BACHELOR OF COMPUTER APPLICATIONS

SEMESTER 3

DCA2104

BASICS OF DATA COMMUNICATION

Unit 3

Data and Signals

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1. INTRODUCTION

Information stored within computer systems and transferred over a computer network can be divided into two categories: data and signals. Data are entities that convey meaning within a computer or computer system. Signal is the transmission of data that convey information. As we already discussed in unit 2, the main responsibility of physical layer is to transmit data from source to destination in the form of electromagnetic signals. These signals are transmitted across a transmission medium. Transmission media work by transmitting electromagnetic signals along a physical path. So, each data must first be modified to signals so that it can be accepted by transmission media.

In this unit, we are going to discuss analog and digital signals. In the next section we will discuss periodic analog signals. Then we will define and illustrate the different transmission impairments such as attenuation, distortion and noise. In this unit, we will also explain data rate limits for noiseless and noisy channel. In the last section, we will list and detail out the different network performance parameters such as bandwidth, throughput, latency, bandwidth-delay product and jitter.

1.1 Objectives:

After studying this unit, you should be able to:

- *Describe and differentiate analog and digital signal*
- *Explain periodic analog signal*
- *Discuss transmission impairments in network*
- *Explain data rate limits*
- *Describe performance characteristics of network.*

2. ANALOG AND DIGITAL SIGNALS

Data can be represented as signals in either analog or digital form. Analog data refers to information that is continuous and digital data refers to information that has discrete states.

Analog data such as voice is considered as continuous values i.e,during a speech, voice is captured by a microphone and converted to either analog signal or sampled and converted to a digital signal. This conversion takes place through a converter called Analog to Digital Converter (ADC). Digital data acquire discrete values. For example, digital data stored in computer memory is in the form of 0s and 1s. This can be converted to a digital signal or modulated into an analog signal for transmission through a medium. Conversion of digital signal to analog signal are done through Digital –to–Analog Converter (DAC).

Signals can be either analog or digital. An analog signal has many levels of intensity over a period. A digital signal has only a limited number of defined values. These days, almost all electronic devices use digital signals,because they remain accurate in shape and amplitude. Digital signals provide better continuous delivery, and are preferred over analog signals. Table 3.1 shows difference between analog and digital signals.

Table 3.1: Difference between Analog and Digital signal

Analog Signal	Digital Signal
1. It is a continuous signal which represents physical measurement. 2. Denoted by sine waves. 3. More likely to get affected by noise, which reduces accuracy. 4. It can be used in analog devices only, but best suited for audio and video transmission. 5. Analog signal stored in the form of wave signal.	1. Digital signals are discrete time signals generated by digit modulation. 2. Denoted by square waves. 3. Less affected by noise, since noiseare analog in nature. 4. It can be used in digital devices, best suited for computing and digital electronics. 5. Digital signal stored in the form of binary bits.

Figure 3.1 shows an analog signal and a digital signal.

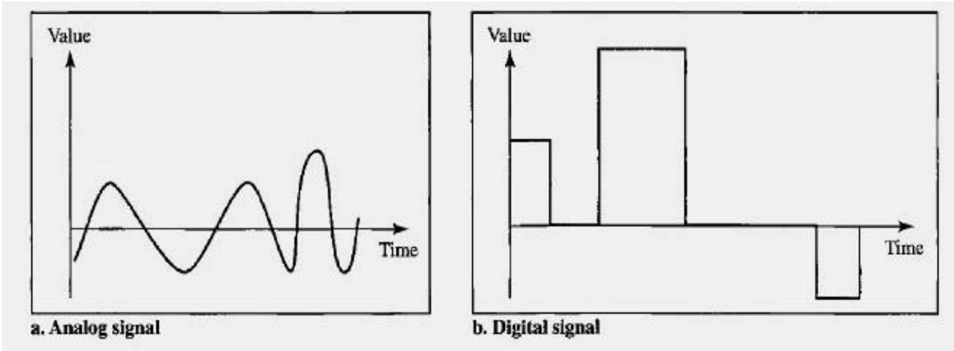

Figure 3.1: Analog and digital signal

In figure, vertical axis represents the value or strength of each signal and horizontal axis represents time. Analog and digital signal can be either periodic or nonperiodic. A periodic signal completes a pattern within a measurable time frame called a period and repeat that pattern over subsequent identical periods. The completion of one full pattern is called a cycle. A nonperiodic signal changes without demonstrating a pattern or cycle that repeats over time. In data communication, periodic analog signals

(Because they need less bandwidth) and nonperiodic digital signals (Because they can represent variation in data) are commonly used.

Self-Assessment Questions - 1

1. Which layer transmit data from source to destination in the form of electromagnetic signals?
   a) Physical layer
   b) Datalink layer
   c) Network layer
   d) Transport layer
2. Information that is continuous is known as___________ .
3. Information that has discrete states is referred as____________.
4. A periodic signal completes a pattern within a measurable time frame called_______.
5. The completion of one full pattern is called __________ .

3. PERIODIC ANALOG SIGNALS

An analog signal is called a periodic signal if it completes a pattern within a measurable time frame, called a period. The completion of a one full pattern is called cycle. Periodic analog signals can be classified as simple or composite. A simple periodic analog signal cannot be decomposed into simpler signals. A simple periodic analog signal is known as a sine wave. A composite periodic analog signal is composed of multiple sine waves.

Sine wave is the basic form of a periodic analog signal. In case of sine wave, each cycle consists of a single arc above the time axis followed by a single arc below it. Figure 3.2 shows a sine wave.

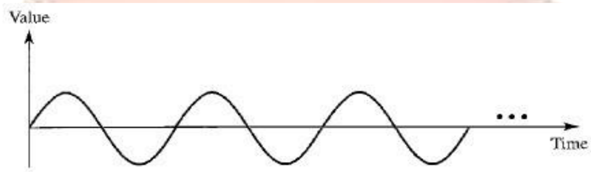

Figure 3.2: A sine wave

A sine wave can be represented by three parameters: peak amplitude, frequency and phase. The peak amplitude of a signal is the highest value it reaches on the vertical axis. Amplitude measured in volts, ampere or watts. A volt is used for voltage, ampere for current and watts for power. Figure 3.3 shows periodic analog signals and its peak amplitude.

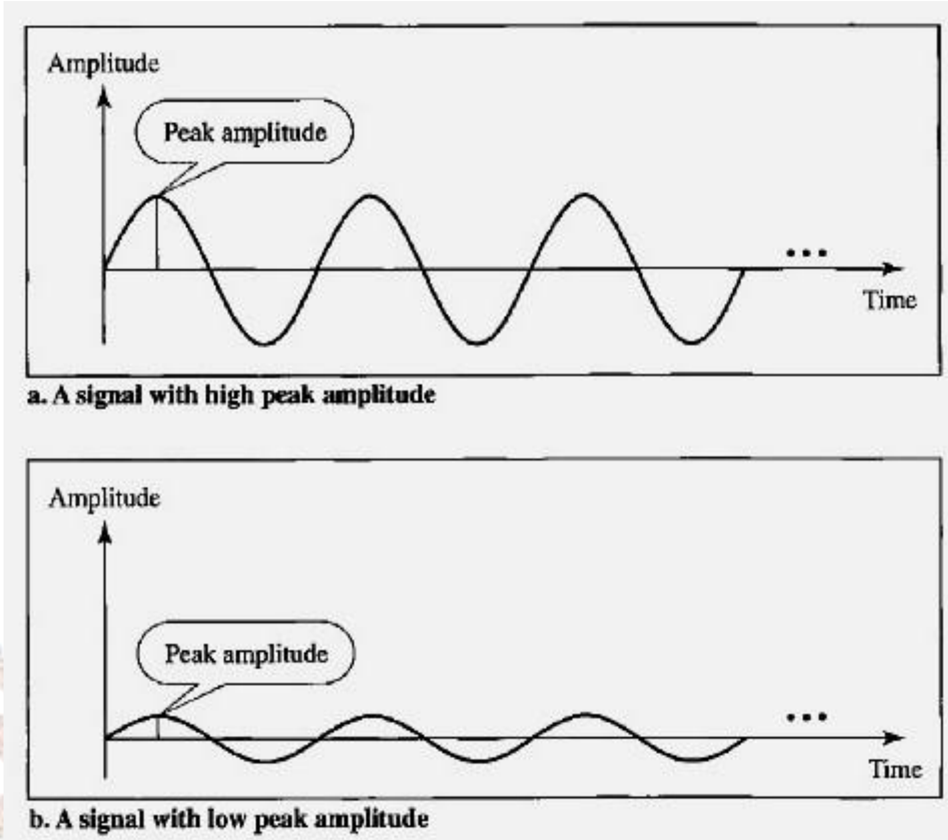

Figure 3.3: Two signals with the same phase and frequency, but different amplitudes

Period refers to the amount of time (in seconds) a signal needs to complete one cycle. The time duration of a period represented by T, may be different for each signal but it is constant for any given periodic signal. Frequency refers to the number of periods per second measured in hertz (Hz). It represents the rate at which signal repeats. Period (T) is the inverse of frequency (f) and frequency is the inverse of period. Figure 3.4 shows two signals with the same amplitude and phase but different frequencies.

f=1/T, ………………………………………………………………………3.1

T=1/f,………………………………………………………………3.2

Where f = cycles per second (Hertz) and

T = Time of one cycle (seconds)

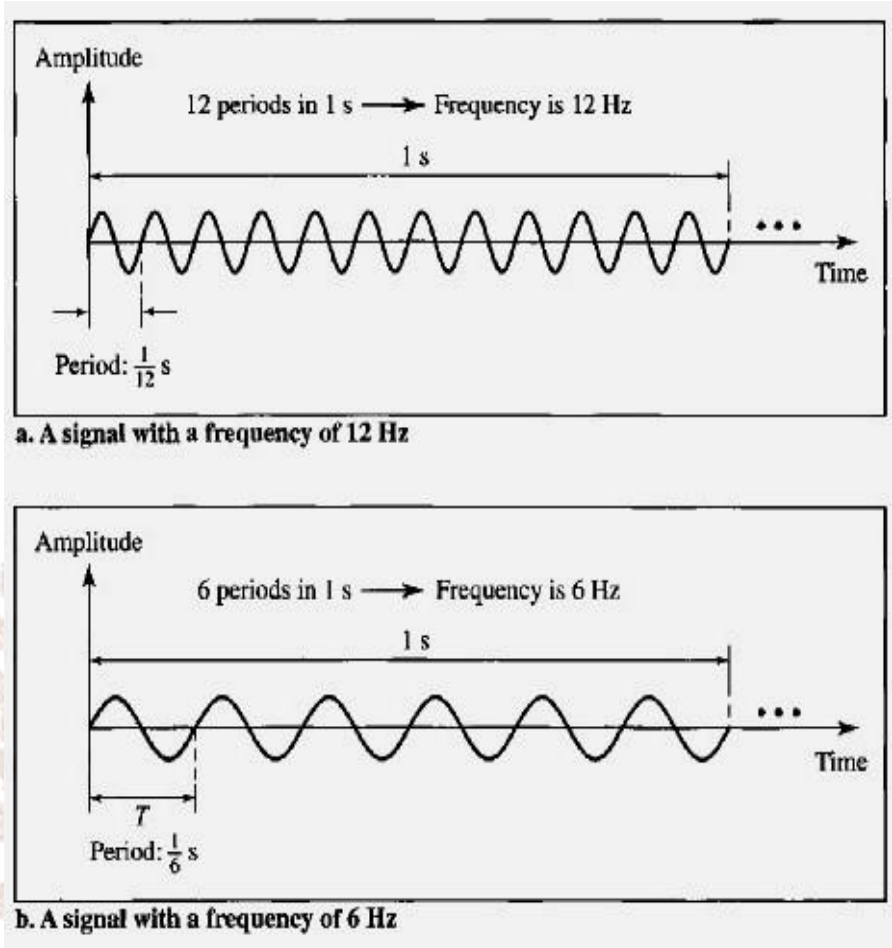

Figure 3.4: Two signals with the same amplitude and phase but different frequencies

Period is expressed in seconds and frequency is expressed in Hertz (Hz), which is cycle per second. If a signal does not change at all, its frequency is zero and if a signal changes instantaneously, its frequency is infinite.

Phase describes the position of the waveform relative to time 0. Assume that the wave is something that can shift backward and forward along the time axis, then phase describes the amount of that shift. Phase is measured in degree or radians. Figure 3.5 shows three waves with different phases.

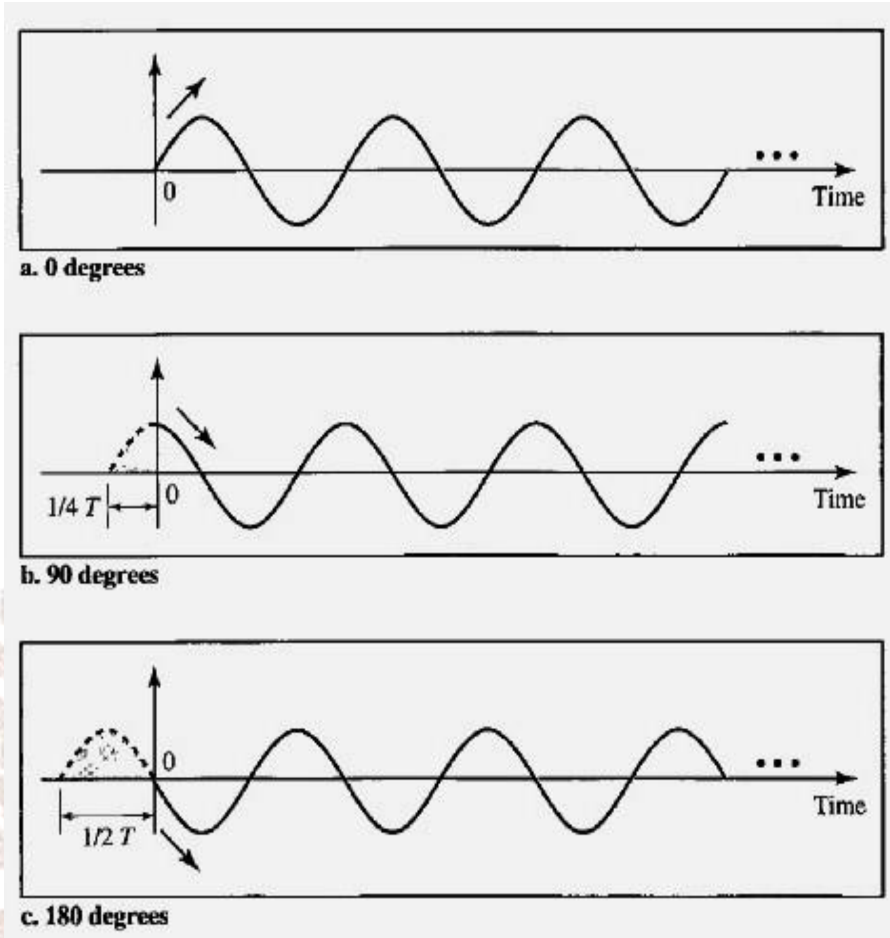

Figure 3.5: Three sine waves with the same amplitude and frequency but different phases

Wavelength is another characteristic of a signal, passing through a transmission medium. Wavelength binds the period or frequency of a simple sine wave to the propagation speed of the medium. Figure 3.6 shows the wavelength of a signal.

Wavelength depends on both frequency and medium. Frequency of a signal is independent of the medium. The wavelength is the distance travelled by a simple signal in one period. The higher the frequency of the signal, the shorter the wavelength. If f is the frequency of the signal as measured in megahertz, and v is wave speed then,

W= v/f………...3.3

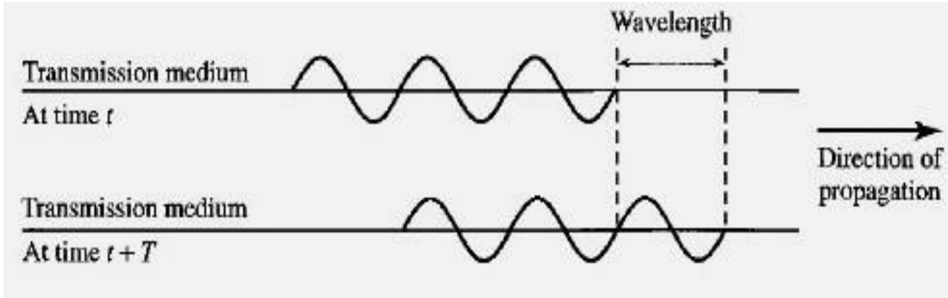

Figure 3.6: Wavelength and period

Composite signals

A single frequency sine wave (simple sine wave) is not useful in data communications. To make it useful we need to change its one or more characteristics. When we change one or more characteristics of a single frequency signal, it becomes a composite signal, made of many signals. For instance, we can use single sine wave to carry electric energy from one place to another. We can also use sine wave to send an alarm to a security centre when a robber opens the door of the house. Here, in first case, the sine wave is carrying energy and in the second, the sine wave is a signal of danger. But if we use a single sine wave to convey a conversation over phone, it would not carry any information. So, in order to communicate data, we need a composite signal. Figure 3.7 shows some periodic composite signal with frequency f.

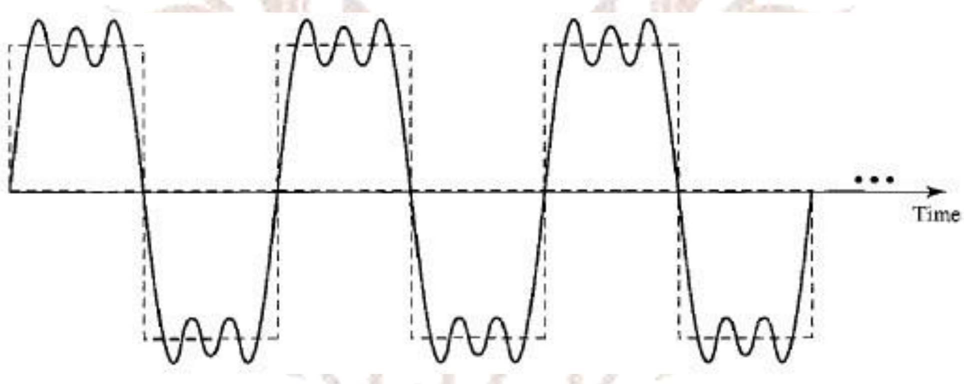

Figure 3.7: A composite periodic signal

In 1990s, the French mathematician Jean-Baptiste Fourier showed that any composite signal is a combination of simple sine wave with different frequencies, amplitudes and phases. A composite signal can be periodic or nonperiodic. A periodic composite signal can be divided into a series of simple sine waves with discrete frequencies (frequencies that have integer values 1, 2, 3 and so on). A nonperiodic composite signal can be decomposed into a combination of an infinite number of simple sine waves with continuous frequencies (frequencies that have real values). The bandwidth of a composite signal is the difference between the highest and the lowest frequencies contained in that signal. For instance, if a composite signal contains frequencies between 1000 and 5000, its bandwidth is 5000

– 1000 = 4000.

Self-Assessment Questions – 2

6. A simple periodic analog signal is known as___________ .
7. ______________ is composed of multiple sine waves.
8. A sine wave can be represented by three parameters, they are_____________ ,_______________and__________________.
9. For electric signals, peak amplitude is measured in volts. State true or false.

   a) True b) False

10. Period is expressed in_____________ and frequency is expressed in______________.
11. The________________ is the distance a simple signal can travel in one period.

4. DIGITAL SIGNALS

In a digital signal, a 1 can be encoded as a positive voltage and a 0 as zero voltage. Sometimes, a digital signal can have more than two levels, in that case, we can send more than one bit for each level. Figure 3.8 shows two signals, one with two levels and other with four.

Bit rate

Most digital signals are nonperiodic, so we cannot describe digital signals with period and frequency characteristics. Another term known as bit rate is used to describe digital signals. The bit rate is the number of bits sent in one second, which is expressed in bits per second (bps).

Bit length

In case of analog signal, wavelength is the distance one cycle occupies on the transmission medium. In digital signal, the bit length is the distance that one bit occupies on the transmission medium.

Bit length = propagation speed × bit duration………………………..3.4

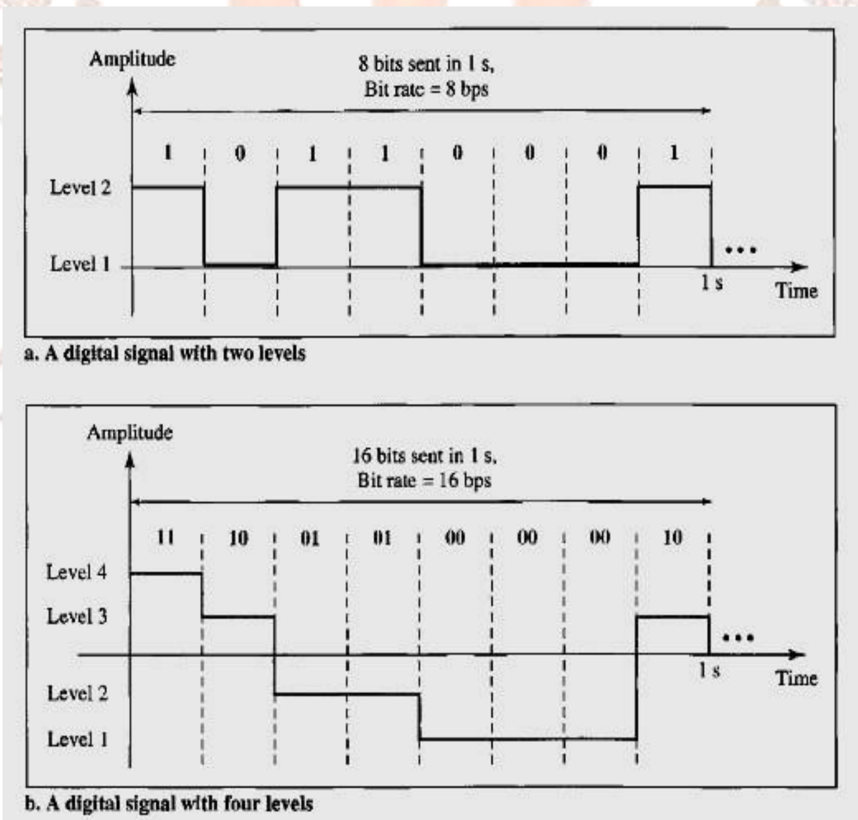

Figure 3.8: Two digital signals- one with two signal levels and other with four signal levels

Transmission of digital signals

A digital signal is a composite analog signal with frequencies between zero and infinity. We can transmit a digital signal by using baseband transmission or broadband transmission.

Baseband transmission requires a low-pass channel, which is a channel with a bandwidth that starts from zero Hz. Figure 3.9 shows a baseband transmission.

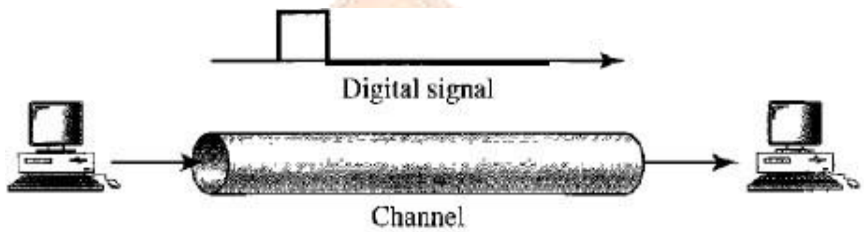

Figure 3.9: Baseband transmission

In broadband transmission or modulation, the digital signal is first converted to an analog signal for transmission. Modulation allows us to use a band pass channel. Bandpass channel is a channel with a bandwidth that does not start from zero Hz. This type of channel is more available than a low- pass channel. Figure 3.10 shows the modulation of a digital signal.

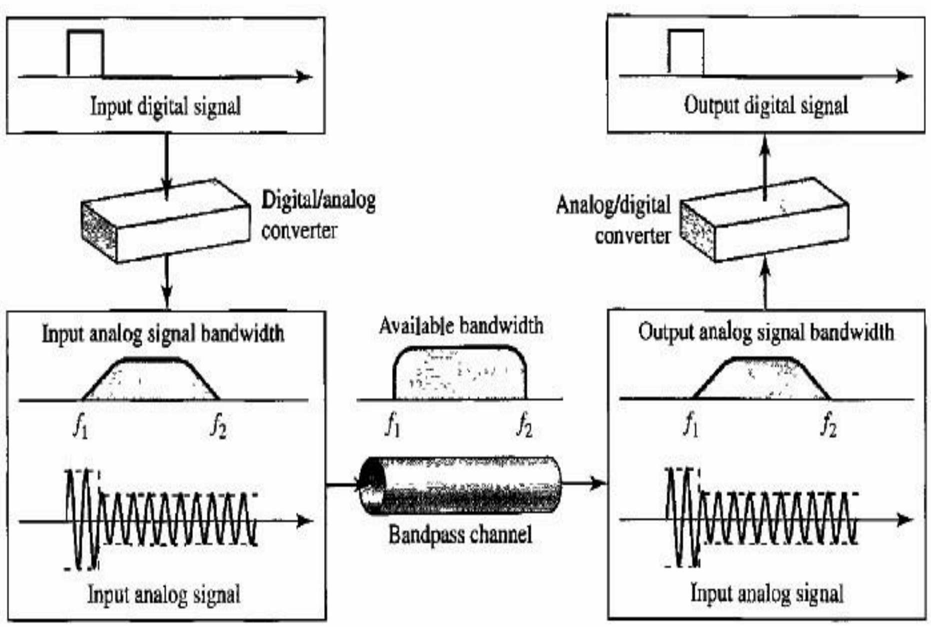

Figure 3.10: Modulation of a digital signal for transmission on a bandpass channel

In the figure 3.10, a digital signal is converted to a composite analog signal. Here a single frequency analog signal (called a carrier) is used. The amplitude of the carrier has been changed to look like a digital signal. The result is a composite signal. At the receiver side, the received analog signal is converted to digital signal.

Self-Assessment Questions – 3

12. The number of bits sent in one second is known as______________ .
13. In________________ transmission, a digital signal sends over a channel without changing the digital signal to analog signal.
14. Broadband transmission is also known as______________.

5. TRANSMISSION IMPAIRMENT

Signals which are transferred though a transmission media are not perfect. During transmission through the medium, the properties of the signal can be changed. This imperfection causes signal impairment. Three causes of impairment are attenuation, distortion and noise. Attenuation means a loss of energy. The strength of a signal falls off with distance over any transmission medium. Distortion means change of form or shape of the signal. Noise refers to an unwanted signal in a channel, which corrupts the signal.

5.1 Attenuation

Attenuation signifies a loss of energy. When a simple or composite signal travels through a medium, it loses some of its energy in overcoming the resistance of the medium. For example, we know a wire carrying electric signals gets warm or hot after transmitting signals for a while. Here, some of the electrical energy is converted to heat. If the strength of the signal is very low, the signal cannot be detected and interpreted properly at the receiving end. So, amplifiers or repeaters are inserted at intervals along the medium to improve the received signal as close to its original level. Attenuation and amplification are measured in decibel (dB). Figure 3.11 shows the effect of attenuation and amplification.

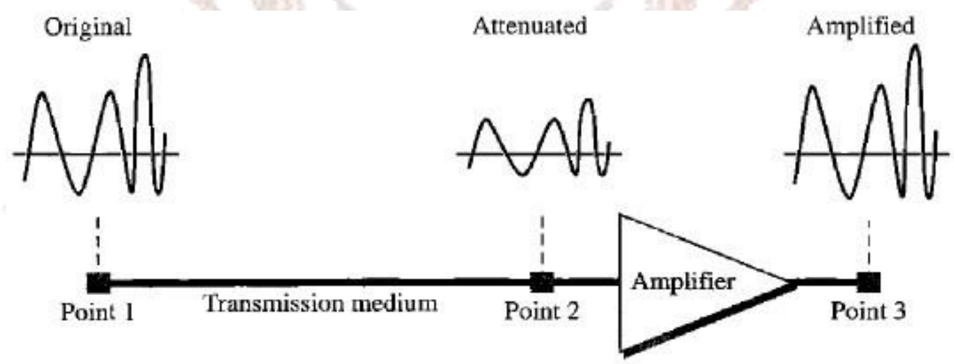

Figure 3.11: Attenuation

5.2 Distortion

Distortion means that the signal changes its form or shape. In a composite signal made of different frequencies, distortion can occur. Every signal component has its own propagation speed through the medium and so the time of arrival at the final destination also varies.

Difference in delay can create a phase difference if the delay is not exactly same as the period duration. That means, signal components at the receiver have phases different from what they had at the sender. So, the shape of the composite signal received is not the same as the signal sent. Figure 3.12 shows the effect of distortion on a composite signal.

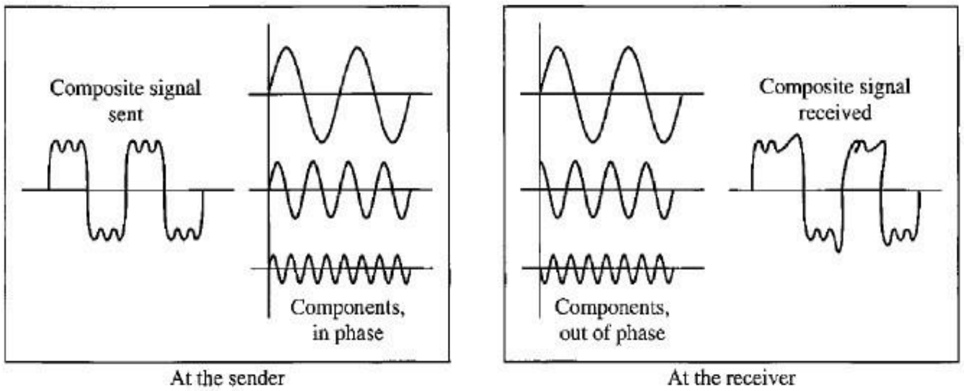

Figure 3.12: Distortion

5.3 Noise

Another cause of impairment is noise. Noise is refered to any unwanted signal in a channel, which corrupts the signal. Different types of noise such as thermal noise, intermodulation noise, crosstalk and impulse noise may corrupt the signal. Figure 3.13 shows the effect of noise on a signal.

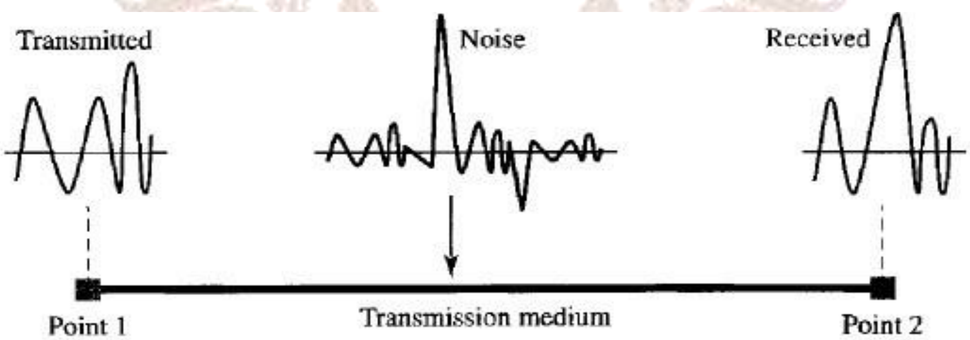

Figure 3.13: Noise

Thermal noise is the random motion of electrons in a wire which creates an extra signal which is not sent by the transmitter It is distributed across the entire spectrum, this phenomenon is caleed as white noise. When more than one signal uses the same transmission medium, Intermodulation Noise is generated. Crosstalk is the effect of one wire on the other during wired communication. Here, one wire acts as a sending antenna and the other as the receiving antenna. 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 a spike (that is, a signal with high energy in a very short time) that comes from power lines, lightning etc.

6. DATA RATE LIMITS

A very important consideration in data communication is data transfer speed, which is how fast we can send data in bits per second, over a channel. Data rate depends on three factors. They are: (i) Bandwidth availability, (ii) Signal Strength (iii) Quality of the data transmitting channel. In order to calculate the data rate, two theoretical formulas were developed.

One by Nyquist for a noiseless channel and another by Shannon for a noisy channel.

6.1 Noiseless Channel: Nyquist Bit Rate

In 1924, Henry Nyquist realized that the transmission capacity of a perfect channel is also finite. Nyquist discovered that it was not necessary to capture the entire analog signal to find the original signal, samples of the signal could be taken at various points to recover the original signal. He derived an equation expressing the maximum data rate for a finite bandwidth noiseless channel.

Bitrate = 2 × bandwidth × $\log_2 L$……………………………………3.5

Here, bandwidth is the bandwidth of the channel, L is the number of signal levels used to represent data and Bitrate is measured in bits per second.

Based on this formula, in a given specific bandwidth, we can have any bit rate we need by increasing the number of signal levels. This idea is theoretically correct, but practically there is a limit. When we increase the number of signal levels, we enforce a burden on the receiver. For example, if the number of levels in a signal is just 2, the receiver can easily distinguish between a 0 and a 1. But if a signal has 64 levels, it will be very difficult for the receiver to distinguish between 64 different levels. That means, increasing the levels of a signal reduces the reliability of the system.

6.2 Noisy Channel: Shannon Capacity

We cannot have a noiseless channel in reality, the channel is always noisy. In 1944, Claude Shannon introduced a formula called the Shannon capacity to determine the theoretical highest data rate for a noisy channel.

Capacity = bandwidth × $\log_2 (1 + SNR)$………………………………… 3.6

Here, bandwidth is the bandwidth of the channel. SNR is the signal-to-noise ratio, which is the ratio of the signal power to the noise power (SNR= average Signal power/average noise power). Capacity is the capacity of the channel in bits per second.

In Shannons' formula, there is no indication of the signal level which means that no matter how many levels we have, we cannot achieve a data rate higher than the capacity of the channel. That means, the formula defines a characteristic of the channel and not the method of transmission.

7. PERFORMANCE

Another important issue in networking is the performance of the network. Characteristics that measure network performance are bandwidth, throughput, latency, bandwidth-delay product and jitter.

7.1 Bandwidth

Bandwidth is one of the characteristics that measures network performance. In two different contexts, bandwidth can be measured with two different measuring values. Bandwidth in hertz and bandwidth in bits per second. Bandwidth in hertz is the range of frequencies contained in a composite signal or range of frequencies a channel can pass. For instance, bandwidth of a subscriber telephone line is 4 kHz. Bandwidth is also the number of bits per second that a channel can transmit. For example, bandwidth of a fast ethernet network is a maximum of 100 Mbps, means that this network can send 100 Mbps.

So, bandwidth in hertz refers to the range of frequencies in a composite signal or the range of frequencies that a channel can pass. Bandwidth in bits per second refers to the speed of bit transmission in a channel or link.

7.2 Throughput

The throughput is a measure of how fast we can send data through a network. Suppose, a link has a bandwidth of B bps, but we can only send T bps through this link with T always less than B. The bandwidth becomes a potential measurement of a link. The throughput is an actual measurement of how fast we can send data. Suppose, we have a link with a bandwidth of 1 Mbps, but the receiver can handle only 200 kbps which means that we can't send more than 200 kbps using this link. So here bandwidth is 1 Mbps and throughput is 200 kbps. Another example is, consider a highway designed to transmit 500 cars per minute, but if there is a traffic jam on the road, only 50 cars can be transmitted per minute. So here, the bandwidth is 500 cars per minute and throughput is 50 cars per minute.

7.3 Latency (Delay)

Latency or delay defines how long it takes for an entire message to completely arrive at the destination from the time that the first bit is sent out from the source. It is made of four components, propagation time, transmission time, queuing time and processing delay.

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

Propagation time is the time required for a bit to travel from the source to the destination. The propagation time is calculated by dividing the distance by the propagation speed. Propagation speed of electromagnetic signals depends on the medium and on the frequency of the signal. For instance, in vacuum, light is propagated with a speed of 3×10^8 m/s. It is lower in air and much lower in cable.

In case of sending a message, the first bit may take time equal to the propagation time to reach its destination. Transmission time is the time between the first bit leaving the sender and the last bit arriving at the receiver. The time required for transmission of a message depends on the size of the message and the bandwidth of the channel (Transmission time= message size/ bandwidth).

Queuing time is the time needed for each intermediate or end device to hold the message before it can be processed. Based on the load on the network, queuing time vary. During heavy traffic, queuing time increases. In that case, an intermediate device known as router, queues the arrived message and processes them one by one. Each message has to wait if there are many messages.

7.4 Bandwidth-Delay Product

Bandwidth and delay are two performance metrics of a link. In data communication, bandwidth-delay product is important. The bandwidth-delay product defines the number of bits that can fill the link. It refers to the product of bandwidth and delay of a network which specifies the maximum number of bits that can be at any time on the link. For example, if a link has a bandwidth of 10 bps and delay is 5s, then the maximum number of bits that can fill the link is 50 bits. Bandwidth-delay product determines the number of data bits that can be fitted in a link for transformation.

7.5 Jitter

Jitter is another performance issue that is related to delay. Jitter is a problem when different packets of data encounter different delays and the application using the data at the receiver site is time sensitive. For example, if the delay for the first packet is 20 ms, for second is 45 ms and for the third is 40 ms, then the real-time application that uses the packets endures jitter.

Self-Assessment Questions – 5

18. In case of noiseless channel, a formula called Shannon capacity defines the theoretical maximum bit rate. State true or false.
    a) True b) False
19. ________________is a measure of how fast we can send data through a network.
20. The time between the first bit leaving the sender and the last bit arriving at the receiver is known as___________.

8. SUMMARY

Let us recapitulate the important concepts discussed in this unit:

- Analog data refers to information that is continuous and digital data refers to information that has discrete states.
- A periodic signal completes a pattern within a measurable time frame called a period and repeat that pattern over subsequent identical periods.
- A nonperiodic signal changes without demonstrating a pattern or cycle that repeats over time.
- A simple periodic analog signal is known as a sine wave. A composite periodic analog signal is composed of multiple sine waves.
- In baseband transmission, a digital signal sends over a channel without changing the digital signal to analog signal.
- In broadband transmission or modulation, the digital signal is first converted to an analog signal for transmission.
- Attenuation signifies a loss of energy. Distortion means that the signal changes its form or shape.
- The Nyquist bit rate formula defines the theoretical maximum bit rate, in case of a noiseless channel.
- A formula called the Shannons' Formula determines the theoretical capacity of the data rate for a noisy channel.
- The throughput is a measure of how fast we can send data through a network.
- Latency is made of four components. They are propagation time, transmission time, queuing time and processing delay.

9. TERMINAL QUESTIONS

1. Write short notes on analog and digital data.
2. Differentiate between simple periodic analog signal and a composite periodic analog signal.
3. Differentiate between baseband and broadband transmission.
4. Describe the causes of transmission impairment.
5. Explain Nyquist bit rate formula.
6. Describe Shannon capacity.
7. Explain the characteristics that measures network performance.

10. ANSWERS

Self-Assessment Questions

1. (a) Physical layer
2. Analog data
3. Digital data
4. Period
5. Cycle
6. Sine wave
7. Composite periodic analog signal
8. Peak amplitude, frequency and phase
9. (a) True
10. Seconds, Hertz (Hz)
11. Wavelength
12. Bit rate
13. Baseband
14. Modulation
15. Attenuation
16. Distortion
17. (b) Induced noise
18. (b) false
19. Throughput
20. Transmission time

Terminal Questions

1. Analog data refers to information that is continuous and digital data refers to information that has discrete states. (Refer section 3.2 for detail).
2. Periodic analog signals can be categorized as simple or composite. A simple periodic analog signal cannot be decomposed into simpler signals. A simple periodic analog signal is known as a sine wave. A composite periodic analog signal is composed of multiple sine waves. (Refer section 3.3 for detail).
3. Baseband transmission requires a low-pass channel, which is a channel with a bandwidth that starts from zero. In broadband transmission or modulation, the digital signal is first converted to an analog signal for transmission. (Refer section 3.4 for detail).
4. Signals which are transferred though a transmission media are not perfect. During transmission through the medium, the properties of the signal can be changed. This imperfection causes signal impairment. Three causes of impairment are attenuation, distortion and noise. (Refer section 3.5 for detail).
5. The Nyquist bit rate formula defines the theoretical maximum bit rate, in case of a noiseless channel. Based on this formula, in a given specific bandwidth, we can have any bit rate we need by increasing the number of signal levels. (Refer section 3.6.1 for detail)
6. In 1944, Claude Shannon introduced a formula called the Shannon capacity to determine the theoretical highest data rate for a noisy channel. (Refer section 3.6.2 for detail)
7. Characteristics that measures network performance are bandwidth, throughput, latency, bandwidth-delay product and jitter. (Refer section 3.7 for detail)

References:

1. A. S. Tanenbaum, Computer Networks, 4 ed., Pearson Education, 2011.
2. B. A. Forouzan and S. C. Fegan, Data Communications and Networking, 4 ed., New Delhi: McGraw-Hill publication, 2007.
3. H. Taub and D. L. Schilling, Principles of Communication Systems, 4 ed., Delhi, 2002.
4. J. Walrand and P. Varaiya, High performance communication networks, 2 ed., San Francisco: Morgan Kaufmann publishing, 1999.
5. N. Olifer and V. Olifer, Computer Networks: Principles, technologies and Protocols for Network design, 1 ed., New Delhi: Wiley India Pvt. Ltd., 2010.
6. S. Poulton, Packet switching and X.25 Networking, 1 ed., Pitman publishing, 2003.
7. S. William, Data and Computer Communications, 6 ed., Delhi: Pearson Education, 2002.