a Information Source :→
Information Source produces the message signal

a Symbol Rate :→
It is rate at which the information source generates source Alphabet. It is represented in symbols/sec.

b Entropy :→
It is defined as Average information content per symbol. It is designated by H.

c Information Rate :→
Information Rate is defined as the maximum rate of transmission of errorless data. It can be achieved by multiplication of Symbol Rate and Entropy.

$\boxed{\text{Information Rate} = \text{Symbol Rate} \times \text{Entropy}}$

6 Channel Demodulator :→
It converts received electrical signal into sequence of bits with minimum error and maximum efficiency.

(5 marks)

1. Introduction (3 hrs)

1.1 Digital Communication sources, Transmitter, transmission channel and Receiver

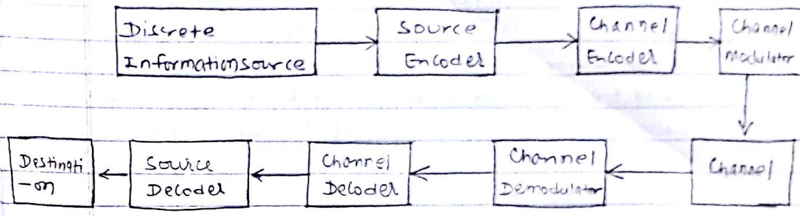


fig :→ Block Diagram of Digital Communication system

Digital Communication System transmits signal (sequence of symbols) in discrete form from source to pre-assigned or designated destination with maximum possible rate and accuracy.

Above figure shows the Block diagram of Digital Communication system

1. Information Source :→
Information source produces the message signal (voice, video, data, image) discrete in nature. It is characterized by parameters like

2. Source Encoder :→
It converts the sequence of symbol at its input into binary sequence of 0's and 1's with addition of code word to the symbol at its input.

3. Channel Encoder :→

The output of the source encoder is then passed through the channel Encoder. Channel Encoder adds redundant (extra control bits) bits to the input sequence. Extra bits are also called error control bit which makes receiver to detect error. Channel Encoder is used to enhance reliability and efficiency of the system.

4. Channel Modulator :→

It converts the bit stream from channel Encoder to electrical form. Channel modulator makes the form suitable to transmit through the medium. Channel modulator also performs modulation where the parameter (Amplitude, Frequency, phase) of carrier signal is changed with respect to the message signal. Basic Digital modulation techniques are Amplitude Shift Keying (ASK), Frequency Shift keying (FSK) and phase shift keying (PSK).

5. Channel :→

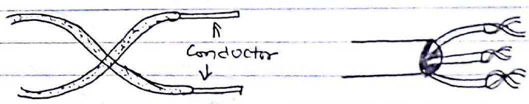
The physical medium over which the signal is passed or transmitted from transmitter to receiver is called communication channel. Depending on the mode of transmission, communication channel is of two types

Communication channel
- Channel based on Guided propagation
  - Telephone Channel
  - Coaxial Cable
  - Optical Fiber
- Channel based on Free propagation
  - Wireless Broadcast Channel
  - Satellite Channel
  - Mobile Radio Channel

a. Channel based on Guided propagation

i) Telephone channel :→

Telephone channel are made using the twisted pair of wires which is shown below



Twisted pair

Shielded Multiple twisted pairs

A twisted pair consists of two insulated conductor twisted together in the spiral form. This is most commonly used medium. It is cheap and can be shield or unshielded.

- Unshielded twisted pair are easy to install and is cheap. It is more prone to noise interference

- Shielded twisted pair is provided with plastic coating have high noise immunity.

Similarly, Telephone channel shows Band pass characteristics over 300 to 3400 Hz. It has high signal to noise Ratio (SNR) about 20 dB. It has 16.8 kbps of maximum transmission rate

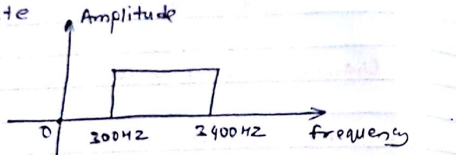


fig :→ Characteristics of telephone Channel.

ii) Coaxial Cable :→

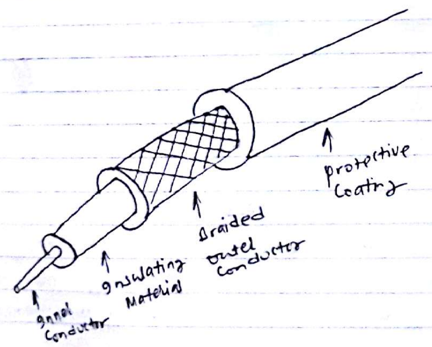


fig :→ Coaxial cable

Coaxial consists of two concentric conductors seperated by dielectric material. The external conductor is metallic braid which provides shielding

* Important facts of Coaxial Cable

a. Coaxial cable was developed for analog communication which carries 10,000 voice channel at a time

b. Coaxial cable is also used in Digital Communication which supports data rate upto 8.5 Mbps to 274 Mbps.

eg :→ Ethernet LAN, TV - cable lines.

c. Has large bandwidth and low losses.

d. It has excellent immunity to noise.

iii) optical Fiber cable →

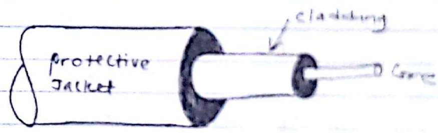


fig :→ optical Fiber cable

An optical fiber is a dielectric wave guide that operates at optical frequency.

As shown in above figure, it

Consist of inner glass core surrounded by Glass cladding which has lower refractive index. Digital signals are transmitted in the form of light trapped in Glass core.

* Advantages

a. It has enormous potential bandwidth of GHz and data rate of terabit per second.

b. Low transmission loss.

c. Immunity to electromagnetic interference.

d. Small size and weight.

e. Ruggedness and Flexibility.

b. Channel based on free propagation

i. Wireless broadcast channel :→

The channel is used for transmission of radio signals and TV signals are called broadcast channel.

ii. Mobile Radio channel :→

In mobile communication the radio propagation takes place due to travelling of electromagnetic waves from the surface of the surrounding buildings and diffraction over and around them. Thus having multipath while reaching to the receiver it is also called multipath communication.

iii) Satellite channel :→

Satellite channel provides broad area coverage which is based on Line of sight (LoS) communication. This system uses satellite placed in Geostationary orbit at an altitude of 36000km. Most popular frequency band for satellite communication is 6 GHz for uplink and 4 GHz for down link.

6. Channel Decoder :→

Channel Decoder recovers information bearing bit stream from coded bit stream with minimum error and maximum efficiency.

7. Source Decoder :→

It converts the binary output of channel decoder into sequence of symbols with minimum error and maximum efficiency. It is then reached to ~~Destination~~

* Advantages of Digital Communication

1. Digital Communication has increased immunity to noise and interference.

2. It is easy to store.

3. It is flexible (Transmission rate can be easily changed to adopt different environment and to interface with different type of equipment)

4. Error Correction ability.

5. Simple and cheap compared to Analog Communication

6. In Digital Communication voice, video, Data and other data may be merged and transmitted over a common channel using Multiplexing.

7. Data Encryption is performed in digital communication, only permitted Receivers are allowed to detect.

* Disadvantages

1. High Bandwidth Required
2. [redacted] Additional encoding and decoding circuits are required to transmit and receive.

3. Digital Communication requires synchronization in case of synchronous modulation.

* Difference betn Analog and Digital Communication

	Analog	Digital
1.	Message signal to be transmitted is Analog in nature	1. Message signal to be transmitted is Digital in nature.
2.	[redacted] Requires less bandwidth than Digital Communication system.	2. Requires more bandwidth than Analog Communication system.
3.	Less Noise Immunity.	3. Digital Communication system has high Noise immunity.
4.	Less secured.	4. More secured, technique like Encryption is performed.
5.	eg:→ A.M, FM, PM	5. eg:→ PCM, DPCM.

1.2 Noise

Noise is defined as an error or undesired signal which interferes the modulated signal in the channel. It is random in nature and are categorized as

1. Internal Noise
a. Thermal/White/Johnson Noise
b. Shot Noise.
c. Partition Noise.
d. Flicker or Low Frequency Noise
e. High Frequency or Transient time Noise
f. Generation-Recombination Noise.

2. External Noise
a. Man Mode Noise
b. Natural Noise

1. Internal Noise :→

Noise which is generated within the system is called Internal Noise. They are

a. Thermal/White/Johnson Noise :→

Noise generated due to random movement of free electrons within the system is called Thermal/White/Johnson Noise.
Mathematically,

Average Noise power is given by
$\boxed{P_n = KTB}$

where K = Boltzman Constant = 1.38×10^{-23} J/K.
T = Temperature in degree kelvin.
B = Bandwidth of Noise spectrum.

b. Shot Noise :→

Noise caused by the random fluctuation in electron emission from cathode in vaccum tube is called Shot Noise.

c. partition Noise :→

Random fluctuation occured due to division of current into two or more path is called partition Noise. eg:→ In transistor division of Emitter current (IE) into base and collector.

d. Low Frequency or Flicker Noise :→

Noise produced due to fluctuation in carrier density (PSDF is called Low Frequency or Flicker Noise. Flicker Noise is inversely proportional to the frequency given as

$\boxed{N(f) \propto \frac{1}{f}}$

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e. High Frequency or Transient time Noise :→
In Semiconductor, if the carrier diffuses back to the source rather than crossing the junction at high frequency causes High Frequency or Transient time Noise.
(power spectral density Function)
* psdf of this Noise increases with frequency.

f. Generation – Recombination Noise :→
Noise generated due to recombination and generation of charge carrier is called Generation – Recombination Noise.

2. External Noise :→
Noise generated externally to the communication system is called External noise. They can be

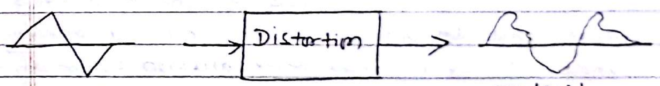
a. Manmade :→ Industries, Manufacturing Quality, semiconductor defects.

b. Natural Noise → Environment, Temperature, Cosmic Noise

* Interference :→
Interference is defined as the superimpose or mixing of transmitted signal from same source or different source. Interference can be constructive or destructive. Here, we generally relate with destructive phenomena

fig :→ Inter Symbol Interference

* Distortion :→
Distortion is defined as the undesirable change of a signal. This undesirable change will change the characteristics of information signal and hence loss the original information.
For eg :→ unwanted change in waveform of the input signal



Input
output

There are two types of distortion

1. Linear Distortion :→
Linear Distortion is produced by linear devices (eg Resistor, capacitor, inductor) due to non uniform frequency and phase responses

A linear device is distortionless if magnitude response/transfer function/impulse response is constant and phase is linearly proportional to frequency for $f \leq f_{max}$.

example

$y(t) = k_1 A_1 \cos(w_1 t + \theta_1) + k_2 A_2 \cos(w_2 t + \theta_2)$ – Linear Distortion.

$y(t) = k A_1 \cos(w_1 t + \theta_1) + k A_2 \cos(w_2 t + \theta_2)$ – Distortionless system.

2. Non Linear Distortion :→

Non Linear Distortion is produced due to Non linear Input/output characterstics of the System or device (eg diode)

example :→

$y(t) = a_1 x(t) + a_2 x^2(t) + a_3 x^3(t) + \dots$

* Fundamental limitation due to Noise, Distortion and Interference

Noise are the unwanted signal that interferes the information bearing Signals. Noise causes transmission error and disrupts the Communication process.

Noise which results distortion of the information signal needs to characterise and model in order to diffrentiate with the information bearing signal.

As Noise, Interference and Distortion are the limiting factors in Communication System. Modelling and Removal of this effects are the challenges and biggest achievement for modern Communication system.

In Fixed length code each codeword has fixed or same length. whereas variable code the codewords may have different length.

DMS ⇒ Discrete time or Discrete amplitude random process where random variable x_i are generated independently with the same distribution.

* Source coding :→

The Conversion of Discrete memoryless source (DMS) output into a sequence of binary symbol (binary code word) is called source coding and the device is called Source Encoder.

Let X be a DMS with finite entropy $H(X)$ and an alphabet $(x_1, x_2 \ldots x_m)$ with corresponding probability of occurence $P_1, P_2 \ldots P_m$.

Let the binary codeword assigned x_i have length n_i bits. Then the average codeword length 'L' per source symbol is

$$\boxed{L = \sum_{i=1}^{m} P(x_i)\, n_i}$$

The code efficiency is given by

$$\boxed{\eta = \frac{L_{min}}{L}}$$

L_{min} ⇒ Minimum possible value of 1 when η approaches unity, the code is said to be efficient.

$$\boxed{\text{Code Redundancy } \gamma = 1 - \eta}$$

According to the Source Coding theorem, average codeword length 'L' per symbol is bounded as

$$\boxed{|L| \geq H(x)}$$

with $L_{min} = H(x)$

$$\boxed{H(x) = \sum_{i=1}^{m} P(x_i) \log_2\left(\frac{1}{P(x_i)}\right)} \qquad H(x) = \sum_{i=1}^{m} P(x_i) \log_2 \frac{1}{P(x_i)}$$

$$\boxed{\text{Code efficiency } \eta = \frac{H(X)}{L}}$$

* Find the average length and which code is better.

Source	P_i	Code A	Code B
S_1	0.5	00	1
S_2	0.1	01	000
S_3	0.2	10	001
S_4	0.2	11	01

For Code A

$$L_A = \sum_{i=1}^{4} P(x_i)\, n_i$$

$$L_A = 2\times0.5 + 2\times0.1 + 2\times0.2 + 2\times0.2$$

$$L_A = 2 \text{ bits/symbol}$$

For Code B

$$L_B = \sum_{i=1}^{4} P(x_i)\, n_i$$

$$L_B = 1\times0.5 + 3\times0.1 + 3\times0.2 + 2\times0.2$$

$$L_B = 1.8 \text{ bits/symbol}$$

Entropy $H(x) = 0.5 \log\left(\frac{1}{0.5}\right) + 0.1 \log\left(\frac{1}{0.1}\right) + 0.2 \log\left(\frac{1}{0.2}\right) + 0.2 \log\left(1/0.2\right)$

$$= 0.5 \times 0.30 + 0.1 \times 1 + 0.2 \times 0.69 + 0.2 \times 0.69$$

$$H(x) = 0.526/\log 2 \doteq 1.747 \text{ bits/Symbol}$$

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For $|L| \geq 1.747$

Code A, efficiency $\eta_A = \frac{1.747}{2} = 0.873 = 87.3\%$

Code B, efficiency $\eta_B = \frac{H(x)}{L} = \frac{1.747}{1.8} = 0.97 = 97\%$

Code Redundancy $\gamma_A = 1 - \eta_A = 1 - 0.873 = 0.127 = 12.7\%$

" " $\gamma_B = 1 - \eta_B = 1 - 0.97 = 0.03 = 3\%$

Code B is better than Code A

* Compact Codes :→

Compact Codes are the technique whose average length is less than other uniquely decodable Codes for the same source or code Alphabet. There are two types of compact codes

1. Shannon-Fano Coding :→

Shannon-Fano Coding is a technique to compress the information or data based on prefix code for a set of symbols. It is a top-down approach.

Algorithm

Step 1 :→ List the source symbols in order of decreasing probability.

Step 2 :→ partition the set into two sets that are as close to equiprobables as possible and assign 0 to upper set, 1 to lower set.

Step 3 :→ Continue this procedure, each time partitioning the sets with as nearly equal probabilities as possible until further partioning is not possible.

* Numerical

1) Find the average length, Code Redundancy and efficiency using Shannon-Fano coding

x_i	x_1	x_2	x_3	x_4	x_5	x_6
$p(x_i)$	0.3	0.25	0.2	0.12	0.08	0.05

Soln :→

x_i	$p(x_i)$	Step 1	Step 2	Step 3	Step 4	Code
x_1	0.3 0.55	0	0	—	—	00
x_2	0.25	0	1	—	—	01
x_3	0.2 0.45	1 0.2	0	—	—	10
x_4	0.12	1 0.25	1 0.12	0	—	110
x_5	0.08	1	1 0.13	1 0.08	0	1110
x_6	0.05	1	1	1 0.05	1	1111

Average Codeword length

$$L = \sum_{i=1}^{6} P(x_i) n_i$$

$L = 0.3 \times 2 + 0.25 \times 2 + 0.2 \times 2 + 0.12 \times 3 + 0.08 \times 4 + 0.05 \times 4$

Average Codeword length $(L) = 2.38$ bits/symbol

$$\text{Entropy } H(x) = \sum_{i=1}^{6} P(x_i) \log_2\left(\frac{1}{P(x_i)}\right)$$

$\text{Entropy } H(x) = 0.3 \log_2\left(\frac{1}{0.3}\right) + 0.25 \log_2\left(\frac{1}{0.25}\right) + 0.2 \log_2\left(\frac{1}{0.2}\right) + 0.12 \log_2\left(\frac{1}{0.12}\right) + 0.08 \log_2\left(\frac{1}{0.08}\right) + 0.05 \log_2\left(\frac{1}{0.05}\right)$

$= 0.156 + 0.150 + 0.139 + 0.11 + 0.087 + 0.065$

Entropy $H(x) = 0.707/\log 2 = 2.34$ bits/symbol

$$\text{Efficiency } (\eta) = \frac{\text{Entropy } H(x)}{\text{Average Codeword length } (L)} = \frac{2.34}{2.38} = 0.9831$$

Efficiency $\eta = 98.31\%$

Code Redundancy $(\gamma) = 1 - \eta = 1 - 0.9831 = 0.0169$

Code Redundancy $(\gamma) = 1.69\%$

* Huffman Code:→

Huffman Code is also a technique to compress the information or data producing prefix codes with lowest expected code word length.

Huffman code produces optimal prefix code, lowest codeword length, easy to compute and efficient than Shano-Fano Coding. It is bottom-up approach.

Algorithm

Step 1: → List source symbol in order of decreasing probability.

Step 2: → Combine the probability of two symbols having lowest probable and reorder the resultant probabilities. Repeat until there are the ordered probabilities remaining.

Step 3: → Start encoding with the last reduction. Assign '0' as the first in codewords for all source symbols associated with the first probability, assign '1' to the second probability.

Step 4: → Now go back and assign 0 & 1 to the second digit for the two probabilities that were combined in the previous reduction step, retaining all assignments until the first column is reached.

* Numerical

Find the average length, code redundancy and efficiency using Huffman code for

$P(x_1) = 0.3$ $P(x_2) = 0.4$ $P(x_3) = 0.06$

$P(x_4) = 0.1$ $P(x_5) = 0.1$ $P(x_6) = 0.04$

x_i	$P(x_i)$	Stage1	Stage2	Stage3	Stage4	Stage5	Code
x_2	1 0.4	1 0.4	1 0.4	1 0.4	0 0.6	1.0	1
x_1	00 0.3	00 0.3	00 0.3	0.3	1 0.4		00
x_5	011 0.1	011 0.1	0100 0.2	010 0.3			011
x_4	0.1	0.1	0101 0.1				0100
x_3	0.06 01010	0.1					01010
x_6	0.04 01011						01011

$$\text{Average length}(L) = \sum_{i=1}^{6} P(x_i) n_i$$

$$\text{Average length } L = P(x_1)n_1 + P(x_2)n_2 + P(x_3)n_3 + P(x_4)n_4 + P(x_5)n_5 + P(x_6)n_6$$

$$L = 0.3 \times 2 + 0.4 \times 1 + 0.06 \times 5 + 0.1 \times 4 + 0.1 \times 3 + 0.04 \times 5$$

$$L = 0.6 + 0.4 + 0.3 + 0.4 + 0.3 + 0.2$$

$$L = 2.2 \text{ bits/symbol}$$

$$\text{Entropy } H(x) = \sum_{i=1}^{6} P(x_i) \log_2\left(\frac{1}{P(x_i)}\right)$$

$$H(x) = P(x_1)\log_2\left(\frac{1}{P(x_1)}\right) + P(x_2)\log_2\left(\frac{1}{P(x_2)}\right) + P(x_3)\log_2\left(\frac{1}{P(x_3)}\right) + P(x_4)\log_2\left(\frac{1}{P(x_4)}\right) + P(x_5)\log_2\left(\frac{1}{P(x_5)}\right) + P(x_6)\log_2\left(\frac{1}{P(x_6)}\right)$$

$$H(x) = 0.3\log_2\left(\frac{1}{0.3}\right) + 0.4\log_2\left(\frac{1}{0.4}\right) + 0.06\log_2\left(\frac{1}{0.06}\right) + 0.1\log_2\left(\frac{1}{0.1}\right) + 0.1\log_2\left(\frac{1}{0.1}\right) + 0.04\log_2(1/0.04)$$

$$H(x) = 0.1568 + 0.1591 + 0.0733 + 0.1 + 0.1 + 0.0559$$

$$H(x) = 0.6451/\log 2 = 2.142 \text{ bits/symbol}$$

$$\text{Efficiency}(\eta) = \frac{\text{Entropy } H(x)}{\text{Average Codeword Length }(L)}$$

$$= \frac{2.142}{2.2} = 0.9736$$

$$\text{Efficiency}(\eta) = 97.36\%$$

$$\text{Code Redundancy}(\gamma) = 1 - \eta = 1 - 0.9736$$

$$\text{Code Redundancy}(\gamma) = 0.0264$$

$$\text{Code Redundancy}(\gamma) = 26.4\%$$

2) Find the average length, code redundancy and efficiency using Huffman code.

$P(x_1) = 0.2$ $P(x_2) = 0.25$ $P(x_3) = 0.01$

$P(x_4) = 0.45$ $P(x_5) = 0.03$ $P(x_6) = 0.06$

x_i	$P(x_i)$	Stage1	Stage2	Stage3	Stage4	Stage5	Code
x_4	0.45	0.45	0.45	0.45	00 0.55	0.1	1
x_2	0.25	0.25	0.25	00 0.3	01 0.45		01
x_1	0.2	0.2	0.2	001 0.25			000
x_6	0.06	0.06 0010	0.1				0010
x_5	0.03 00110	0.04					00110
x_3	0.01 00111						00111

$$\text{Average Codeword length }(L) = \sum_{i=1}^{6} P(x_i) n_i$$

$$L = 0.45 \times 1 + 0.25 \times 2 + 0.2 \times 3 + 0.06 \times 4 + 0.03 \times 5 + 0.01 \times 5$$

$$L = 1.99 \text{ bits/symbol}$$

$$\text{Entropy } H(x) = \sum_{i=1}^{6} p(x_i) \log_2 \left(\frac{1}{p(x_i)}\right)$$

$$= 0.45 \times \log_2\left(\frac{1}{0.45}\right) + 0.25 \log_2\left(\frac{1}{0.25}\right) + 0.2 \log_2\left(\frac{1}{0.2}\right)$$

$$+ 0.06 \times \log_2\left(\frac{1}{0.06}\right) + 0.03 \log_2\left(\frac{1}{0.03}\right) + 0.01 \log_2\left(\frac{1}{0.01}\right)$$

$$= 0.156 + 0.150 + 0.139 + 0.073 + 0.045 + 0.02$$

$$= 0.583 / \log 2 = 1.93 \text{ bits/symbol}$$

$$\text{Efficiency } (\eta) = \frac{H(x)}{L} = \frac{1.93}{1.99} = 0.969 = 96.9\%$$

$$\text{Redundancy } (\gamma) = 1 - \eta = 0.031 = 3.1\%$$