Distortion

↳ Signal changing its form or shape

↳ happens when receiver has phases different from sender

Noise

↳ unwanted electrical or electromagnetic interface that distorts or disrupts the original signal.

signal to noise ration $SNR = \frac{\text{signal power}}{\text{noise power}}$

$SNR_{dB} = 10 \log_{10} SNR$

Data rate depends on,

i. bandwidth

ii. signal level

iii. quality of channel (noise)

noiseless: Nyquist bit rate

$\text{Bitrate} = 2 \times \text{bandwidth} \times \log_2 L$

* Increasing L will result in, the receiver distinguishing more levels, reducing the reliability of the system.

Noisy: Shannon Capacity

theoritical highest data rate in a noisy channel,

$$C = \text{bandwidth} \times \log_2(1+SNR)$$

Throughput

↳ actual measurement of how fast we can send data.

Propagation time → time for a bit to reach destination

$$T_p = \text{Distance} / V_p$$

Transmission time → time to send entire data

$$T_t = \text{Message size} / \text{bandwidth}$$

Latency = $T_p + T_t$ + queuing time + processing delay

Total bits in single line = bandwidth × delay chapter 4

Line coding

i. process of converting digital data to digital signals.

signal rate/pulse rate/ baud rate

$$S = N / r$$

$N \rightarrow$ Data rate

$r \rightarrow \dfrac{\text{data element}}{\text{signal element}}$

$S \rightarrow$ signal rate

$$S_{ave} = c \times N \times \frac{1}{r}$$

$\hookrightarrow$ case factor

* when 'c' is a to b tak average.

actual bandwidth of a digital signal is infinite but the effective bandwidth is finite.

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

↳ min bandwidth

$$N_{max} = B \times r \frac{1}{c} = 2B \log_2 L$$

Baseline

↳ the receiver calculates a running average of the received signal power.

↳ ~~log~~ long string of 0s or 1s can cause the Baseline to drift (wander)

DC components

↳ long string of same bit or constant digital signal for a while creates very low frequency (around 0), called dc components

Self Synchronization

↳ a digital self synchronizing signal includes transition/timing info like beginning, midle, end of pulse. whe receiver is out of sync. these points can reset the clock.

Line coding

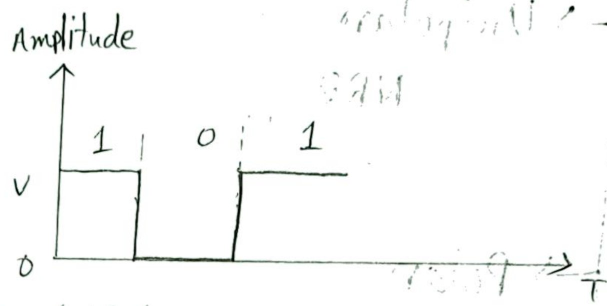
- Unipolar
  - NRZ
- Polar
  - NRZ, RZ and biphase (Manchester, d Manchester)
- Bipolar
  - AMI and pseudoternary
- Multilevel
  - 2B/1Q, 8B/6T and 4D-PAM5
- Multitransition
  - MLT-3

NRZ (Non-Return-to-Zero) Unipolar

costly

+V → 1

0V → 0

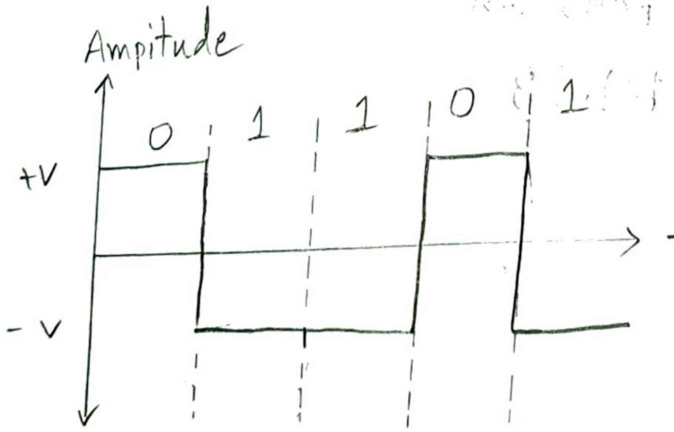


pros → simple

cons → High power consumption
→ Baseline wandering
→ inefficiency
→ DC

NRZ - Polar

NRZ-L



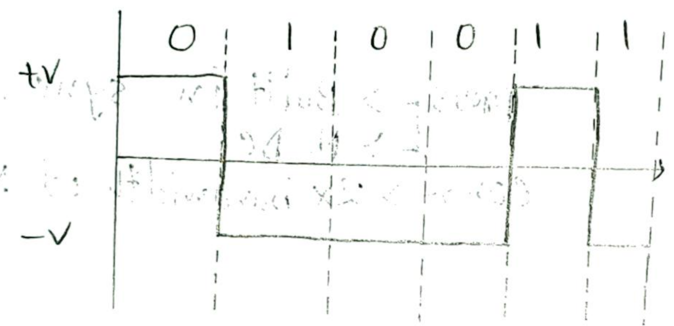
+V → 0

-V → 1

NRZ-I

change in voltage level → 1

No " " " " → 0

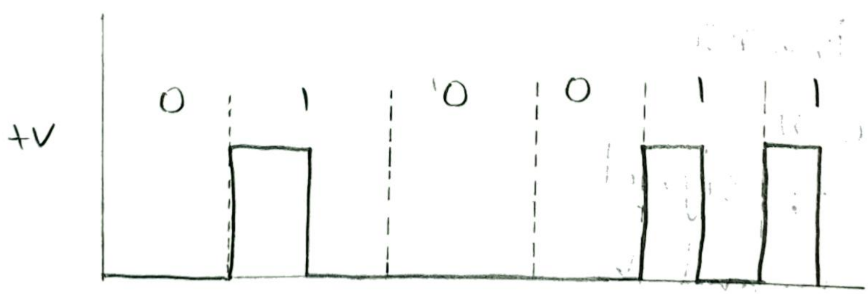


RZ - Return-to-Zero

RZ unipolar

0V for binary 0

half 1V " " 1



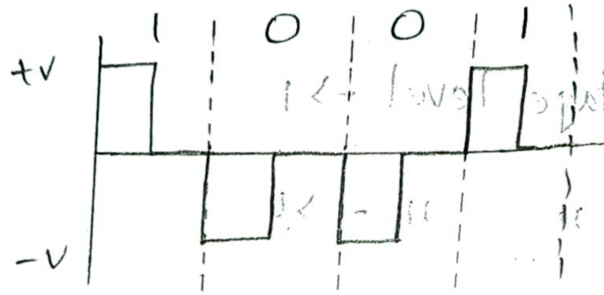
pros → Better sync than NRZ, No DC

cons → high band width, complex than NZR

RZ polar

$\frac{1}{2}(-V) \longrightarrow 0$

$\frac{1}{2}(+V) \longrightarrow 1$



lessen DC than RZ

Biphase

pros → Built in sync, Error detection
→ No DC

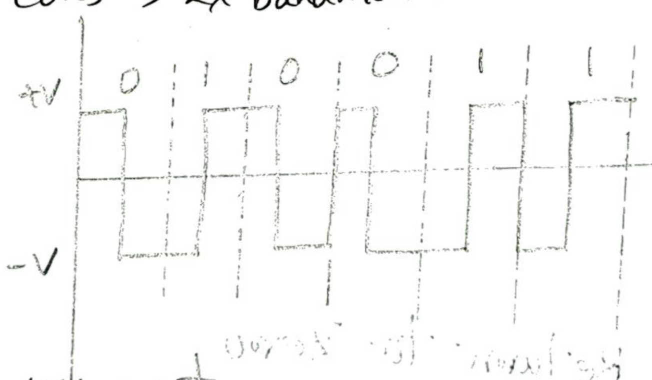
cons → 2x bandwidth of NRZ

Manchestar

0 →

1 →

↑ these can be different



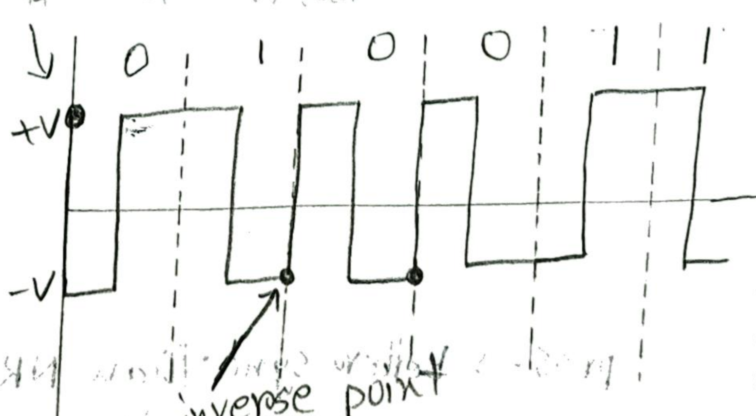
Differential Manchester

can start from any side

next bit
0 → inverse

1 → No "

for every bit the signal will stay at +V and -V

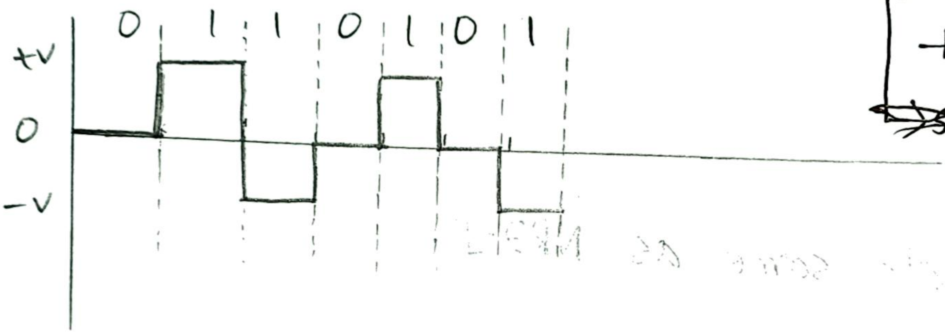


AMI

0 → 0V

1 → alternate one by one

starts from +V



con → self sync (for 0)

pro → no DC
→ better bandwidth than NRZ
→ ~~self sync~~

pseudoternary

litterally reverse of AMI

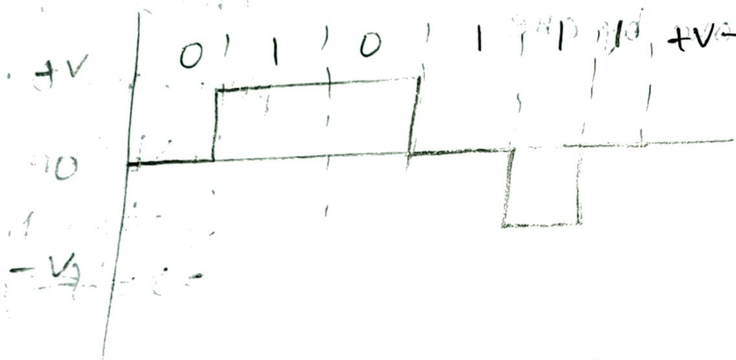
0 → alternate one by one   starts from +V

1 → 0V

MLT-3 (multitransition)

0 → no change
1 → alternate

+V → 0 → -V → 0 → +V



signal rate same as NRZ-I

Block coding

Takes m bits (in a block) returns n bits (block)

$m < n$

$2^m \rightarrow$ usable ~~b~~ data sequence

$2^n - 2^m \rightarrow$ invalid " "

8B/10B similar to $\underbrace{5B/6B + 3B/4B}$

$\downarrow$

better for error check & sync.

Scrambling

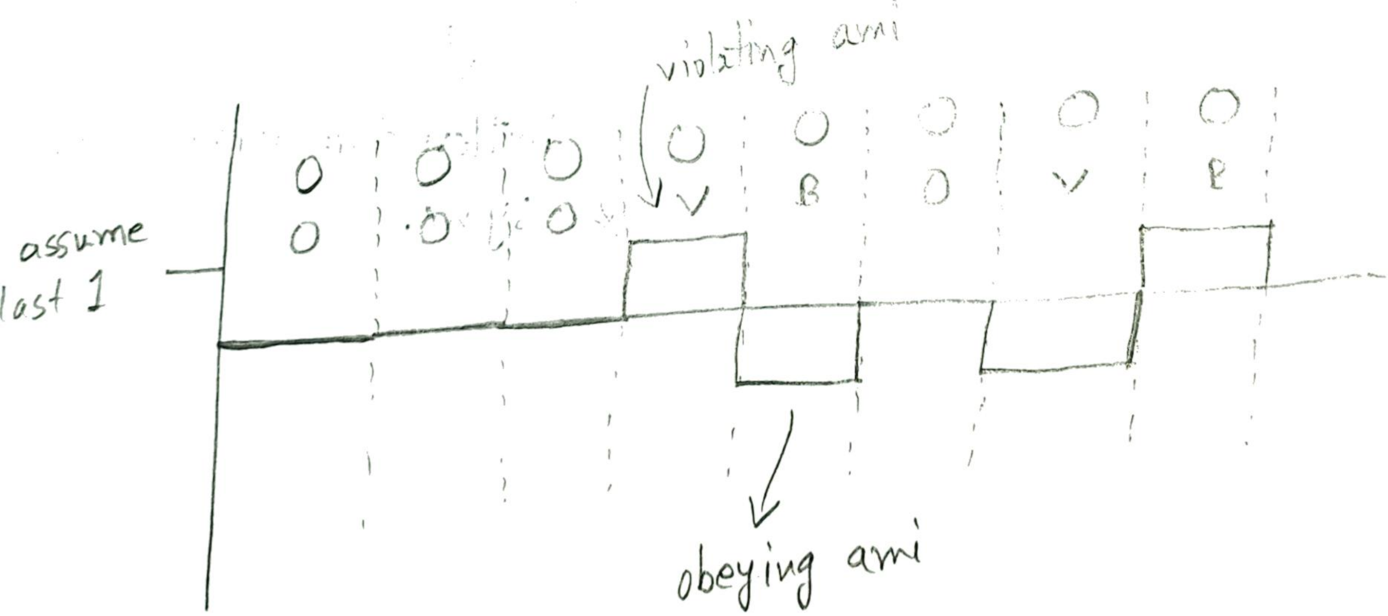
Both of thes techniques follow bipolar AMI

B8ZS North americ

If there is 8 consecutive 0 we will replace if with 000 VB 0 VB

V → violation of rule

B → By the rule



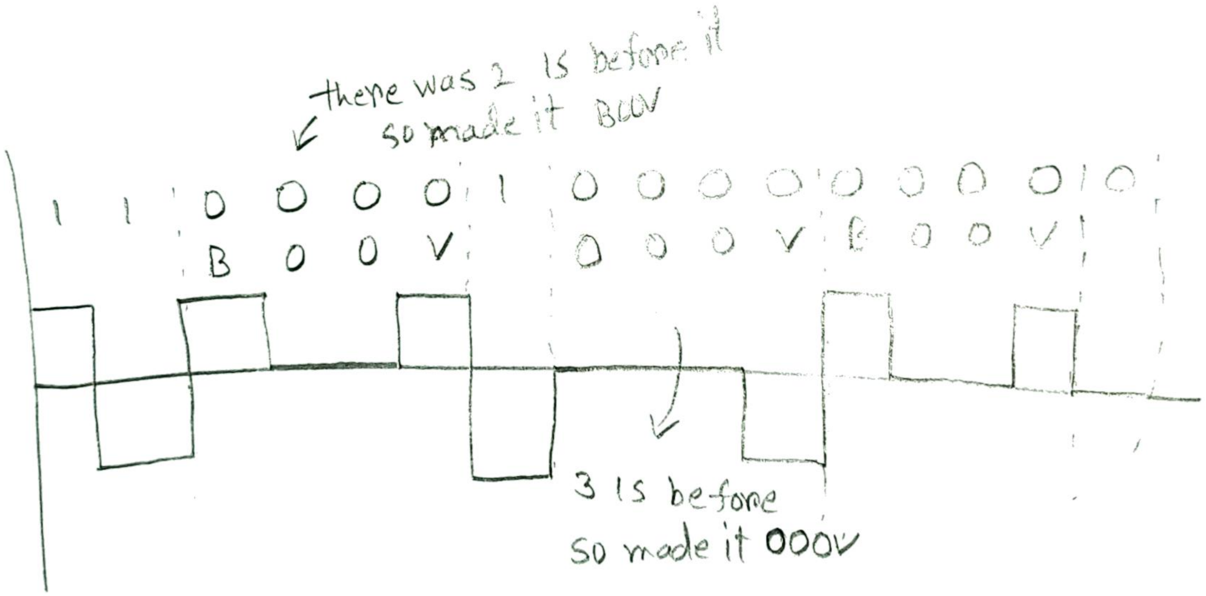
HDB3 Europe / Japan

consequtive 4 0s,

B00V → Even non 0 signal (1)

000V → odd " 0 " (0)

we count the non zero signals before continuous 4 0s and ~~ad~~ ~~no~~ make it B00V/000V to make ~~not~~ non zero signals even.



chapter six

Multiplexing → simultaneous transmission of multiple signals across a single data link.

multiplexer (MUX) → combines signal into a single stream.

demultiplexer (DEMUX) → [Reverse]

Multiplexing

- Frequency division multiplexing
- Wavelength dm
- Time dm

FDM -> analog multiplexing technique that combines analog signals.

-> happens if:

link (bandwidth) > Signal combination (bandwidth)

*) Carrier frq. are increased a bit. These bandwidth ranges are called channels.

*) channels can be separated by strips of unused bandwidth called guard bands

modulator turns an analog signal into a carrier signal.

Multiplexer combines them.

Demultiplexer uses filers to decompose the combined signal to component signals.

Demodulator separates the signal from carrier signal.

WDM (fiber optic cable)

- conceptually same as FDM
- frequencies are very high
- complex technology

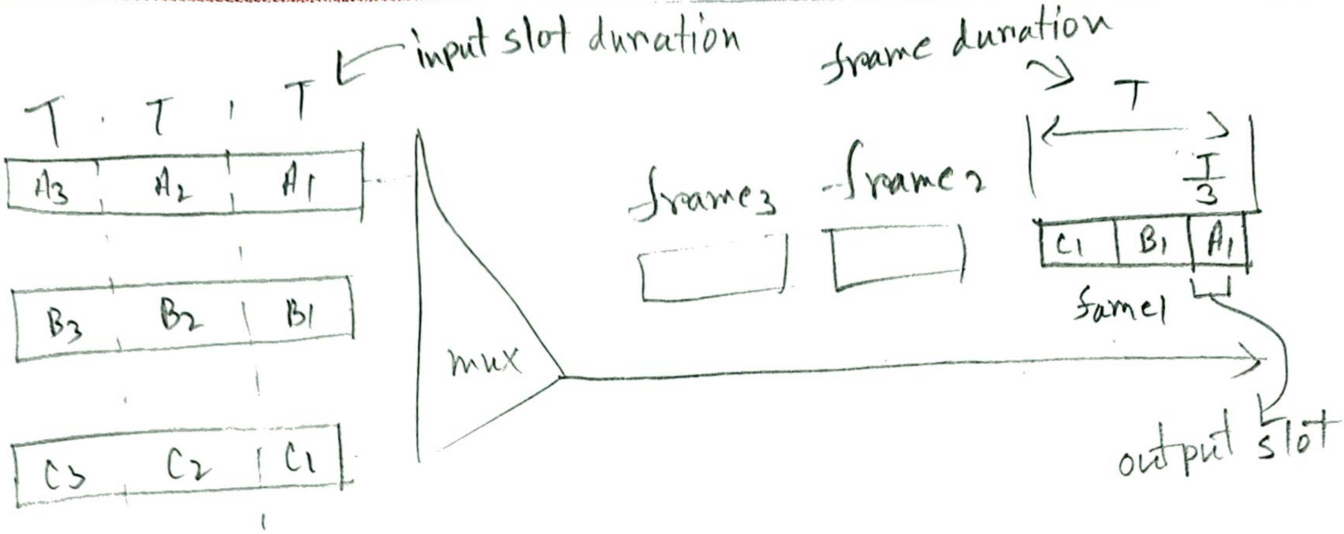
combine multiple light source into one (done by prism)

TDM (digital)

- Each occupies a portion of time in the link.
- delivery is fixed.

Synchronous TDM

each input connection has an allotment in output, even if it is not sending data.



Input bit duration = 1/ input bit rate

" slot " = $\square$ × No. of bits per slot

Frame duration = $\square$

Output slot " = $\square$ / No. of channel

Frame rate (fps) = 1/ frame duration

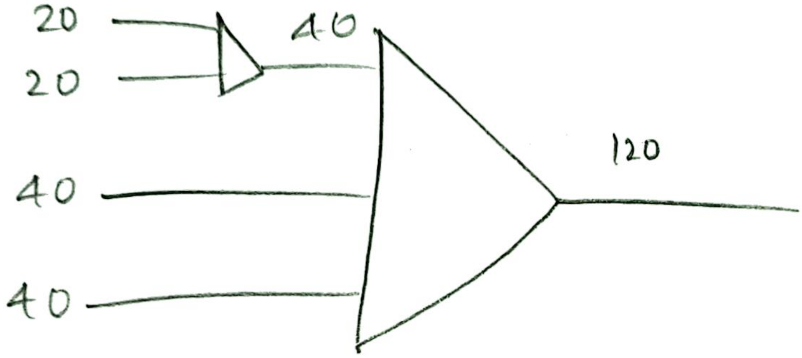
Frame size = No. of bits perslot × No. of channel + synchronization bits

Output bitrate (bps) = Frame rate × frame size = $\frac{1}{\text{Out bit dur.}}$

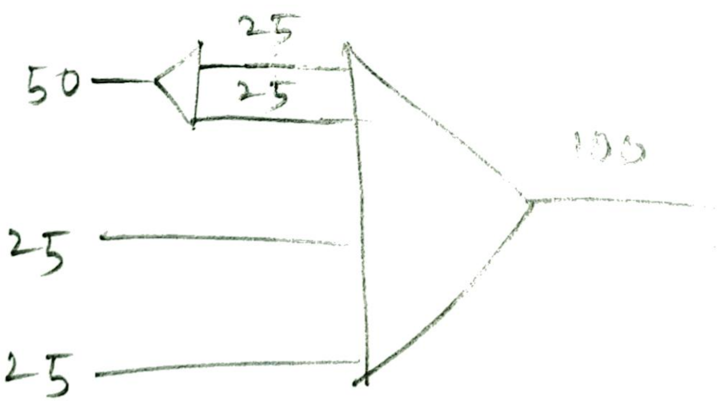
Output bit duration = 1/ output bit rate

= Input bit. dur/ no. of channel

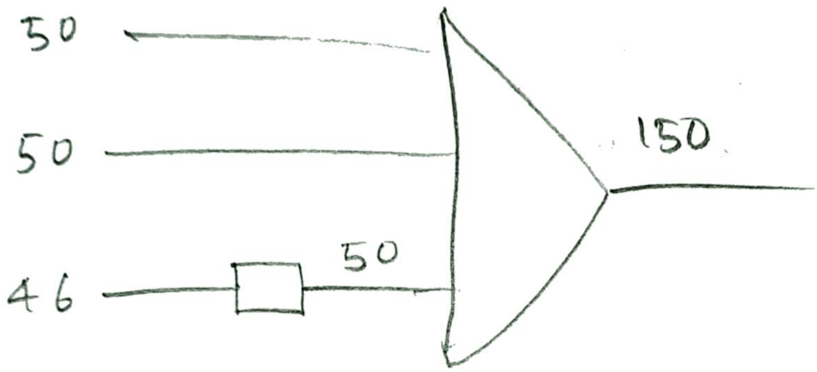
multilevel multiplex



multislot allocation



Pulse stuffing



Statistical TDM

slots are dynamically allocated.

If the input line has data it allocates a slot.

needs address of destination in every slot.

10

Block Coding

Here we divide our message into blocks, each of k bits (datawords)

codewords		datawords		redundant bits
n	$=$	k	$+$	r

$\downarrow$

(size of blocks)

reciever has a list of valid codwords
The original cw. changed to an invalid one } detection

but even after currruption the word matches a valid cw. the error stays undetected.

Can detect 1 bit error only (not for ~~b~~ burst error)
" correct 1 " " "

Hamming Distance → the number of differences between corresponding bits (between two words)

Xor

same bit → 0

diff. bit → 1

sent · corrupted

hamming distance $d(000, 011)$ is 2

$000 \oplus 011 \Rightarrow 011$ (there is 2 ones)

Minimum Hamming Distance

dataword		Codeword
00	-	000
01	-	011
10	-	101
11	-	110

take all combination and find hamming distance for codewords

$000 \oplus 011 = 011 = 2$

$000 \oplus 101 = 101 = 2$

$000 \oplus 110 = 110 = 2$

$011 \oplus 101 = 110 = 2$

$011 \oplus 110 = 101 = 2$

$101 \oplus 110 = 011 = 2$

$d_{min} = 2$

Error detect = $(d_{min}-1)$ bit

" correct = $(d_{min}-1)/2$ bit

Ham. dis.

If we recieve a wrong block, we will $\oplus$ it with over codewords. The cw. that has min(1) hamming dis. is the actual code words.

CRC encode

Dataword = 1001

divisor = 1011 {L = 4}
(known)

(ignore the procedure)

```
1011 ) 1001,000 --> L-1
     ⊕ 1011
       0100
       0000
       ----
       1000
     ⊕ 1011
       ----
       0110
       0000
       ----
        110 remainder (L-1)
```

dataword

~~CW. 1000~~

CW. | 1 0 0 1 | 1 1 0 |

if remider was 110 and divisor L was 5
cw would be 1001,0110

decode

```
1011 ) 1 0 0 1 1 1 0
       1 0 1 1
     ⊕ 0 1 0 1
       0 0 0 0
         1 0 1 1
         1 0 1 1
       ⊕ 0 0 0 0
           0 0 0 0
             0 0 0
```

if there was a reminder then the data was corrupted

dataword accepted } 1001

$$
\begin{array}{r}
1010 \\
1011 \overline{)\,1001000} \\
\oplus \quad 1011 \\
\hline
\cancel{0}0100 \\
0000 \\
\hline
\cancel{0}1000 \\
1011 \\
\hline
\cancel{0}0110 \\
0000 \\
\hline
\cancel{0}110
\end{array}
$$

cut the first 0

after cutting if still its 0 divide with 0

CRC → Cyclic Redundary check (Lan / Wan)

can detect all odd errors single bit and burst error of length equal to polynomial degree.

divisor length

Polynomial

dataword - 100110 → $1x^5 + 0x^4 + 0x^3 + 1x^2 + 1x^1 + 0x^2$

$= x^5 + x^2 + x$

Divisor - 1011 → $x^3 + x + 1$

100110000 → $x^8 + x^5 + x^4$

dataword × x^{L-1} = Codeword

$\Rightarrow (x^5 + x^2 + x)\, x^{4-1} = x^8 + x^5 + x^4$

$$
\begin{array}{l}
x^3+x+1 \,)\, x^8 + x^5 + x^4 \,(\, x^5 + x^3 + 1 \\
\qquad\qquad\; \underline{x^8 + x^6 + x^5} \\
\qquad\qquad\quad x^6 + x^4 \\
\qquad\qquad\quad \underline{x^6 + x^4 + x^3} \\
\qquad\qquad\qquad x^3 \\
\qquad\qquad\qquad \underline{x^3 + x + 1} \\
\qquad\qquad\qquad x + 1 < x^3
\end{array}
$$

CW = $x^8 + x^5 + x^4 + x + 1$

CHECKSUM

encode

$$
\left.\begin{array}{rrrr}
 & 0 & 0 & 1\,0 \\
 & 1 & 0 & 0\,0 \\
 & 1 & 0 & 1\,1 \\
 & 1 & 1 & 1\,1 \\
+ & 0 & 1 & 1\,0
\end{array}\right\}\text{(send)}
$$

$$
\begin{array}{r}
10\,|\,1\;0\;1\;0 \\
+\;1\;0 \\
\hline
1\;1\;0\;0 \rightarrow \text{sum}
\end{array}
$$

0 0 1 1 → 1's complimen / $\boxed{\text{checksum}}$

→ (send)

$$
\begin{array}{r}
7 \\
11 \\
12 \\
0 \\
+\;6 \\
\hline
36
\end{array}
$$

12 → max ~~8~~ → $\underline{(1100)}$ 4

36 → 10|0100

+ 10

0110

1001 → 9

ecode

add all sent data (inc. checksum)

$$\begin{array}{r} 7 \\ 11 \\ 12 \\ 0 \\ 6 \\ +\ 9 \\ \hline 45 \end{array} \rightarrow \begin{array}{r} 10\,1101 \\ 10 \\ \hline 1111 \\ 0000 \end{array}$$

0000 (1's com.)

↳ correct

DisAd.

Odd number of bits can be detected.

error detect won't happen if two bits lie at the same position in two distinct words.

Multiple Access protocol

- Random access
  useː less traffic
- Controlled access
  medium traffic
- Channelization
  high traffic

Randon Access

→ Each station can transmit data when it desires if it followed the predefined procedure.

→ If multiple station sends data, ~~there~~ a collision occurs

→ No station is superior

Propagation time (1bit) $T_p = \cancel{time/speed}\ \dfrac{\text{Distance}}{\text{speed (P)}}$

Transmission time T_t = Messagesize / Bandwidth

(time need to bring whole packet to the link)

Random Access Protocol

- → ALOHA
- → CSMA
- → CSMA/CD
- → CSMA/CA

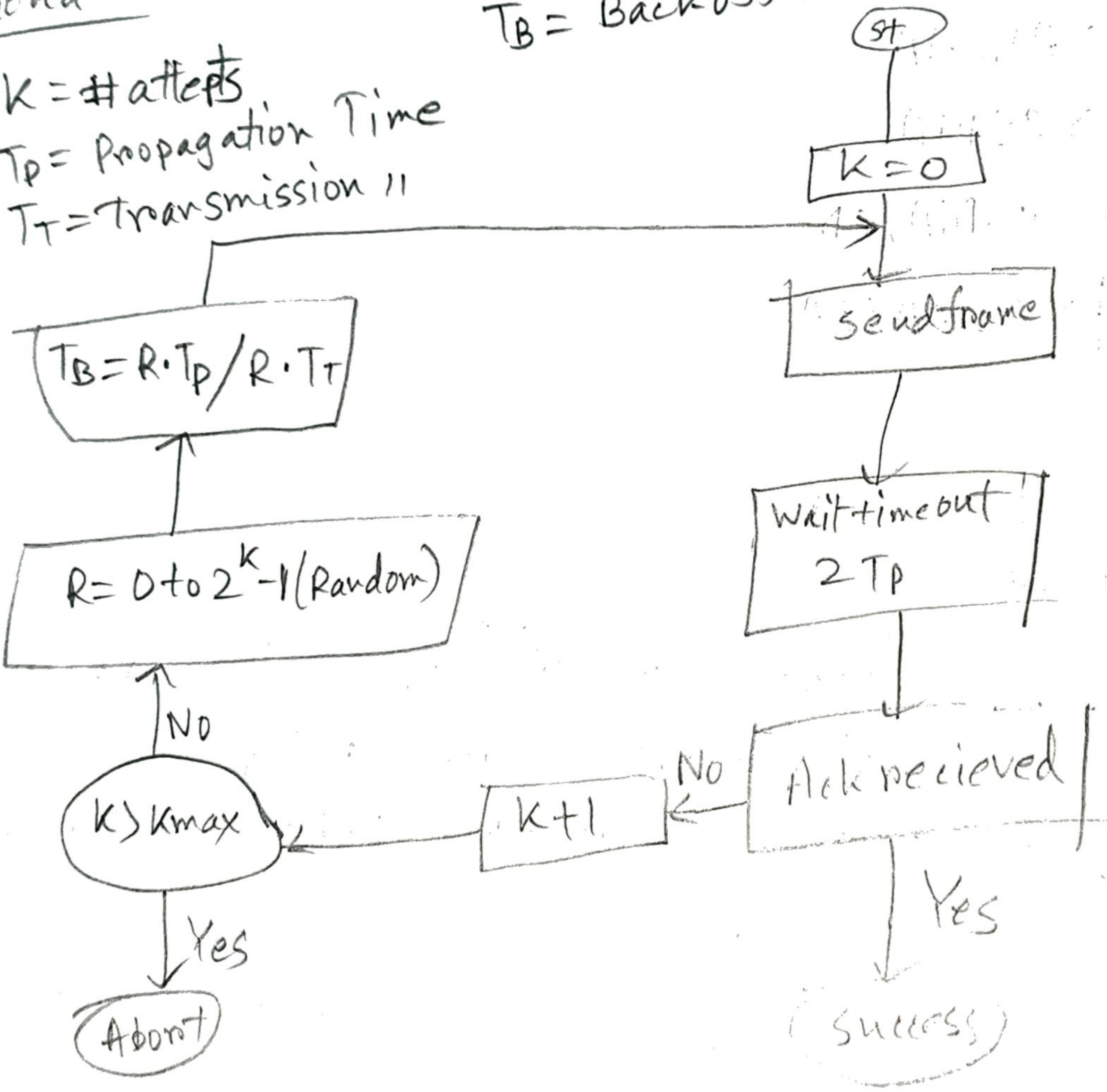
Pure Aloha

- → relies on "Acknowledgement" from the receiver. If the ack. doesn't arrive after a time period station assumes frame/ack. has been destroid and resend frame.
- → If collision happens with two or more station and they resend their frames again it will collide again.
- → Pure Aloha make the station wait a random amount of time before resend. It is called backoff time T_B.

P. Aloha

T_B = Backoff time

K = # attempts
T_P = Propagation Time
T_T = Transmission "



Kmax = 15

vulnerable time $= 2T_T$

$\boxed{\text{frames in } T_T}$

Throughput, $S = G \times e^{-2G}$ [G → # station transmit at same time]

$S_{max} = 0.184 \left(G = \frac{1}{2}\right)$

Slotted ALOHA

- Divide time into slots of T_T
- Station sends frame only at the beginning of a time slot
- Vulnerable time T_T

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

$$S_{max} = \cancel{3.68}\ 0.368 \ (G=1)$$

CSMA

Carrier Sense Multiple Access

- senses voltage before sending
- Reduce the possibility of collision but can't eliminat it due to propagation delay.

vulnerable time = T_P (propagation time)

CSMA/CD

$T_T \geq 2T_P$