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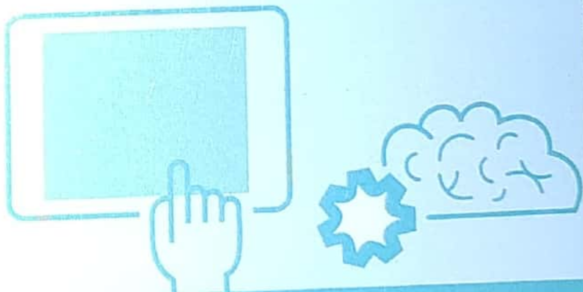

2020

THEORY BOOK

Computer Networks

Well illustrated theory with solved examples

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CHAPTER 01

Networking Fundamentals and Physical Layer

1.1 Introduction

Source (as shown in the following figure) is where the data is originated. Typically it is a computer, but it can be any other electronic equipment such as telephone handset, video camera, etc., which can generate data for transmission to some destination.

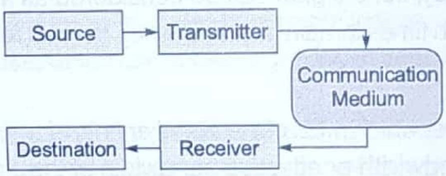

***Figure:** Simplified model of a data communication system*

Transmitter

As data cannot be sent in its native form, it is necessary to convert it into signal. This is performed with the help of a transmitter such as modem.

Communication Medium

The signal can be sent to the receiver through a communication medium, which could be a simple twisted-pair of wire, a coaxial cable, optical fiber or wireless communication system. It may be noted that the signal that comes out of the communication medium is different from that was sent by the transmitter (received data may not be same as it was send).

The receiver receives the signal and converts it back to data before forwarding to the destination. Destination is where the data is absorbed. Again, it can be a computer system, a telephone handset, a television set and so on.

For bandwidth, bit rate, etc., kilo means 10^3, mega means 10^6, and so on.
For data, addresses, etc., kilo means 2^10, mega means 2^20, and so on.

Data

Data refers to information that conveys some meaning based on some mutually agreed up rules or conventions between a sender and a receiver and today it comes in a variety of forms such as text, graphics, audio, video and animation.

Data can be of two types; analog and digital. *Analog data* take on continuous values on some interval. *Digital data* take on discrete values.

1.2 Signal

It is electrical, electronic or optical representation of data, which can be sent over a communication medium.

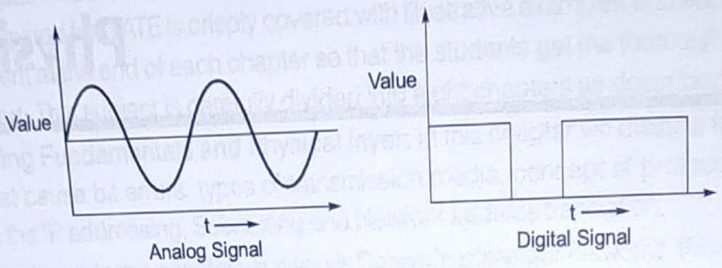

Figure: *Analog signal and Digital signal*

Digital signal can have only a limited number of defined values, usually two values 0 and 1. Analog signals are continuous with the wave forms as shown in the figure.

1.2.1 Signal Characteristics

A signal can be represented as a function of time, i.e. it varies with time. However, it can be also expressed as a function of frequency, i.e. a signal can be considered as a composition of different frequency components. Thus, a signal has both time-domain and frequency domain representation.

Bandwidth The term 'bandwidth' for digital signals is similar to bit rate.

The range of frequencies over which most of the signal energy of a signal is contained is known as **bandwidth** or effective bandwidth of the signal. The term 'most' is somewhat arbitrary. Usually, it is defined. The frequency spectrum and spectrum of a signal is shown in Figure.

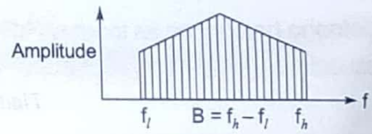

Figure: *Frequency spectrum and bandwidth of a signal*

Bandwidth (B) = $F_h - f_l$ = the difference between the highest and lowest frequencies in a signal

1.2.2 Digital Signal

Most digital signals are aperiodic and thus, period or frequency is not appropriate. Two new terms, *bit interval* (instead of period) and *bit rate* (instead of frequency) are used to describe digital signals. The bit interval is the time required to send one single bit. The bit rate is the number of bit interval per second. This mean that the bit rate is the number of bits sent in one second, usually expressed in bits per second (bps) as shown in Figure.

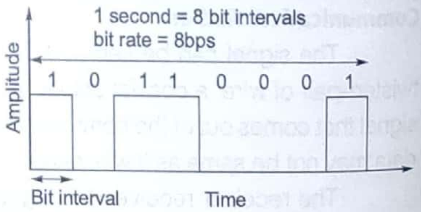

Figure: *Bit Rate and Bit Interval*

A digital signal can be considered as a signal with an infinite number of frequencies and transmission of digital requires a low-pass channel as shown in Figure. On the other hand, transmission of analog signal requires band-pass channel shown in Figure.

Baseband transmission – Sending digital signal without changing to analog.
Broadband transmission (aka modulation) – Sending digital signal after changing to analog.

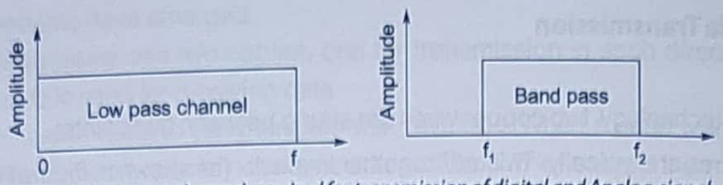

Figure: *Low pass channel required for transmission of digital and Analog signal*

Digital transmission has several advantages over analog transmission. That is why there is a shift towards digital transmission despite large analog base. Some of the advantages of digital transmission are highlighted below:

- Analog circuits require amplifiers, and each amplifier adds distortion and noise to the signal. In contrast, digital amplifiers regenerate an exact signal, eliminating cumulative errors. An incoming (analog) signal is sampled, its value is determined, and the node then generates a new signal from the bit value; the incoming signal is discarded. With analog circuits, intermediate nodes amplify the incoming signal, noise and all.
- Voice, data, video, etc. can all by carried by digital circuits. What about carrying digital signals over analog circuit? The modem example shows the difficulties in carrying digital over analog. A simple encoding method is to use constant voltage levels for a "1" and a "0". Can lead to long periods where the voltage does not change.
- Easier to multiplex large channel capacities with digital.
- Easy to apply encryption to digital data.
- Better integration if all signals are in one form. Can integrate voice, video and digital data.

Base-band and Broadband Signals

Base-band is defined as one that uses digital signaling, which is inserted in the transmission channel as voltage pulses. In baseband LANs, the entire frequency spectrum of the medium is utilized and transmission is bi-directional. Baseband systems used for small distance communication.

Broadband systems are those, which use analog signaling to transmit information using a carrier of high frequency.

Since broadband systems use analog signaling, frequency division multiplexing is possible, where the frequency spectrum of the cable is divided into several sections of bandwidth. These separate channels can support different types of signals of various frequency ranges to travel at the same instance.

Broadband is a unidirectional medium where the signal inserted into the media propagates in only one direction. Two data paths are required, which are connected at a point in the network called *headend*. All the stations transmit towards the headend on one path and the signals received at the headend are propagated through the second path.

1.3 Transmission Media

Transmission media can be defined as physical path between transmitter and receiver in a data transmission system. Classified as:

- **Guided:** Transmission capacity depends critically on the medium, the length, and whether the medium is point-to-point or multipoint (e.g. LAN). Examples are co- axial cable, twisted pair, and optical fiber.
- **Unguided:** Provides a means for transmitting electro-magnetic signals but do not guide them. Example wireless transmission.

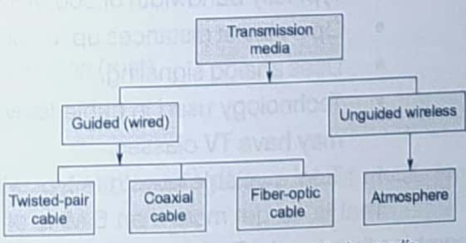

Figure: *Classification of the transmission media*

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1.3.1 Guided Media Transmission

(a) Twisted Pair

In twisted pair technology, two copper wires are strung between two points:

- The two wires are typically "twisted" together in a helix (as shown in Figure) to reduce interference and cross- talk interference.
- Can carry both analog and digital signals.
- Data rates of several Mbps common.
- Spans distances of several kilometers.
- Data rate determined by wire thickness and length.
- Good, low-cost communication.

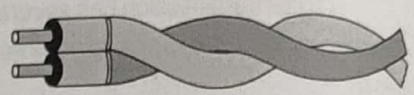


***Figure:* CAT5 cable (twisted cable)**

Typical Characteristics

The data rate that can be supported over a twisted-pair is inversely proportional to the square of the line length. Maximum transmission distance of 1 km can be achieved for data rates up to 1 Mb/s.

To reduce interference, the twisted pair can be shielded with metallic braid. This type of wire is known as *Shielded Twisted-Pair* (STP) and the other form is known as *Unshielded Twisted-Pair* (UTP). Used for telephone lines small LAN(100m).

(b) Base Band Coaxial

With "coax", the medium consists of a copper core surrounded by insulating material and a braided outer conductor. The term *base band* indicates digital transmission (as opposed to *broadband* analog).

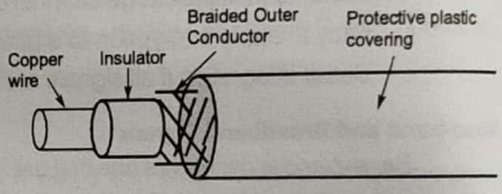


***Figure:* Co-axial cable**

Characteristics

Co-axial cable has superior frequency characteristics compared to twisted-pair and can be used for both analog and digital signaling. In baseband LAN, the data rates lies in the range of 1 KHz to 20 MHz over a distance in the range of 1 km. Coaxial cables are used both for *baseband* and *broadband* communication.

In broadband signaling, signal propagates only in one direction, in contrast to propagation in both directions in baseband signaling. Needed for every kilometer or so. Data rate depends on physical properties of cable, but 10 Mbps is typical.

Use: One of the most popular use of co-axial cable is in cable TV (CATV) for the distribution of TV signals. Another importance use of co-axial cable is in LAN.

(c) Broadband Coaxial

The term *broadband* refers to analog transmission over coaxial cable. (Note, however, that the telephone folks use broadband to refer to any channel wider than 4 kHz). The technology:

- Typically bandwidth of 300 MHz, total data rate of about 150 Mbps.
- Operates at distances up to 100 km (metropolitan area!).
- Uses analog signaling.
- Technology used in cable television. Thus, it is already available at sites such as universities that may have TV classes.
- Total available spectrum typically divided into smaller channels of 6 MHz each.

That is, to get more than 6 MHz of bandwidth, you have to use two smaller channels and somehow combine the signals. Requires amplifiers to boost signal strength; because amplifiers are one way, data flows in only one direction.

Two types of systems have emerged:

1. **Dual cable systems use two cables, one for transmission in each direction:**
   (a) One cable is used for receiving data.
   (b) Second cable used to communicate with *headend*. When a node wishes to transmit data, it sends the data to a special node called the *headend*. The headend then resends the data on the first cable. Thus, the headend acts as a root of the tree, and all data must be sent to the root for redistribution to the other nodes.
2. **Midsplit** systems divide the raw channel into two smaller channels, with each sub channel having the same purpose as above.

Which is better, broadband or base band? There is rarely a simple answer to such questions. Base band is simple to install, interfaces are inexpensive, but doesn't have the same range. Broadband is more complicated, more expensive, and requires regular adjustment by a trained technician, but offers more services (e.g., it carries audio and video too).

(d) Fiber Optics

In fiber optic technology, the medium consists of a hair-width strand of silicon or glass, and the signal consists of pulses of light. For instance, a pulse of light means "1", lack of pulse means "0". It has a cylindrical shape and consists of three concentric sections: the *core*, the ***cladding***, and the ***jacket*** as shown in Figure.

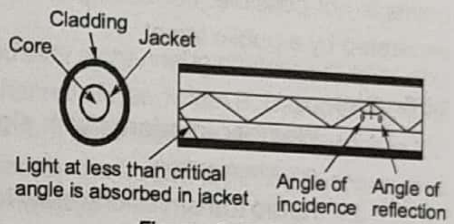


Figure: *Optical Fiber*

The core, innermost section consists of a single solid dielectric cylinder of diameter d_1 and of refractive index n_1. The core is surrounded by a solid dielectric cladding of refractive index n_2 that is less than n_1. As a consequence, the light is propagated through multiple total internal reflection. The core material is usually made of ultra pure fused silica or glass and the cladding is either made of glass or plastic. The cladding is surrounded by a jacket made of plastic. The jacket is used to protect against moisture, abrasion, crushing and other environmental hazards. Three components are required:

1. **Fiber medium:** Current technology carries light pulses for tremendous distances (e.g., 100s of kilometers) with virtually no signal loss.
2. **Light source:** Typically a Light Emitting Diode (LED) or laser diode. Running current through the material generates a pulse of light.
3. A photo diode light detector, which converts light pulses into electrical signals.

Advantages

1. Very high data rate, low error rate. 1000 Mbps (1 Gbps) over distances of kilometers common. Error rates are so low they are almost negligible.
2. Difficult to tap, which makes it hard for unauthorized taps as well. This is responsible for higher reliability of this medium.
   How difficult is it to prevent coax taps? Very difficult indeed, unless one can keep the entire cable in a locked room!
3. Much thinner than existing copper circuits.
4. Not susceptible to electrical interference (lightning) or corrosion (rust).
5. Greater repeater distance than coax.

Disadvantages

- Difficult to tap. It really is point-to-point technology. In contrast, tapping into coax is trivial. No special training or expensive tools or parts are required.
- One-way channel. Two fibers needed to get full duplex (both ways) communication.

Fiber Uses: Because of greater bandwidth (2 Gbps), smaller diameter, lighter weight, low attenuation, immunity to electromagnetic interference and longer repeater spacing, optical fiber cables are finding widespread use in long-distance telecommunications. Especially, the single mode fiber is suitable for this purpose. Fiber optic cables are also used in high-speed LAN applications. Multi-mode fiber is commonly used in LAN.

- Long-haul trunks-increasingly common in telephone network (Sprint ads)
- Metropolitan trunks-without repeaters (average 8 miles in length)
- Rural exchange trunks-link towns and villages
- Local loops-direct from central exchange to a subscriber (business or home)
- Local area networks-100Mbps ring networks.

1.3.2 Unguided Transmission

Unguided transmission is used when running a physical cable (either fiber or copper) between two end points is not possible. For example, running wires between buildings is probably not legal if the building is separated by a public street.

Difficulties

1. **Weather interferes with signals:** For instance, clouds, rain, lightning, etc. may adversely affect communication.
2. **Radio transmissions easy to tap:** A big concern for companies worried about competitors stealing plans.
3. Signals bouncing off of structures may lead to out-of-phase signals that the receiver must filter out.

1.4 Noise

As signal is transmitted through a channel, undesired signal in the form of noise gets mixed up with the signal, along with the distortion introduced by the transmission media. Noise can be categorised into the following four types:

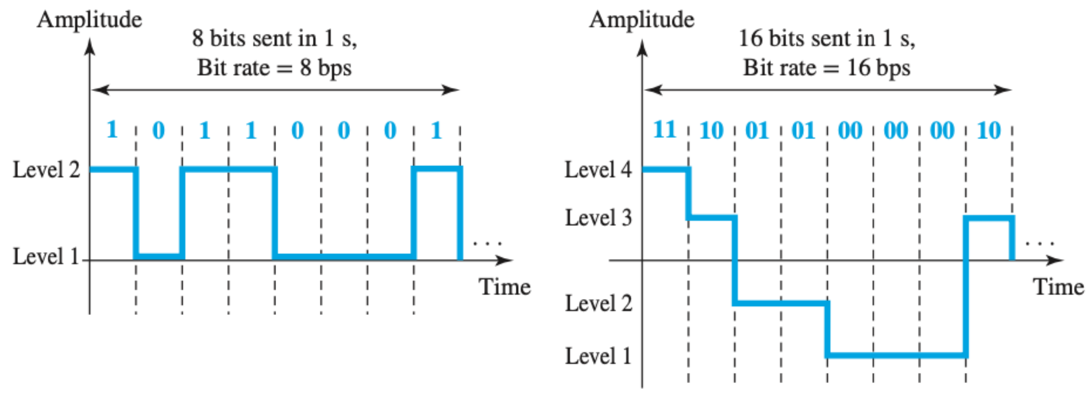
- Thermal Noise
- Intermodulation Noise
- Cross talk
- Impulse Noise

The ***thermal noise*** is due to thermal agitation of electrons in a conductor. It is distributed across the entire spectrum and that is why it is also known as *white noise* (as the frequency encompass over a broad range of frequencies). When more than one signal share a single transmission medium, ***intermodulation noise*** is generated. For example, two signals f_1 and f_2 will generate signals of frequencies $(f_1 + f_2)$ and $(f_1 - f_2)$, which may interfere with the signals of the same frequencies sent by the transmitter. Intermodulation noise is introduced due to nonlinearity present in any part of the communication system.

Cross talk is a result of bunching several conductors together in a single cable. Signal carrying wires generate electromagnetic radiation, which is induced on other conductors because of close proximity of the conductors. While using telephone, it is a common experience to hear conversation of other people in the background. This is known as *cross talk*.

Impulse noise is irregular pulses or noise spikes of short duration generated by phenomena like lightning, spark due to loose contact in electric circuits, etc. Impulse noise is a primary source of bit-errors in digital data communication. This kind of noise introduces burst errors.

Later on, for eg., for flow control, etc., bandwidth will simply be used to refer to the bit rate. So, unless specifically mentioned about calculating channel capacity, consider bit rate to be equal to bandwidth. (Also see the bottom of this page)



a. A digital signal with two levels

b. A digital signal with four levels

~~...nal (usually~~ ~~as shown in~~ ~~...n of analog~~

Nyquist Bit Rate (for noiseless channels)

The maximum rate at which data can be correctly communicated over a channel in presence of noise and distortion is known as its *channel capacity*. Consider first a noise- free channel of Bandwidth B. Based on Nyquist formulation it is known that given a bandwidth B of a channel, the maximum data rate that can be carried is 2B. This limitation arises due to the effect of intersymbol interference caused by the frequency components higher than B. If the signal consists of *m* discrete levels, then Nyquist theorem states:

Maximum data rate $C = 2B \log_2 m$ bits/sec,

where C is known as the channel capacity, (in bps)

B is the bandwidth of the channel (in Hz)

and *m* is the number of signal levels used.

In the context of channel capacity, bandwidth has been defined previously, i.e. the difference between the highest and lowest frequencies in a signal.

Baud Rate

The baud rate or signaling rate is defined as the number of distinct symbols transmitted per second, irrespective of the form of encoding. For baseband digital transmission $m = 2$.

~~So, the maximum baud rate = 1/Element width (in Seconds) = 2B~~

When 1 bit represents 1 symbol, then the bit rate is the same as the baud rate. The baud rate has nothing to do with the number of signal levels.

Bit Rate

The bit rate or information rate I is the actual equivalent number of bits transmitted per second.

$$I = \text{Baud Rate} \times \text{Bits per Baud}$$

$$= \text{Baud Rate} \times N = \text{Baud Rate} \times \log_2 m$$

For binary encoding, the bit rate and the baud rate are the same; i.e., I = Baud Rate.

Example - 1.1 Let us consider the telephone channel having bandwidth B = 4 kHz. Assuming there is no noise, determine channel capacity for the following encoding levels: (a) 2, and (b) 128.

Solution:

(a) $C = 2B = 2 \times 4000 = 8$ Kbits/s

(b) $C = 2 \times 4000 \times \log_2 128 = 8000 \times 7 = 56$ Kbits/s

Effects of Noise

When there is noise present in the medium, the limitations of both bandwidth and noise must be considered. A noise spike may cause a given level to be interpreted as a signal of greater level, if it is in positive phase or a smaller level, if it is negative phase. Noise becomes more problematic as the number of levels increases.

Technically, throughput means the actual bit rate, and bandwidth means the theoretical bit rate, but in questions, bandwidth is simply used to refer to the actual bit rate. So, bandwidth = bit rate = number of bits passing through any cross-section of the channel per second.

Transmission delay – The time taken by the sender to deposit an entire piece of data (for eg., an entire packet) onto the sender's end of the channel, bit by bit.
So, Tt = L / B, where Tt = transmission delay (in seconds), L = number of bits in the packet, and B = bandwidth (in bits per second) = bit rate.

Propagation delay – The time taken by a bit to reach from the sender's end of the channel to the receiver.
So, Tp = d / v, where Tp = propagation delay (in seconds), d = distance between the sender's end of the channel & the receiver, and v = speed at which every bit is moving forward in the channel.

Queuing delay – The amount of time for which a packet waits in the input & output queues of a router (generally considered to be zero in most of the questions).

Processing delay – The amount of time required by the receiver to process a packet (i.e. to receive the packet from the input port, to remove the header, to perform error-detection, etc.) (generally considered to be zero in most of the questions).

The sender and the receiver may mean hosts, switches, routers, etc.

So, if there are n routers in between the sender host and the receiver host, then there will be (n + 1) channels, and if we assume equal delays for the sender host, the routers and the receiver host, then the total delay will be (n + 1) (Tt + Tp + processing delay) + n (queuing delay).

Latency (Delay)

The latency or delay defines how long it takes for an entire message to completely arrive at the destination from the time the first bit is sent out from the source. We say that normally there are four types of delay: propagation delay, transmission delay, queuing delay, and processing delay. ~~The latency or total delay is~~

~~Latency = propagation delay + transmission delay + queuing delay + processing delay~~

Bandwidth-Delay Product

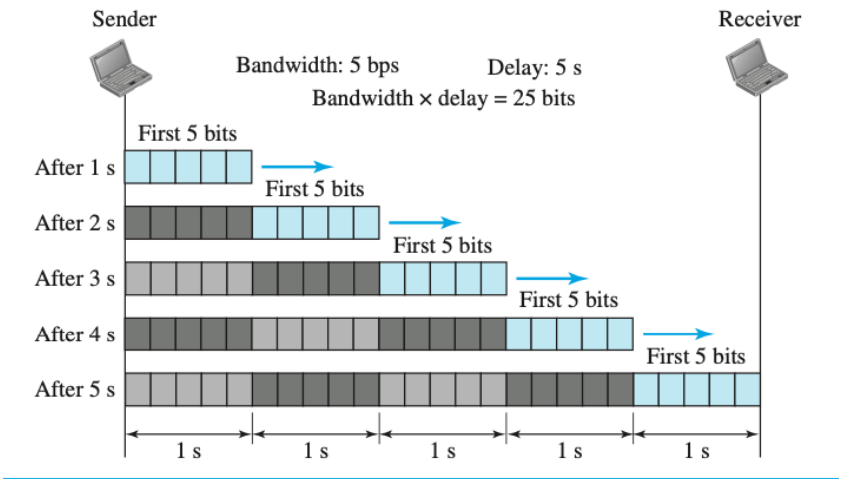
Bandwidth and delay are two performance metrics of a link. However, what is very important in data communications is the product of the two, the bandwidth-delay product. Let us elaborate on this issue, using two hypothetical cases as examples.

- **Case 1.** Let us assume that we have a link with a bandwidth of 1 bps. We also assume that the delay of the link is 5 s (also unrealistic). We want to see what the bandwidth-delay product means in this case. We can see that the bandwidth-delay product (1×5) is the maximum number of bits that can fill the link. There can be no more than 5 bits at any one time on the link.
- **Case 2.** Now assume we have a bandwidth of 5 bps with a delay of 5 s. We can see that there can be a maximum of $5 \times 5 = 25$ bits on the line. The reason is that, at each second, there are 5 bits on the line.

The bandwidth-delay product defines the number of bits that can fill the link.

This diagram shows one-way communication.

For a full-duplex channel, the actual number of bits that may be present on the channel at any given time is equal to twice of the bandwidth-delay product.



SNR in decibels = 10 log_10(SNR).
So, if SNR in decibels = 30 dB, then 30 = 10 log_10(SNR)
=> 3 = log_10(SNR)
=> SNR = 10^3 = 1000.

Shannon Capacity (Noisy Channel)

In presence of Gaussian band-limited white noise, Shannon-Hartley theorem gives the maximum data rate capacity

$$C = B\log_2(1 + S/N),$$

S/N is also written as SNR. Its value should be given in the question.

Signal to noise ratio is represented in dB (decibell).

$\log_{10}(S/N)$ is in bells

$10 \times \log_{10}(S/N)$ is in decibells

+ve value of S/N means signal power is dominating, where as –ve value of S/N represents noise power is dominating signal.

Where S and N are the signal and noise power, respectively, at the output of the channel. This theorem gives an upper bound of the data rate which can be reliably transmitted over a thermal-noise limited channel.

~~Example: Suppose we have a channel of 3000 Hz bandwidth, we need an S/N ratio (i.e. signal to noise ration, SNR) of 30 dB to have an acceptable bit error rate. Then, the maximum data rate that we can transmit is 30,000 bps~~. In practice, because of the presence of different types of noises, attenuation and delay distortions, actual (practical) upper limit will be much lower.

NOTE: In case of extremely noisy channel, C = 0. Between the Nyquist Bit Rate and the Shannon limit, the result providing the smallest channel capacity is the one that establishes the limit.

Example-1.2 A channel has B = 4 KHz. Determine the channel capacity for each of the following signal-to-noise ratios: (a) 20 dB, (b) 30 dB, (c) 40 dB.

Solution:

(a) $C = B\log_2(1 + S/N) = 4 \times 10^3 \times \log_2(1 + 100) = \cancel{4 \times 10^3 \times 3.32 \times 2.004} = 26.6$ kbits/s

(b) $C = B\log_2(1 + S/N) = 4 \times 10^3 \times \log_2(1 + 1000) = \cancel{4 \times 10^3 \times 3.32 \times 3.0} = 39.8$ kbits/s

(c) $C = B\log_2(1 + S/N) = 4 \times 10^3 \times \log_2(1 + 10000) = \cancel{4 \times 10^3 \times 3.32 \times 4.0} = 53.1$ kbits/s

Example-1.3 A channel has B = 4 KHz and a signal-to-noise ratio of 30 dB. Determine maximum information rate for 4-level encoding.

Solution:

For B = 4 KHz and 4-level encoding the *Nyquist Bit Rate* is 16 Kbps.

Again for B = 4 KHz and S/N of 30 dB the *Shannon capacity* is 39.8 Kbps.

The smallest of the two values has to be taken as the Information capacity I = 16 Kbps.

Example-1.4 A channel has B = 4 kHz and a signal-to-noise ratio of 30 dB. Determine maximum information rate for 128-level encoding.

Solution:

The *Nyquist Bit Rate* for B = 4 kHz and M = 128 levels is 56 kbits/s.

Again the *Shannon capacity* for B = 4 kHz and S/N of 30 dB is 39.8 Kbps.

The smallest of the two values decides the channel capacity C = 39.8 kbps.

Example-1.5 The digital signal is to be designed to permit 160 kbps for a bandwidth of 20 kHz. Determine (a) number of levels and (b) S/N ratio.

Solution:

(a) Apply *Nyquist Bit Rate* to determine number of levels. $C = 2B \log_2(M)$,

or $\quad 160 \times 10^3 = 2 \times 20 \times 10^3 \log_2(M)$,

or $\quad M = 2^4$, which means ~~4bits/baud~~. 16 levels

(b) Apply *Shannon capacity* to determine the S/N ratio $C = B \log2(1 + S/N)$,

or $\quad 160 \times 10^3 = 20 \times 10^3 \log_2(1 + S/N) \times 10^3 \log_2(M)$,

or $\quad S/N = 2^8 - 1$, or $S/N = 255$,

or $\quad S/N = 24.07$ dB. (i.e. 10 log_10(255))

Example-1.6 Assuming there is no noise in a medium of B = 4 kHz, determine channel capacity for the encoding level 4.

Solution:

$$I = 2 \times 4000 \times \log_2 4 = 16 \text{ Kbps}$$

Example-1.7 A channel has B = 10 MHz. Determine the channel capacity for signal-to-noise ratio 60 dB.

Solution:

$$C = B \times \log_2(1 + S/N) = \cancel{10 \times \log_2(1 + 60)}$$

Example-1.8 The digital signal is to be designed to permit 56 kbps for a bandwidth of 4 kHz. Determine (a) number of levels and (b) S/N ratio.

Solution:

$$\text{Nyquist bit rate } 56 \times 10^3 = 2 \times 4 \times 10^3 \times \log_2 M$$

$$7 = \log_2 M \quad \Rightarrow M = 128 \text{ levels}$$

$$\text{Shannon capacity } 56 = B \times \log(1 + S/N)$$

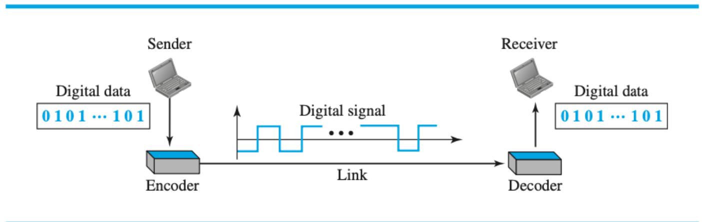
$$\cancel{S = 10^7 - 1 = 70 \text{ dB}}$$

1.5 Transmission of Signals

baseband transmission

The first approach converts digital data to digital signal, known as line coding, as shown in Figure. Important parameters those characteristics line coding techniques are mentioned below.

Figure 4.1 *Line coding and decoding*



Number of Signal Levels

This refers to the number values allowed in a signal, known as **signal levels**, to represent data. Figure (a) shows two signal levels, whereas Figure (b) shows three signal levels to represent binary data.

Bit Rate versus Baud Rate

The **bit rate** represents the number of bits sent per second, whereas the **baud rate** defines the number of signal elements per second in the signal. Depending on the encoding technique used, baud rate may be more than or less than the ~~data~~ bit rate.

In most of the questions, 1 bit represents 1 symbol, i.e. bit rate = baud rate.
However, this may not always be true.
For eg., 1 bit may represent 2 symbols, 1 symbol may be represented by 2 bits, 4 symbols may be represented by 3 bits, and so on.

In NRZ-L, if there is a long sequence of 0s or 1s, then the average signal power and the DC value of the signal becomes skewed.
In NRZ-I, this problem occurs if there is a long sequence of 0s.

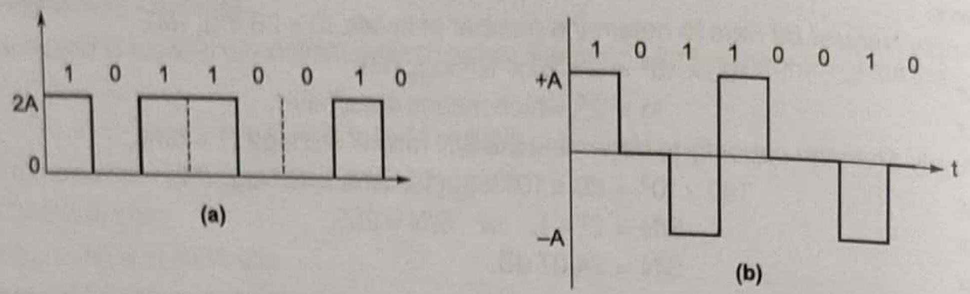


Figure: *(a) Signal with two voltage levels (b) Signal with three voltage levels*

Line Coding Techniques

Line coding techniques can be broadly divided into three broad categories: Unipolar, Polar and Bipolar, as shown in Figure.

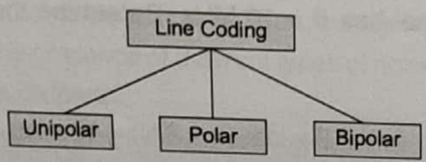


Figure: *Three basic categories of line coding techniques*

Unipolar All signal levels are on one side of the axis, either above or below

In unipolar encoding technique, only two voltage levels are used. It uses only one polarity of voltage level as shown in Figure. In this encoding approach, the bit rate same as data rate. Unfortunately, DC component present in the encoded signal and there is loss of synchronization for long sequences of 0's and 1's. It is simple but obsolete.

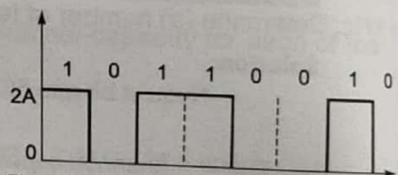


Figure: *Unipolar encoding with two voltage levels*

Polar Unipolar is NRZ

Polar encoding technique uses two voltage levels – one positive and the other one negative. Four different encoding schemes shown in Figure under this category discussed below:

For eg., the voltage level for 0 can be positive and the voltage level for 1 can be negative.

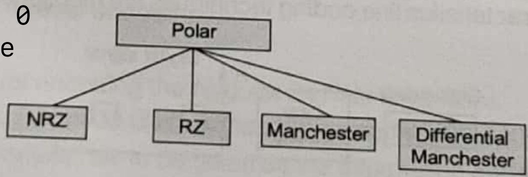
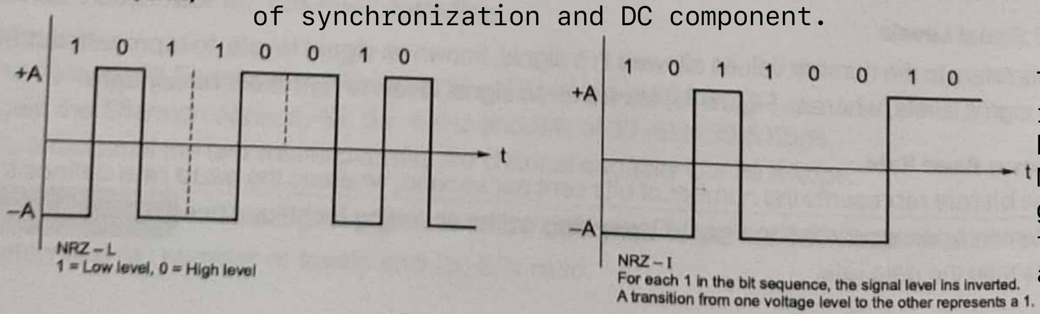


Figure: *Encoding Schemes under polar category*

Non Return to Zero (NRZ) NRZ schemes (unipolar and polar) suffer from the problems of synchronization and DC component.



The first 1 is at -A because in NRZ-I, 1 is generally taken to be at -A.

Figure: *NRZ encoding scheme*

In NRZ-L (NRZ-Level), the level of the voltage determines the value of the bit.
In NRZ-I (NRZ-Invert), the inversion or the lack of inversion determines the value of the bit. If there is no change, the bit is 0; if there is a change, the bit is 1.

In NRZ-L & NRZ-I, 1 is generally taken to be at -A, and 0 is generally taken to be at +A.
In RZ, 1 is generally taken to be at +A, and 0 is generally taken to be at -A.

The most common and easiest way to transmit digital signals is to use two different voltage levels for the two binary digits. Usually a negative voltage is used to represent one binary value and a positive voltage to represent the other. The data is encoded as the presence or absence of a signal transition at the beginning of the bit time. As shown in the figure below, in NRZ encoding, the signal level remains same throughout the bit-period. There are two encoding schemes in NRZ: NRZ-L and NRZ-I, as shown in Figure.

The **advantages** of NRZ coding are:

- Detecting a transition in presence of noise is more reliable than to compare a value to a threshold.
- NRZ codes are easy to engineer and it makes efficient use of bandwidth.

Return to Zero RZ

In RZ, the signal goes to 0 in the middle of each bit, and remains there until the beginning of the next bit.

To ensure synchronization, there must be a signal transition in each bit as shown in Figure. Key characteristics of the RZ coding are:

RZ solves the problems of synchronization and DC component.

- Three levels
- ~~Bit rate is double than that of data rate~~
- No dc component
- Good synchronization
- Main limitation is the increase in bandwidth

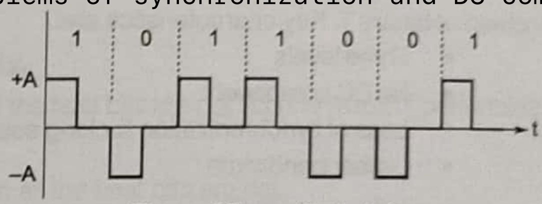


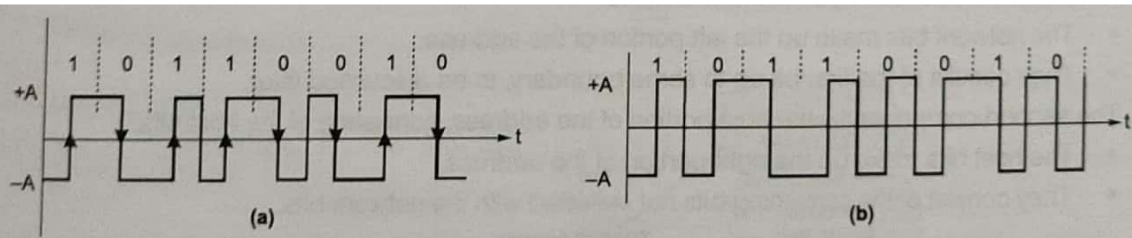
Figure: RZ encoding technique

Biphase

RZ becomes complex due to the usage of 3 levels of voltage.

To overcome the limitations of NRZ and RZ encoding, biphase encoding techniques can be adopted. *Manchester* and *differential Manchester Coding* are the two common Biphase techniques in use, as shown in Figure (a) & (b). In Manchester coding the mid-bit transition serves as a clocking mechanism and also as data.

The idea of RZ and the idea of NRZ-L are combined into the standard manchester encoding scheme, whereas the idea of RZ and the idea of NRZ-I are combined into the differential manchester encoding scheme.
There will be transition at the middle of every bit in both standard as well as differential manchester encoding schemes.



The first 1 is at -A because in NRZ-I, 1 is generally taken to be at -A.

Figure: *(a) Standard Manchester Encoding Scheme (b) Differential Manchester Encoding Scheme*

Key Characteristics

Biphase solves the problems of synchronization and DC component, and uses only 2 levels of voltage.

- Two levels
- No DC component
- Good synchronization
- Higher bandwidth ~~due to doubling of bit rate with respect to data rate~~

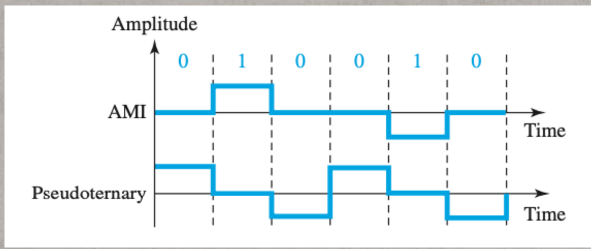
The bandwidth required for biphase and RZ techniques are greater than that of NRZ techniques, but due to the predictable transition during each bit time, the receiver can synchronize properly on that transition. Biphase encoded signals have no DC components. A Manchester code is now very popular and has been specified for the IEEE 802.3 standard for base band coaxial cables and twisted pair CSMA/CD bus LANs.

In RZ and Biphase, every bit corresponds to 2 symbols. So, baud rate is twice of bit rate.

Standard manchester - If the current bit is 0, then the left half of the current bit will be at +A, and if the current bit is 1, then the left half of the current bit will be at -A. Now, complete the signal by adding transitions at the middle of every bit.

Differential manchester – If the next bit is 0, then the left half of the next bit will be at the same level as the left half of the current bit (i.e. lack of inversion), and if the next bit is 1, then the left half of the next bit will be at the other level w.r.t. the left half of the current bit (i.e. inversion).
Now, complete the signal by adding transitions at the middle of every bit.

Bipolar Encoding (aka multilevel binary)



Bipolar AMI uses three voltage levels. Unlike RZ, the zero level is used to represent a 0 and a binary 1's are represented by alternating positive and negative voltages, as shown in Figure.

Pseudoternary

This encoding scheme is same as AMI, but alternating positive and negative pulses occur for binary 0 instead of binary 1. Key characteristics are:

- Three levels
- No DC component
- Loss of synchronization for long sequences of 0's
- Lesser bandwidth

AMI means alternate mark inversion.
AMI and pseudoternary are two variations of the bipolar encoding scheme.
Bipolar also has the problem of synchronization, but not of DC.

Modulation Rate

Data rate is expressed in bits per second. On the other hand, modulation rate is expressed in bauds. General relationship between the two is given below:

$$D = R/b \cancel{= R/\log_2 L}$$

Where, D is the modulation rate in bauds, R is the data rate in bps, ~~L is the number of different signal elements~~ and b is the number of bits per signal element.

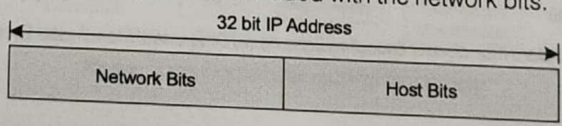
1.6 IP Addressing IPv4

The IP address is a 32-bit address that consists of two components. One component is the network portion of the address, consisting of the network bits.

- The network bits make up the left portion of the address.
- They consist of the first bit up to some boundary, to be discussed later.

The second component is the host portion of the address, consisting of the host bits.

- The host bits make up the right portion of the address.
- They consist of the remaining bits not included with the network bits.



The Mask

- The network portion of the address is separated from the host portion of the address by a mask. The mask simply indicates how many bits are used for the network portion, leaving the remaining bits for the host portion.
- A 24-bit mask indicates that the first 24 bits of the address are network bits, and the remaining 8 bits are host bits.
- A 16-bit mask indicates that the first 16 bits of the address are network bits, and the remaining 16 bits are host bits. And so forth...
- The difference between a network mask and a subnet mask will be explained as this tutorial progresses.

Dotted Decimal Notation

Machines read the IP address as a stream of 32 bits. However, for human consumption, the IP address is written in dotted decimal notation.

- The 32-bit address is divided into 4 groups of 8 bits (an octet or a byte).
- Each octet is written as a decimal number ranging from 0 to 255.
- The decimal numbers are separated by periods, or dots.

$$\underbrace{1\ 1\ 0\ 0\ 0\ 0\ 0\ 0}_{192}\ \underbrace{1\ 0\ 1\ 0\ 1\ 0\ 0\ 0}_{168}\ \underbrace{0\ 0\ 1\ 0\ 0\ 0\ 0\ 0}_{32}\ \underbrace{0\ 0\ 0\ 0\ 1\ 0\ 1\ 0}_{10}$$

For a given IP network...

- The network bits remain <u>fixed</u> and the host bits <u>vary</u>.
- The network address is the one that results when all the host bits are <u>not</u> set (the result of performing an AND operation on the address and its mask).
- The broadcast address is the one that results when all the host bits are set.
- Host addresses are those that result with all remaining combinations of the host bits.

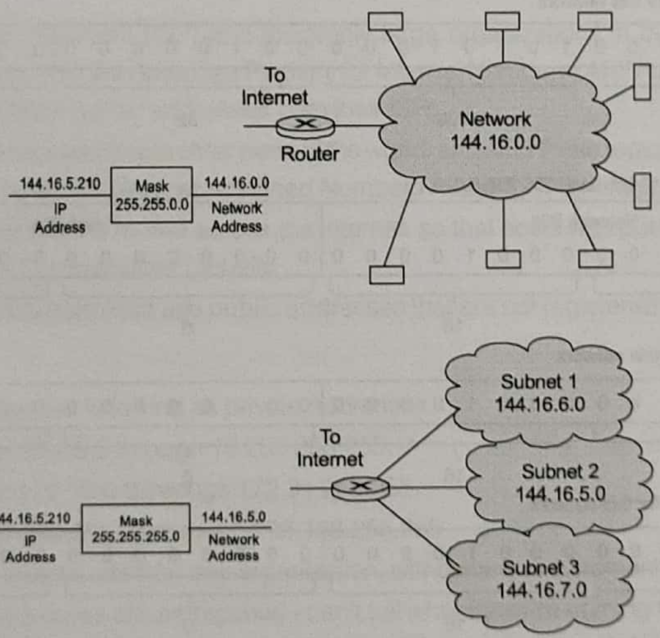


Figure: *Sub netting masking with the help of router*

Network, Host and Broadcast Addresses

24-bit mask (255.255.255.0)

Network address w/24-bit mask 255.255.255.0

Network bits			Host bits
1 1 0 0 0 0 0 0	1 0 1 0 1 0 0 0	0 0 1 0 0 0 0 0	0 0 0 0 0 0 0 0
192 .	168 .	32 .	0

First hot address for this network

1 1 0 0 0 0 0 0	1 0 1 0 1 0 0 0	0 0 1 0 0 0 0 0	0 0 0 0 0 0 0 1
192 .	168 .	32 .	1

Second hot address for this network

1 1 0 0 0 0 0 0	1 0 1 0 1 0 0 0	0 0 1 0 0 0 0 0	0 0 0 0 0 0 1 0
192 .	168 .	32 .	2

Last hot address for this network

1 1 0 0 0 0 0 0	1 0 1 0 1 0 0 0	0 0 1 0 0 0 0 0	1 1 1 1 1 1 1 0
192 .	168 .	32 .	254

Broadcast address for this network

1 1 0 0 0 0 0 0	1 0 1 0 1 0 0 0	0 0 1 0 0 0 0 0	1 1 1 1 1 1 1 1
192 .	168 .	32 .	255

16 bit Mask

Network address w/ 16-bit mask 255.255.0.0

Network Bits		Host Bits	
1 0 1 0 1 1 0 0	0 0 0 1 0 0 0 0	0 0 0 0 0 0 0 0	0 0 0 0 0 0 0 0
172 .	16 .	0 .	0

First hot address for this network

1 0 1 0 1 1 0 0	0 0 0 1 0 0 0 0	0 0 0 0 0 0 0 0	0 0 0 0 0 0 0 1
172 .	16 .	0 .	1

Second hot address for this network

1 0 1 0 1 1 0 0	0 0 0 1 0 0 0 0	0 0 0 0 0 0 0 0	0 0 0 0 0 0 1 0
172 .	16 .	0 .	2

Last hot address for this network

1 0 1 0 1 1 0 0	0 0 0 1 0 0 0 0	1 1 1 1 1 1 1 1	1 1 1 1 1 1 1 0
172 .	16 .	255 .	254

Broadcast address for this network

1 0 1 0 1 1 0 0	0 0 0 1 0 0 0 0	1 1 1 1 1 1 1 1	1 1 1 1 1 1 1 1
172 .	16 .	255 .	255

IP Networks and Hosts

- An IP host is any device with an IP address, such as a PC.
- Multiple hosts reside on a given IP network or subnet (short for subnetwork). Subnets will be discussed later.
- A group of IP networks is an internetwork, with the largest internetwork being the Internet.
- What is typically called a "data network" is technically an internetwork, because multiple IP networks are connected together by routers.
- This internetwork contains 6 IP networks.
- Note that even a link between routers is a network.

Determining Number of hosts in given network

- Given that there are N host bits in an address, the number of hosts for that network is $2^N - 2$. Two addresses are subtracted for the network address and the broadcast address.
- 8 host bits: $2^8 - 2 = 254$ hosts
- 16 host bits: $2^{16} - 2 = 65534$ hosts
- 24 host bits: $2^{24} - 2 = 16777214$ hosts

Public IP Addresses

- Most IP addresses are public addresses. Public addresses are registered as belonging to a specific organization.
- Internet Service Providers (ISP) and extremely large organizations in the U.S. obtains blocks of public addresses from the American Registry for Internet Numbers (ARIN http://www.arin.net). Other organizations obtain public addresses from their ISPs.
- There are ARIN counterparts in other parts of the world, and all of these regional registration authorities are subject to the global Internet Assigned Numbers Authority (IANA http://www.iana.org).
- Public IP addresses are routed across the Internet, so that hosts with public addresses may freely communicate with one another globally.
- No organization is permitted use public addresses that are not registered with that organization!

Private Addresses

RFC 1918 designates the following as private addresses.

- **Class A range:** 10.0.0.0 through 10.255.255.255.
- **Class B range:** 172.16.0.0 through 172.31.255.255.
- **Class C range:** 192.168.0.0 through 192.168.255.255.

Private addresses may be used by any organization, without any requirement for registration.

Because private addresses are ambiguous - can't tell where they're coming from or going to because anyone can use them - private addresses are not permitted to be routed across the Internet.

- ISPs block private addresses from being routed across their infrastructure.

NOTE

- The use of private addresses, network address translation (NAT), and proxy servers solved the IP address shortage problem for the short and medium terms. The projected long-term solution is IPv6.

1.6.1 Classful IP Addressing and its Shortcomings

- Class A networks:
  (a) First octet values range from 1 through 126.
  (b) First octet starts with bit **0**.
  (c) Network mask is 8 bits, written /8 or 255.0.0.0.
  (d) 1.0.0.0 through 126.0.0.0 are class A networks with 16777214 hosts each.
- Class B networks:
  (a) First octet values range from 128 through 191.
  (b) First octet starts with binary pattern **10**.
  (c) Network mask is 16 bits, written /16 or 255.255.0.0.
  (d) 128.0.0.0 through 191.255.0.0 are class B networks, with 65534 hosts each.
- Class C networks:
  (a) First octet values range from 192 through 223.
  (b) First octet starts with binary pattern **110**.
  (c) Network mask is 24 bits, written /24 or 255.255.255.0.
  (d) 192.0.0.0 through 223.255.255.0 are class C networks, with 254 hosts each.
- Class D addresses:
  (a) First octet values range from **224 through 239**.
  (b) First octet starts with binary pattern **1110**.
  (c) Class D addresses are multicast addresses, which will not be discussed in this tutorial.
- Class E addresses:
  (a) Essentially everything that's left.
  (b) Experimental class, which will not be discussed in this tutorial.
- Reserved addresses:
  (a) **0.0.0.0** is the default IP address, and it is used to specify a **default route**. The default route will be discussed later.
  (b) Addresses beginning with 127(**127.x.y.z**) are reserved for **internal loopback addresses**.
- It is common to see 127.0.0.1 used as the internal loopback address on many devices. Try pinging this address on a PC or UNIX station.

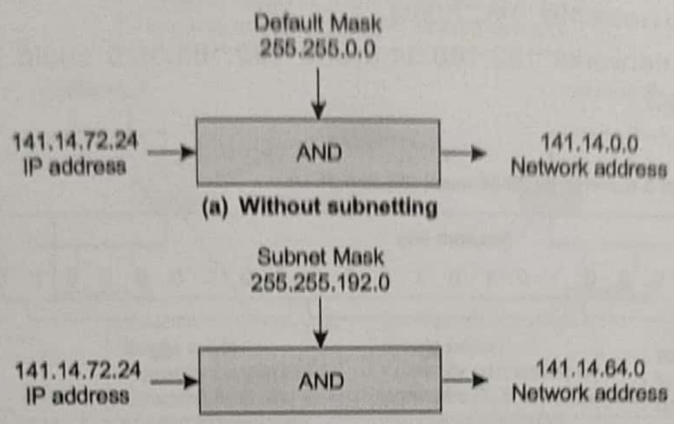
1.6.2 IP Addresses Efficiency

- As IP networking and internetworking progressed, it became very apparent that class A and B networks were simply too large.
- 254 hosts on one network segment are manageable, but 65534 hosts or more on a single network segment is difficult to manage.
  (a) This would result in class A and B networks not being fully utilized, meaning that not all the host addresses would get used.
  (b) Or it would result in more hosts being put onto a single network segment than could reasonably be managed.
- For these and other reasons, there was a need to improve the efficiency of IP addressing. That is, to provide a way to limit the number of host addresses per network segment to what is actually needed, regardless of the network class.
- This need was met progressively through the conceptions of subnet masks, variable-length subnet masks, and classless inter-domain routing.

1.7 Subnetting

Subnet masks are used to make classful networks more manageable and efficient, by creating smaller subnets and reducing the number of host addresses per subnet to what is actually required. Subnet masks were first used on class boundaries.

Default Mask and Subnet Mask



(a) Without subnetting

(b) With subnetting

Example:

- Take class A network 10.0.0.0 with network mask 255.0.0.0.
- Add additional 8 subnet bits to network mask.
- New subnet mask is 255.255.0.0.
- New subnets are 10.0.0.0, 10.1.0.0, 10.2.0.0, and so on with 65534 host addresses per subnet.
- Still too many hosts per subnet.

Example:

- Take class A network 10.0.0.0 with network mask 255.0.0.0.
- Add additional 16 subnet bits to network mask.
- New subnet mask is 255.255.255.0
- New subnets are 10.0.0.0, 10.0.1.0, 10.0.2.0… 10.1.0.0, 10.1.1.0, 10.1.2.0… 10.2.0.0, 10.2.1.0, 10.2.2.0, and so on with 254 host addresses per subnet.

Example

- Take class B network 172.16.0.0 with network mask 255.255.0.0. Add additional 8 subnet bits to network mask.
- New subnet mask is 255.255.255.0
- New subnets are 172.16.0.0, 172.16.1.0, 172.16.2.0, and so on with 254 host addresses per subnet.

As shown in these examples...

- A class A network can be subnetted to create 256 (2^8) /16 subnets.
- A class A network can be subnetted to create 65536 (2^{16}) /24 subnets.
- A class B network can be subnetted to create 256 (2^8) /24 subnets.

NOTE

- Technically there really is no such thing as a classful subnet or classful subnet mask. However, terms such as "class C subnet" and "class C subnet mask" are used routinely to describe a class A or B network that has been subnetted with a 24-bit mask.
- It should also be apparent by now that the terms network mask and subnet mask technically mean two different things.

1.8 CIDR (Classless Inter Domain Routing)

Super Netting

Very simply stated, CIDR is combining two or more classful networks to create a supernetwork.

- The most common use of CIDR for actual addressing is to combine two or more class C networks to create a /23 or /22 supernet. For *example*, the class C networks 192.168.32.0 and 192.168.33.0 could be combined to create 192.168.32.0/23.
- The class C networks 192.168.34.0 and 192.168.35.0 could be combined to create 192.168.34.0/23.

Example:

Network address of a supernet w/ 23-bit mask 255.255.254.0

Network Bits			Host Bits
1 1 0 0 0 0 0 0	1 0 1 0 1 0 0 0	0 0 1 0 0 0 0	0 0 0 0 0 0 0 0 0
192 .	168 .	32 .	0

First host address for this network

1 1 0 0 0 0 0 0	1 0 1 0 1 0 0 0	0 0 1 0 0 0 0	0 0 0 0 0 0 0 0 1
192 .	168 .	32 .	1

Second host address for this network

1 1 0 0 0 0 0 0	1 0 1 0 1 0 0 0	0 0 1 0 0 0 0	0 0 0 0 0 0 0 1 0
192 .	168 .	32 .	2

Second host address for this network

1 1 0 0 0 0 0 0	1 0 1 0 1 0 0 0	0 0 1 0 0 0 0	1 1 1 1 1 1 1 1 0
192 .	168 .	33 .	254

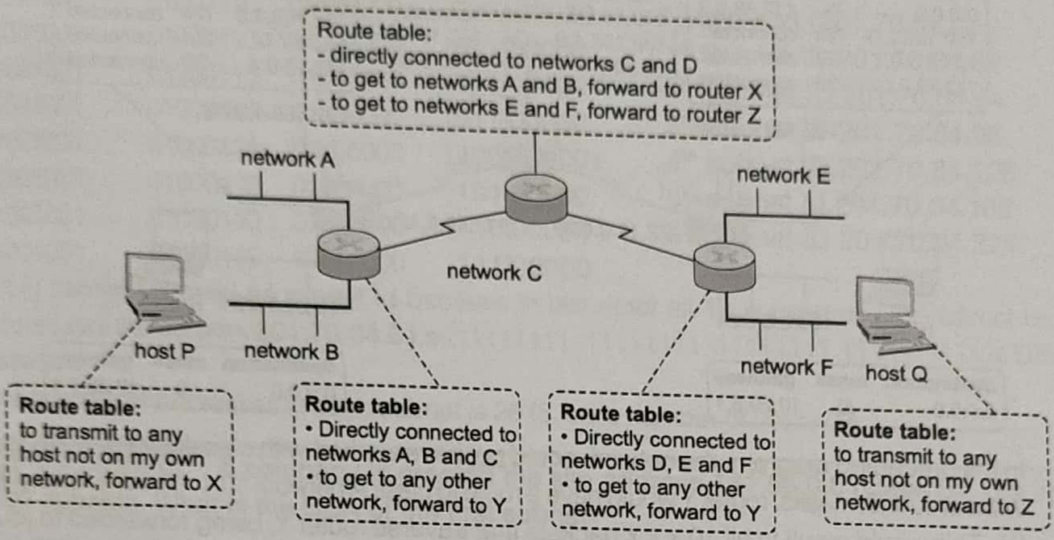
Broadcast address for this network

1 1 0 0 0 0 0 0	1 0 1 0 1 0 0 0	0 0 1 0 0 0 0	1 1 1 1 1 1 1 1 1
192 .	168 .	33 .	255

- There really is no significant difference between the /23 supernet examples just shown and the /2 subnet examples shown previously.
  (a) Both networks utilize the same 23-bit mask.
  (b) Both networks have 510 host addresses.
  (c) The only difference is that a class A network was subnetted in one set of examples, and tw class C networks were supernetted in the other.
- As with all things in IP addressing, supernets must fall on bit boundaries.
  (a) There must be a power of 2 number (2, 4, 8, ...) of networks in a supernet.
- A/23 supernet must include two class C networks.
- A/22 supernet must include four class C networks.

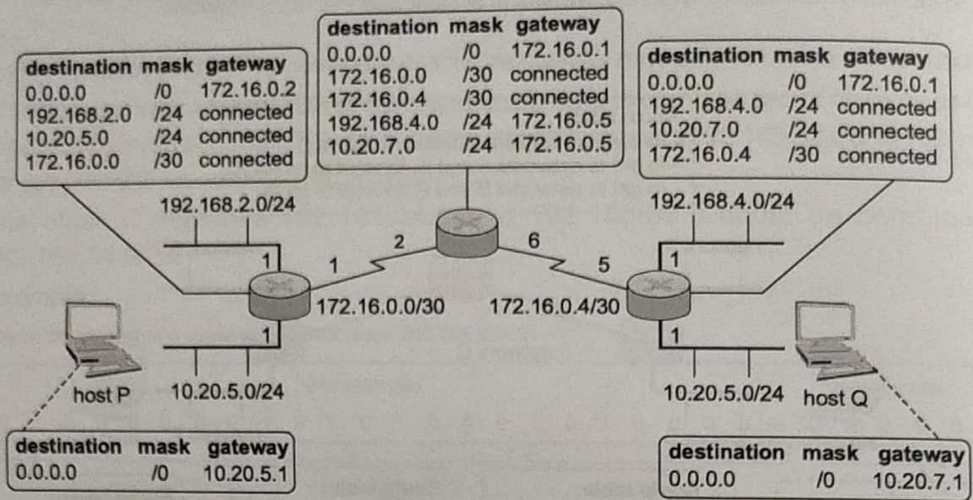
  For *example*, it is not possible to create a supernet that includes just 192.168.1.0 and 192.168.2.0 To include both these networks the mask must be 22 bits, and a 22-bit mask must also include th networks 192.168.0.0 and 192.168.3.0.

- Although the term supernet is used in this tutorial to explain CIDR, this term is not commonly used in casual communication. Instead, most will simply use the term network.



- Hosts P and Q
  - (a) Hosts P and Q have only one way to get off their networks, and that is to forward traffic to the router connected to their respective networks.
  - (b) These hosts each have a default route to a default gateway-router X or Z.
- Router X
  - (a) Router X has interfaces directly connected to networks A, B, and C, so it can route traffic between these networks w/o additional configurations.
  - (b) This router has only one option to get to other networks, and that is to forward traffic to router Y. So it has a default route to router Y.
- Router Z
  - (a) Router Z has interfaces directly connected to networks D, E, and F, so it can route traffic between these networks w/o additional configurations.
  - (b) This router has only one option to get to other networks, and that is to forward traffic to router Y. So it has a default route to router Y.
- Router Y
  - (a) Router Y automatically knows how to route traffic between networks C and D.
  - (b) To get to networks A and B, this router forwards traffic to router X.
  - (c) To get to networks E and F, this router forwards traffic to router Z.
  - (d) One of these routes could be made the default route.

Same Routing with IP addresses



- In the preceding diagram, the network could not have worked with classful routing.
- Without subnet masks, router Y would have a route to class A network 10.1.1.1 via gateway 172.16.0.5.
  (a) This would result in all 10.x.x.x packets that traverse router Y, being forwarded to router Z.
  (b) For example, router Z would forward destination 10.20.5.x packets to router Y, and router Y would return them to router Z.
  (c) This is because router Y has no way to distinguish between 10.20.5.0 and 10.20.4.0 without a subnet mask.
  (d) Destination 10.20.5.x packets within router X-that is, those sourced from 192.168.2.x - would not be affected by this phenomenon.

Example-1.9 What is the subnetwork address if the destination address is 200.45.34.56 and the subnet mask is 255.255.240.0?

Solution:

200	45	34	56
11001000	00101101	00100010	00111000
11111111	11111111	1111 0000	00000000
11001000	00101101	00100000	00000000

The subnet work address is 200.45.32.0

Example-1.10 A company is granted the site address 201.70.64.0 (class C). The company needs six subnets of 25 host each. Design the subnets.

Solution:

The number of 1s in the default mask is 24 (class C).

The company needs six subnets. This number 6 is not a power of 2. The next number that is a power of 2 is 8 (2^3). We need 3 more 1s in the subnet mask. The total number of 1s in the subnet mask is 27 (24 + 3).

The total number of 0s is 5 (32 - 27). The mask is

11111111 11111111 11111111 11100000 or 255.255.255.224

the number of subnets theoretically is 8. But Practically only 6 subnets are possible. (All 1's and all 0's in subnet Id bits because they are Direct Broad Cast address and Network Id respectively). The subnets are

201	70	64		
11001001	01000110	01000000	[000] 00000	Network Id (201.70.64.0)
11001001	01000110	01000000	[001]00000	1st Subnet ID 201.70.64.32
11001001	01000110	01000000	[010]00000	2nd subnet ID 201.70.64.64
11001001	01000110	01000000	[011]00000	3rd subnet ID 201.70.64.96
11001001	01000110	01000000	[100]00000	4th subnet ID 201.70.64.128
11001001	01000110	01000000	[101]00000	5th subnet Id 201.70.64.160
11001001	01000110	01000000	[110]00000	6th subnet ID 201.70.64.224
11001001	01000110	01000000	[111]00000	

[111] cannot be used as subnet id because in last octet all 1's is used as DBA (direct broadcast address) of the network **201.70.64.0 i.e.** 11111111 11111111 11111111 [111]11111 is DBA of the network.

The number of addresses in each subnet is 25 (5 is the number of 0s) or 32.

Example-1.11 A company is granted the site address 181.56.0.0 (class B). The company needs 1000 subnets. What is the DBA of the first subnet?

Solution:

The company needs 1000 subnets. We need 10 bits to represent those 1000 subnets.

The total number of 1s in the subnet mask is 26 (16 + 10). Six bits are left for host bits.

Therefore we can have $2^6 - 2$ hosts. (All 1's in host bits represent DBA and all 0's would be the case of Network ID (181.56.0.0)

The MASK for these subnets is

11111111 11111111 11111111 11000000 or 181.56.255.192

The first subnet ID is

10110101 00111000 00000000 01000000 or 181.56.0.64

The first host of first subnet is

10110101 00111000 00000000 01000001 or 181.56.0.65

2nd host

10110101 00111000 00000000 01000010 or 181.56.0.66

DBA (direct broadcast address) of first subnet

10110101 00111000 00000000 01111111 or 181.56.0.127

The number of subnets is 1024 and the number of addresses in each subnet is 26 (6 is the number of 0s) or 64.

Example-1.12 A company is granted the site address 181.56.0.0 (class B). The company needs 1000 subnets. What is the DBA of the 4th subnet?

Solution:

4th subnet id is

10110101 00111000 00000001 00000000 or 181.56.1.0

DBA of 4th subnet (all host bits 1's) is

10110101 00111000 00000001 00111111 or 181.56.1.63

Example-1.13 Which of the following can be used as both source IP as well as destination IP (a) 192.168.11.255 (b) 143.18.255.255 (c) 255.255.255.255 (d) 19.19.19.25

Solution:

(a) NO it cannot be used as source IP as it is a DBA (direct broadcast address)

(b) NO it is DBA

(c) NO it is Limited broadcast address and it cannot be used as source

(d) YES it can be used as both source and destination IP

Example-1.14 Identify which of the following IP's belong to same subnet. Given subnet mask is 255.255.255.240?

(a) 207.19.36.58 (b) 207.19.36.75

(c) 207.19.36.89 (d) 207.19.36.97

(e) None of them

Solution: (e)

240 (11110000) first four bits of last octet are subnet bits. If first 4 bits match then they both belong to same subnet

58-00111010

75-01001011

89-01011001

97-01110001

None of them belong to same subnet.

Example-1.15 A company needs 600 addresses. Which of the following set of class C blocks can be used to form a supernet for this company?

(a) 198.47.32.0 198.47.33.0 198.47.50.0

(b) 198.47.32.0 198.47.42.0 198.47.52.0 198.47.62.0

(c) 198.47.31.0 198.47.32.0 198.47.33.0 198.47.52.0

(d) 198.47.32.0 198.47.33.0 198.47.34.0 198.47.35.0

Solution: (d)

In order to combine networks into a single Network (super netting) the networks must be continuous and number of networks to be combined should be powers of 2.

Example-1.16 We need to make a supernetwork out of 16 class C blocks. What is the supernet mask?

Solution:

We need 16 blocks. For 16 blocks we need to change four 1s to 0s in the default mask. So the mask is

11111111 11111111 11110000 00000000 or 255.255.240.0

Example-1.17 A supernet has a first address of 205.16.32.0 and a supernet mask of 255.255.248.0. A router receives three packets with the following destination addresses:

205.16.37.44, 205.16.42.56 and 205.17.33.76

Which packet belongs to the supernet?

Solution:

We apply the supernet mask to see if we can find the beginning address

205.16.37.44 AND 255.255.248.0 $\Rightarrow$ 205.16.32.0

205.16.42.56 AND 255.255.248.0 $\Rightarrow$ 205.16.40.0

205.17.33.76 AND 255.255.248.0 $\Rightarrow$ 205.17.32.0

Only the first address belongs to this supernet.

Example-1.18 A supernet has a first address of 205.16.32.0 and a supernet mask of 255.255.248.0. How many blocks are in this supernet and what is the range of addresses?

Solution:

The supernet has 21 1s. The default mask has 24 1s. Since the difference is 3, there are 2^3 or 8 blocks in this supernet. The blocks are 205.16.32.0 to 205.16.39.0. The first address is 205.16.32.0. The last address is 205.16.39.255.

Example-1.19 Which of the following can be the beginning address of a block that contains 16 addresses?

(a) 123.45.24.52
(b) 17.17.33.80
(c) 190.16.42.44
(d) 205.16.37.32

Solution:

The condition on the number of addresses in a block; it must be a power of 2 (2, 4, 8 ...)

The beginning address must be evenly divisible by the number of addresses. For example, if a block contains 4 addresses, the beginning address must be divisible by 4.

If the block has less than 256 addresses, we need to check only the rightmost byte. If it has less than 65,536 addresses, we need to check only the two rightmost bytes, and so on.

The address 205.16.37.32 is eligible because 32 is divisible by 16. The address 17.17.33.80 is eligible because 80 is divisible by 16.

Example-1.20 Which of the following can be the beginning address of a block that contains 1024 addresses?

(a) 205.16.37.32
(b) 190.16.42.0
(c) 17.17.32.0
(d) 123.45.24.52

Solution: (c)

To be divisible by 1024, the rightmost byte of an address should be 0 and the second rightmost byte must be divisible by 4. Only the address 17.17.32.0 meets this condition.

Example-1.21 A small organization is given a block with the beginning address and the prefix length 205.16.37.24/29 (in slash notation). What is the range of the block?

Solution:

The beginning address is 205.16.37.24. To find the last address we keep the first 29 bits and change the last 3 bits to 1s.

Beginning:	11001111	00010000	00100101	00011000
Ending:	11001111	00010000	00100101	00011111

There are only 8 addresses in this block

Example-1.22 What is the network address if one of the addresses is 167.199.170.82/27?

Solution:

The prefix length is 27, which means that we must keep the first 27 bits as is and change the remaining bits (5) to 0s. The 5 bits affect only the last byte. The last byte is 01010010. Changing the last 5 bits to 0s, we get 01000000 or 64. The network address is 167.199.170.64/27.

Example-1.23 An ISP is granted a block of addresses starting with 190.100.0.0/16. The ISP needs to distribute these addresses to three groups of customers as follows:

(a) The first group has 64 customers; each needs 256 addresses.

(b) The second group has 128 customers; each needs 128 addresses.

(c) The third group has 128 customers; each needs 64 addresses.

Design the sub blocks and give the slash notation for each sub block. Find out how many addresses are still available after these allocations.

Solution:

Group 1

For this group, each customer needs 256 addresses. This means the suffix length is 8 ($2^8 = 256$). The prefix length is then $32 - 8 = 24$.

01: 190.100.0.0/24 ⇒ 190.100.0.255/24

02: 190.100.1.0/24 ⇒ 190.100.1.255/24...

And so on up to

64: 190.100.63.0/24 ⇒ 190.100.63.255/24

Total = $64 \times 256 = 16{,}384$

Group 2

For this group, each customer needs 128 addresses. This means the suffix length is 7 ($2^7 = 128$). The prefix length is then $32 - 7 = 25$.

The addresses are:

001: 190.100.64.0/25 ⇒ 190.100.64.127/25

002: 190.100.64.128/25 ⇒ 190.100.64.255/25

003: 190.100.127.128/25 ⇒ 190.100.127.255/25

Total = $128 \times 128 = 16{,}384$

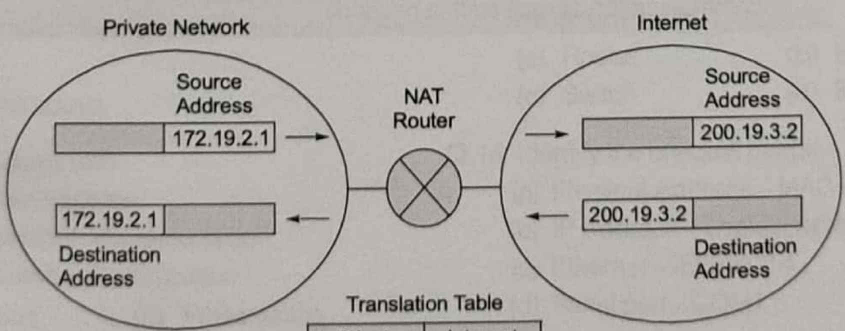
Group 3
For this group, each customer needs 64 addresses. This means the suffix length is 6 ($2^6 = 64$). The prefix length is then $32 - 6 = 26$.
001:190.100.128.0/26 ⇒ 190.100.128.63/26
002:190.100.128.64/26 ⇒ 190.100.128.127/26...
And so on up to
128: 190.100.159.192/26 ⇒ 190.100.159.255/26
Total = $128 \times 64 = 8,192$
Number of granted, allocated and available addresses are : 65,536 , 40,960 and 24,576 respectively.

1.9 Network Address Translation (NAT)

With the increasing number of internet users requiring an unique IP address for each host, there is an acute shortage of IP addresses (until everybody moves to IPV6). The *Network Address Translation* (NAT) approach is a quick interim solution to this problem. NAT allows a large set of IP addresses to be used in an internal (private) network and a handful of addresses to be used for the external internet. The internet authorities has set aside three sets of addresses to be used as private addresses as shown in Table. It may be noted that these addresses can be reused within different internal networks simultaneously, which in effect has helped to increase the lifespan of the IPV4. However, to make use of the concept, it is necessary to have a router to perform the operation of address translation between the private network and the internet. As shown in Figure, the NAT router maintains a table with a pair of entries for private and internet address. The source address of all outgoing packets passing through the NAT router gets replaced by an internet address based on table look up. Similarly, the destination address of all incoming packets passing through the NAT router gets replaced by the corresponding private address, as shown in the figure. The NAT can use a pool of internet addresses to have internet access by a limited number of stations of the private network at a time.

Range of addresses		Total number
10.0.0.0	to 10.255.255.255	2^{24}
172.16.0.0	to 172.31.255.255	2^{20}
192.168.0.0	to 192.168.255.255	2^{16}

Addresses for Private Network



Private	Internet
172.19.2.1	200.19.3.2

Figure: *NAT Address translation*

Summary

- A data communications system must transmit data to the correct destination in an accurate and timely manner.
- The five components that make up a data communications system are the message, sender, receiver, medium, and protocol. Text, numbers, images, audio, and video are different forms of information. Data flow between two devices can occur in one of three ways: simplex, half-duplex, or full-duplex.
- **Base-band** is defined as one that uses digital signaling, which is inserted in the transmission channel as voltage pulses.
- **Broadband** systems are those, which use analog signaling to transmit information using a carrier of high frequency.
- Co-axial cable has superior frequency characteristics compared to twisted-pair and can be used for both analog and digital signaling.
- The term *broadband* refers to analog transmission over coaxial cable.
- Fibre optics has very high data rate, and low error rate.
- Unguided transmission is used when running a physical cable (either fiber or copper) between two end points is not possible.
- The baud rate or signaling rate is defined as the number of distinct symbols transmitted per second, irrespective of the form of encoding.
- The bit rate or information rate is the actual equivalent number of bits transmitted per second.
- The **bit rate** represents the number of bits sent per second, whereas the **baud rate** defines the number of signal elements per second in the signal. Depending on the encoding technique used, baud rate may be more than or less than the data rate.
- In the standard Manchester coding there is a transition at the middle of each bit period. A binary **1** corresponds to a ***low-to-high transition*** and a binary **0** to a ***high-to-low transition*** in the middle.
- In Differential Manchester, inversion in the middle of each bit is used for synchronization.
- IP defines how computers can get data to each other over a routed, interconnected set of networks. TCP defines how applications can create reliable channels of communication across such a network.

Student's Assignment

Q.1 A researcher wishes to digitally record analog sounds for testing animal hearing with frequencies of up to 100 [KHz]. Use Shannon's formula to find the minimum signal to noise ratio (in dB!) required to sustain the given data rate over a 500 KHz radio channel.
(a) 19.2 (b) 18
(c) 14 (d) 19.5

Q.2 The correct order of the corresponding OSI layers for a Router, Medium Access Control, Repeater and FTP is
(a) Network, Data link, Application and Physical
(b) Physical, Data Link, Session and Transport
(c) Network, Data Link, Physical and Application
(d) Presentation, Network, Transport and Application

Q.3 Which of the following statement is correct with respect to Half Duplex communication?
(a) Error correction is not possible
(b) Always a pair of physical links is necessary
(c) Two connections can be used for sending and receiving data
(d) It cannot be used in broadcast networks

Q.4 What addressing information is shipped with every network interface card?
(a) The Internet protocol (IP) address
(b) The physical (MAC) address
(c) The address resolution protocol (ARP) address
(d) None of the above

Q.5 Which layer deals with
(*i*) File system transfer
(*ii*) Virtual terminals implementation
(*iii*) Inter process communication
(a) Application (b) Presentation
(c) Session (d) Transport

Q.6 The data link layer is responsible for
(a) Flow control (b) Error control
(c) Access control (d) All of these

Q.7 The topology with highest reliability is
(a) BUS (b) STAR
(c) RING (d) MESH

Q.8 Transport layer is responsible for
(a) node-to-node delivery
(b) end-to-end delivery
(c) station-to-station delivery
(d) network-to-network delivery

Q.9 Which network topologies degrades most gracefully in high network load situations?
(a) Ring (b) Star
(c) Mesh (d) Bus

Q.10 You have been asked to wire a conference room with six computers for a demonstration tomorrow. It needs be done as quickly and with the lowest possible expense. What network topology is best suited to this situation?
(a) Star (b) Ring
(c) Mesh (d) Bus

Q.11 Which layer is responsible for data translating?
(a) Application (b) Network
(c) Presentation (d) Data link

Q.12 Which one is the least expensive that can support 100 Mbps?
(a) Coaxial (b) UTP
(c) Fiber-optic (d) STP

Q.13 With the use of which of the following device(s) and cables can a LAN based on star topology be setup?
(a) Router (b) Bridge
(c) Switch (d) Repeater

Q.14 Identify the unequal pair(s).
(a) Physical Address – MAC Address
(b) IP Address – Logical Address
(c) Ethernet – IEEE 802.4
(d) Serial port – COM1

Q.15 In a topology, if there are n devices in a network, each device has $n-1$ ports for cables. Identify it
(a) Mesh (b) Star
(c) Ring (d) Bus

Q.16 In a mesh topology with n devices and half duplex links, if a new device is added, how many new links are needed.
(a) $n-1$ (b) n
(c) $n+1$ (d) $2n$

Q.17 Match List-I (Function) with List-II (Layer) and select the correct answer using the codes given below the lists:

List-I
A. Reassembly of packets
B. Responsibility for delivery between adjacent nodes
C. Mechanical electrical and functional interface
D. Error correction and retransmission

List-II
1. Transport
2. Data link
3. Physical

Codes:

	A	B	C	D
(a)	1	2	3	4
(b)	1	3	2	2
(c)	1	1	3	2
(d)	1	2	3	1, 2

Q.18 Consider the OSI standard for LANs,
(a) the OSI network layer is subdivided into a MAC layer and a LLC layer
(b) the OSI data link layer is subdivided into an Ethernet layer and a Token ring layer
(c) the OSI data link layer is subdivided into a MAC layer a LLC layer
(d) the OSI physical layer is subdivided in to an Ethernet layer and a Token Ring layer

Q.19 Match List-I with List-II and select the correct answer using the codes given below the lists:

List-I
A. Data link layer
B. Physical layer
C. Presentation layer
D. Network layer

List-II
1. The lowest layer whose function is to activate, deactivate and maintain the circuit between DTE & DCE
2. Performs routing and communication
3. Detection and recovery from errors in the transmitted data
4. Provides for the syntax of the data

Codes:

	A	B	C	D
(a)	3	1	4	2
(b)	2	1	4	3
(c)	4	1	2	3
(d)	3	4	1	2

Q.20 The header added by the transport layer to the packet coming from the upper layer includes the
(a) Logical address
(b) Services-point address
(c) Physical address
(d) Network address

Q.21 If there are n devices (nodes) in a network, what is the number of cable links required for a mesh and a star topology respectively.
(a) $n, n-1$ (b) $n(n-1)/2, n-1$
(c) $n-1, n$ (d) $n-1, n(n-1)/2$

Q.22 A system has an n-layer protocol hierarchy. Applications generate messages of length M bytes. At each of the layers, an h-byte header is added. What fractions of the network bandwidth is filled with headers?
(a) h/M (b) $hn/(M+nh)$
(c) nh/M (d) $1-(nh/M)$

Q.23 ______ addresses on headers change as a packet moves from network to network but the ______ do not.
(a) Logical, port (b) Logical, network
(c) Logical, physical (d) Physical, logical

Q.24 ______ used in telephone network for bi-directional, real time transfer between computers
(a) Message switching (b) Circuit switching
(c) Packet switching (d) Circular switching

Q.25 If the value of signal changes over a very short span of time, it's frequency is
(a) Short (b) Low
(c) High (d) Long

Q.26 ________ is used to optimize the use of the channel capacity available in a network, to minimize the transmission latency and to increase robustness of communication
(a) Message switching
(b) Linear switching
(c) Circuit switching
(d) Packet switching

Q.27 ________ splits traffic data into chunks
(a) Message switching (b) Linear switching
(c) Circuit switching (d) Packet switching

Q.28 The key concern in design of data transmission system is Data Rate and ________
(a) Data path (b) Data flow
(c) Distance (d) Frequencies

Q.29 The router connecting a company's network to the internet applies the mask 255.255.255.192 to the destination address of incoming IP packets. If one of the incoming packet has a destination address of 154.33.7.220, then find the network ID, subnet bits and host ID bits of incoming packets respectively
(a) 154.33.7, 11, 011100
(b) 154.33, 11000000, 011100
(c) 154.33, 0000011111, 011100
(d) 154.33.7, 011111, 011100

Q.30 If one of the address of a block is 210.69.92.39/26, then find the last host of the 2nd last subnet, where the addresses are referred in lexicographic order.
(a) 210.69.92.127/26
(b) 210.69.92.192/26
(c) 210.69.92.191/26
(d) 210.69.92.254/26

Answer Key:

1. (a)	2. (c)	3. (a)	4. (b)	5. (a)
6. (d)	7. (d)	8. (b)	9. (a)	10. (d)
11. (c)	12. (b)	13. (c)	14. (c)	15. (a)
16. (d)	17. (d)	18. (c)	19. (a)	20. (b)
21. (b)	22. (b)	23. (d)	24. (b)	25. (c)
26. (d)	27. (d)	28. (c)	29. (c)	30. (c)