BACHELOR OF COMPUTER APPLICATIONS

SEMESTER 3

DCA2104

BASICS OF DATA COMMUNICATION

Unit 9

Multiplexing

Table of Contents

1. INTRODUCTION

This unit introduces the concept of Multiplexing. Multiplexing is about sharing a communications line. Suppose two devices are connected by a link and there are multiple frames to be sent. In that case, this data link does not become a problem between the stations. Another scenario is if two communicating stations will not utilize the full capacity of a data link. In that case, it should be possible to share that capacity. Such sharing is known as multiplexing. The device that combines the signals on the sending end of a channel is called a multiplexer and the device on the receiving end that separates them into their original order is called a demultiplexer. There are different types of multiplexing such as frequency division multiplexing, wavelength division multiplexing and time division multiplexing.

In this unit, we are going to discuss different multiplexing techniques that include frequency division multiplexing, wavelength division multiplexing. We will also know what is time division multiplexing and its two categories namely time division multiplexing such as synchronous time division multiplexing and statistical time division multiplexing. In the last section, we will discuss asymmetric digital subscriber line.

1.1 Objectives:

After studying this unit, you should be able to:

- *Describe multiplexing*
- *Explain frequency division multiplexing*
- *Describe wavelength division multiplexing*
- *Explain time division multiplexing*
- *Describe asymmetric digital subscriber line*

2. FREQUENCY DIVISION MULTIPLEXING

Frequency division multiplexing (FDM) is a method of transmission in which numerous signals are combined on a single communication line or channel. A different frequency is assigned to each signal within the main channel. FDM is used when the useful bandwidth of the transmission medium exceeds the required bandwidth of signals to be transmitted. A number of signals can be carried simultaneously if each signal is modulated onto a different carrier frequency and the carrier frequencies are sufficiently separated that the bandwidths of the signals do not overlap. Figure 9.1 shows a frequency division multiplexing.

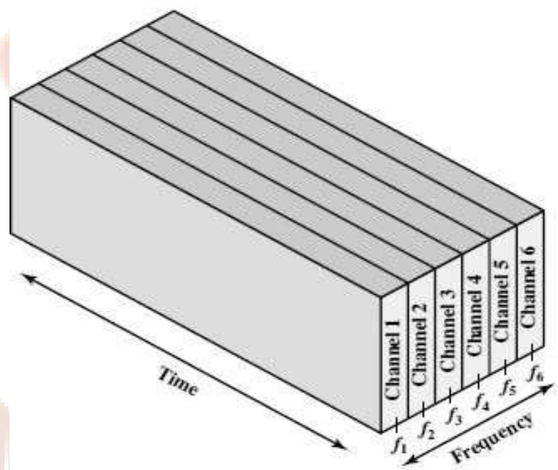

Figure 9.1: Frequency division multiplexing

Here, six signal sources are fed into a multiplexer, which modulates each signal onto a different frequency (f_1, ..., f_6). Each modulated signal requires a certain bandwidth centered on its carrier frequency, referred to as a **channel**. To prevent interference, the channels are separated by guard bands. Guard bands are unused portions of the spectrum.

The input signals may be either digital or analog, but the composite signal transmitted across the medium is analog. In case of digital input signal, it is converted into analog by passing it through modems. Input analog signals then be modulated to move it to the appropriate frequency band.

The motivation for using this technology includes using existing physical media more efficiently by maximizing the amount of data that can be transferred. Once data is multiplexed, we can amplify, conduct or change the frequency of the signal as needed to match our needs. An attractive feature of FDM is that the transmitting end and receiving end do not have to be close to each other. This made FDM widely used in the first telecommunication mediums. This was later replaced with digital methods. Broad cast and cable television are familiar examples of FDM. For years, cable TV companies have used FDM to transmit many channels over the same wire. The cable company simultaneously sends the signals for all TV channels we need, at the same time through a single coaxial cable. When FDM is used in a communications network, each input signal is sent and received at maximum speed at all times. But, if many signals must be sent along a single long distance line and the necessary bandwidth is large, a different method known as time division multiplexing is used.

Another method of FDM is orthogonal frequency division multiplexing (OFDM). This technology was first developed in 1960s and 1970s during research to minimize interference among channels that had frequencies near each other. OFDM is similar to FDM in few aspects. The difference lies in the way in which signals are combined and separated. With OFDM, priority is given to minimize the interference among the channels rather than focusing on improving the individual channels. OFDM is used in European digital audio broadcast services such as digital television. It is also used in wireless local area networks.

Self-Assessment Questions - 1

1. In which of the following multiplexing, different frequencies are assigned to each signal?
   a) Frequency division multiplexing
   b) Wavelength division multiplexing
   c) Synchronous time division multiplexing
   d) Statistical time division multiplexing
2. In order to prevent interference, the channels are separated by___________.
3. Multiplexing used to minimize interference among channels that had frequencies near each other, is known as___________ .
4. European digital audio broadcast services such as digital television used_____________ multiplexing.

3. WAVELENGTH DIVISION MULTIPLEXING

Now, optical networks has made their way into enterprise networks. Wavelength division multiplexing is the optical equivalent to early carrier system. Wavelength division multiplexing is a form of frequency division multiplexing specifically for combining many optical carrier signals into a single optical fiber. In fiber optic transmissions, data is represented as pulses of light travelling through silicon glass. In current optical networks, a single laser signal provides the carrier signal on which the data is multiplexed. The laser is a single color. All the light beams are sent at the same time, with each signal attached to a laser that emits a different color beam. The receiver splits the colors into the original signals again.

The first WDM systems which appeared around 1985, combined two signals. Because a single optical fiber has an extremely high capacity, this type of multiplexing offers the greatest potential for future communications. Modern systems can handle up to 128 signals. These systems are sometimes called dense wave division multiplexing (DWDM) systems. DWDM is a technology that puts data from different sources together on an optical fiber with each signal carried at the same time on its own light wavelength. By combining multiple wavelengths, each representing a separate data channel, the same optic fiber has the bandwidth capacity of multiple cables. Incoming optical signals are assigned to specific frequencies within a designated band.

The capacity of the fiber is increased when these signals are multiplexed out onto one fiber. Using this technology, up to 128 separate wavelengths or channels of data can be multiplexed into a light stream transmitted on a single optical fiber. Because each channel is demultiplexed back into the original source, different data formats being transmitted at different data rates can be transmitted together.

Self-Assessment Questions -2

5. A form of frequency division multiplexing which combines many optical carrier signals into a single optical fiber is known as__________ .
6. _____________ is a technology that puts data from different sources together on an optical fiber with each signal carried at the same time on its own light wavelength.
7. Dense wave division multiplexing (DWDM) systems can handle up to_________ signals.

4. TIME DIVISION MULTIPLEXING (TDM)

In time division multiplexing (TDM), multiple data streams are combined in a single signal and transmitted over the same link by allocating a different time slot for the transmission of each channel. *Synchronous time division multiplexing (or slotted time division multiplexing)* is a form of TDM in which the time allocated to a device or workstation is fixed. This method is popular for digital voice telephone circuits because each voice call delivers data at exactly the same rate. Another category is *statistical time division multiplexing (STDM)*. This is a form of TDM that improves sharing efficiency by allowing some of the multiplexed channels to increase their allotted time if other stations are not using theirs to full capacity. Many data networks use the STDM because it is considered more efficient. Based on past and current transmission needs or statistics, STDM would allocate more time to the busy fax server and less time to the little used printer.

4.1 Synchronous Time Division Multiplexing

Synchronous time division multiplexing is possible when the achievable data rate (sometimes called bandwidth) of the medium exceeds the data rate of digital signals to be transmitted. Multiple digital signals (or analog signals carrying digital data) can be carried on a single transmission path by interleaving portions of each signal in time. The interleaving can be at the bit level or in blocks of bytes.

Figure 9.2 shows a synchronous TDM system. A number of signals are to be multiplexed onto the same transmission medium. The signals carry digital data and are generally digital signals. The incoming data from each source are briefly buffered. Each buffer is typically one bit or one character in length. The buffers are scanned sequentially to form a composite digital data stream $m_c(t)$. The scan operation is sufficiently rapid so that each buffer is emptied before more data can arrive. Thus, the data rate of $m_c(t)$ must at least equal the sum of the data rates of the $m_i(t)$. The digital signal $m_c(t)$ may be transmitted directly, or passed through a modem so that an analog signal is transmitted. In either case, transmission is typically synchronous.

The transmitted data may have a format something like Figure 9.2 (b).The data are organized into *frames*. Each frame contains a cycle of time slots. In each frame, one or more slots are dedicated to each data source. The sequence of slots dedicated to one source, from frame to frame, is called a *channel*. The slot length equals the transmitter buffer length, typically a bit or a byte.

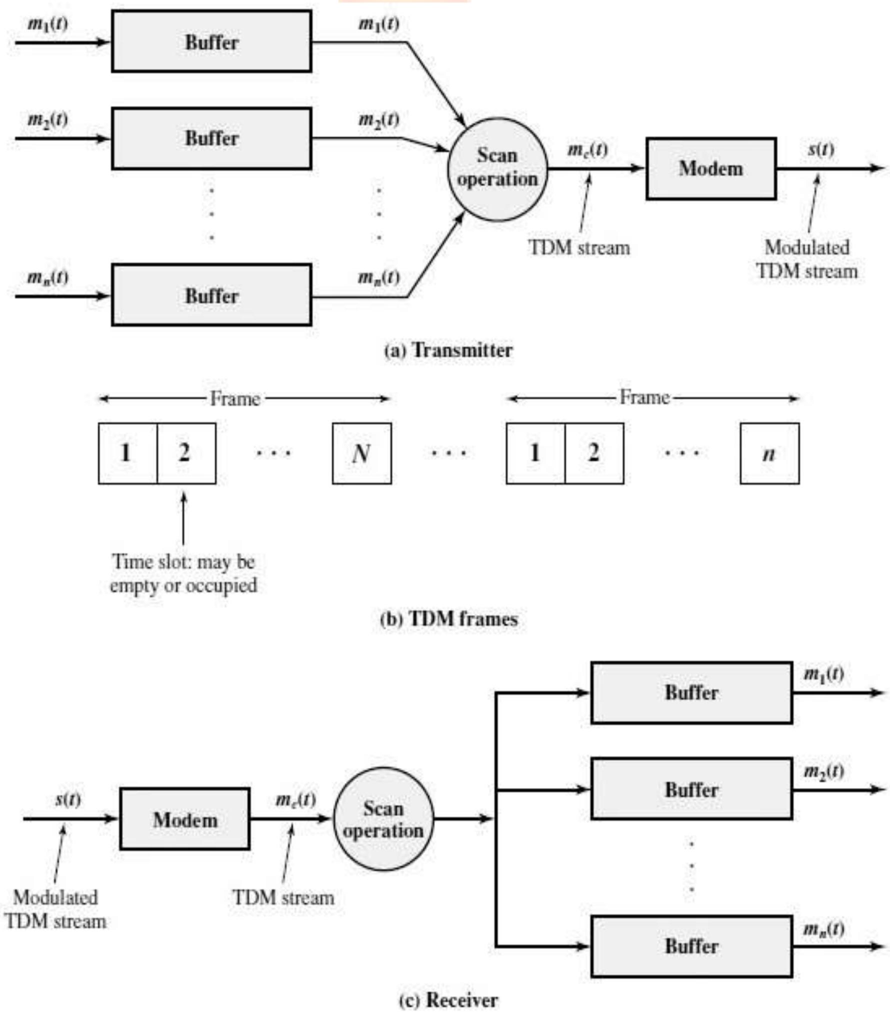

Figure 9.2: Synchronous TDM system

In asynchronous and synchronous sources, the byte-interleaving technique is used. Each time slot contains one character of data. Typically, the start and stop bits of each character are eliminated before transmission and reinserted by the receiver, hence improving efficiency. The bit-interleaving technique is used with synchronous sources and may also be used with asynchronous sources. Each time slot contains just one bit.

At the receiver, the interleaved data are demultiplexed and routed to the appropriate destination buffer. For each input source $m_i(t)$, there is an identical output destination that will receive the output data at the same rate at which it was generated. Synchronous TDM is called synchronous not because synchronous transmission is used, but because the time slots are preassigned to sources and fixed. The time slots for each source are transmitted whether or not the source has data to send. In FDM also, same process is followed. In both cases, capacity is wasted to achieve simplicity of implementation. Even when fixed assignment is used, however, it is possible for a synchronous TDM device to handle sources of different data rates. For example, the slowest input device could be assigned one slot per cycle, while faster devices are assigned multiple slots per cycle.

TDM Link Control

Data frames contain header and trailer information in synchronous transmission. But here in figure 9.2 (b), we can see that the transmitted data stream does not contain the headers and trailers. The reason is that the control mechanisms provided by a data link protocol are not needed. These information are used for flow control and error control, but as far as the multiplexer and demultiplexer are concerned, flow control is not needed. The data rate on the multiplexed line is fixed, and the multiplexer and demultiplexer are designed to operate at that rate. But in case if one of the output lines failed and is temporarily unable to accept data, transmission of TDM frame should not stop because the remaining output lines are expecting to receive data at predetermined times. The solution is that the failed output device stops the data flow from corresponding input device, so for a while this channel will carry empty slots but the frames as a whole will maintain the same transmission rate. Error control is also not required in TDM. Since the error occurs on one channel, it would not request retransmission of an entire TDM frame. Error control is done on a per- channel basis. The devices using the other channels do not want a retransmission and they do not know that a retransmission has been requested by some other device on another channel.

Framing

We have seen that a link control protocol is not needed to manage the overall TDM link. There is a basic requirement for framing. Since we are not providing flag or SYNC characters to group TDM frames, some means is required to assure frame synchronization. It is clearly important to maintain framing synchronization because, if the source and destination are out of step, data on all channels are lost.

The most common mechanism for framing is known as added-digit framing. In this scheme, one control bit is added to each TDM frame. An identifiable pattern of bits, from frame to frame, is used as a control channel. A typical example is the alternating bit pattern, 101010…This is a pattern which is not likely to appear on a data channel. So, inorder to synchronize, a receiver compares the incoming bits of one frame position to the expected pattern. If the pattern does not match, successive bit positions are searched until the pattern persists over multiple frames. Once framing synchronization is established, the receiver continues to monitor the framing bit channel. If the pattern breaks down, the receiver must again enter a framing search mode.

Pulse stuffing

The most difficult problem in the design of a synchronous time division multiplexer is that of synchronizing the various data sources. If each source has a separate clock, any variation among clocks could cause loss of synchronization. Also, in some cases, the data rates of the input data streams are not related by a simple rational number. For both these problems, a technique known as pulse stuffing is an effective solution.

With pulse stuffing, the outgoing data rate of the multiplexer, excluding framing bits, is higher than the sum of the maximum instantaneous incoming rates. The extra capacity is used by stuffing extra dummy bits or pulses into each incoming signal until its rate is raised to that of a locally generated clock signal. The stuffed pulses are inserted at fixed locations in the multiplexer frame format so that they may be identified and removed at the demultiplexer.

4.2 Statistical Time Division Multiplexing

In a synchronous time division multiplexer, it is often the case that many of the time slots in a frame are wasted. A typical application of a synchronous TDM involves linking a number of terminals to a shared computer port. Even if all terminals are actively in use, most of the time there is no data transfer at any particular terminal.

An alternative to synchronous TDM is statistical TDM. In statistical time division multiplexing, time slots are allocating dynamically on demand. Similar to synchronous TDM, the statistical multiplexer has a number of I/O lines on one side and a higher-speed multiplexed line on the other. Each I/O line has a buffer associated with it. In the case of the statistical multiplexer, there are *n* I/O lines, but only *k*, where $k<n$, time slots available on the TDM frame. For input, the function of the multiplexer is to scan the input buffers, collecting data until a frame is filled, and then send the frame. On output, the multiplexer receives a frame and distributes the slots of data to the appropriate output buffers.

Statistical TDM is functioning based on the fact that the attached devices are not all transmitting all of the time. So, the data rate on the multiplexed line is less than the sum of the data rates of the attached devices. Thus, a statistical multiplexer can use a lower data rate to support as many devices as a synchronous multiplexer. Alternatively, if a statistical multiplexer and a synchronous multiplexer both use a link of the same data rate, the statistical multiplexer can support more devices.

Figure 9.3 shows the comparison between synchronous TDM and statistical TDM. Figure shows four data sources and the data produced in four time periods (t_0, t_1, t_2, t_3). In the case of the synchronous multiplexer, the multiplexer has an effective output rate of four times the data rate of any of the input devices. During each period, data are collected from all four sources and sent out. For example, in the first period, sources C and D produce no data. Thus, two of the four time slots transmitted by the multiplexer are empty.

The statistical multiplexer does not send empty slots if there are data to send. Thus, during the first period, only slots for A and B are sent. However, the positional significance of the slots is lost in this scheme. It is not known ahead of time which source's data will be in any particular slot. Because data arrive from and are distributed to I/O lines unpredictably, address information is required to assure proper delivery. Thus, there is more overhead per slot for statistical TDM because each slot carries an address as well as data.

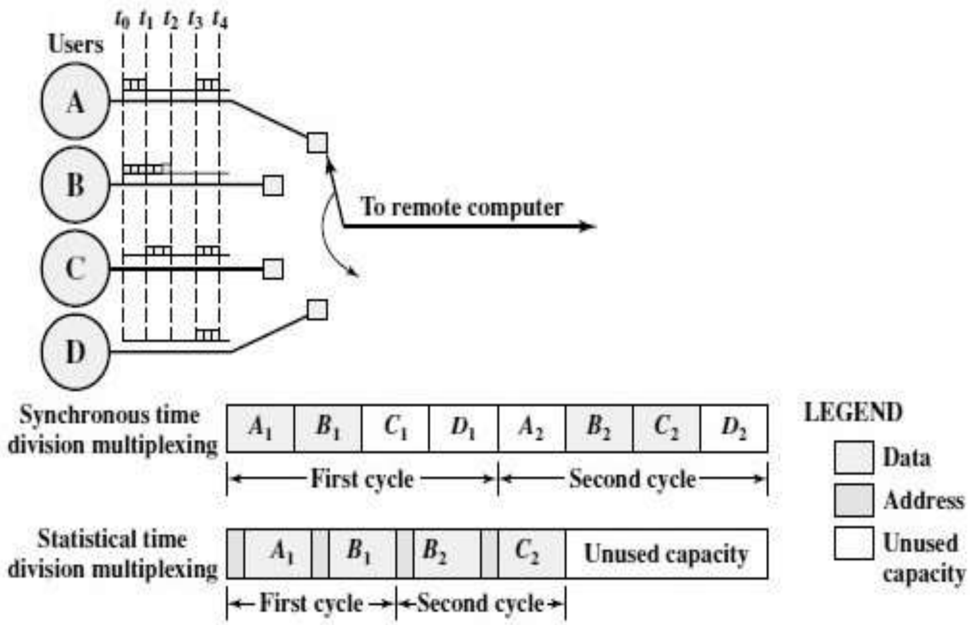

Figure 9.3: Comparison between synchronous TDM and Statistical TDM

The frame structure used by a statistical multiplexer has an impact on performance. It is desirable to minimize overhead bits to improve throughput. A statistical TDM system will use a synchronous protocol such as HDLC (High-Level Data Link Control). Within the HDLC frame, the data frame must contain control bits for the multiplexing operation. Figure 9.4 shows two possible formats.

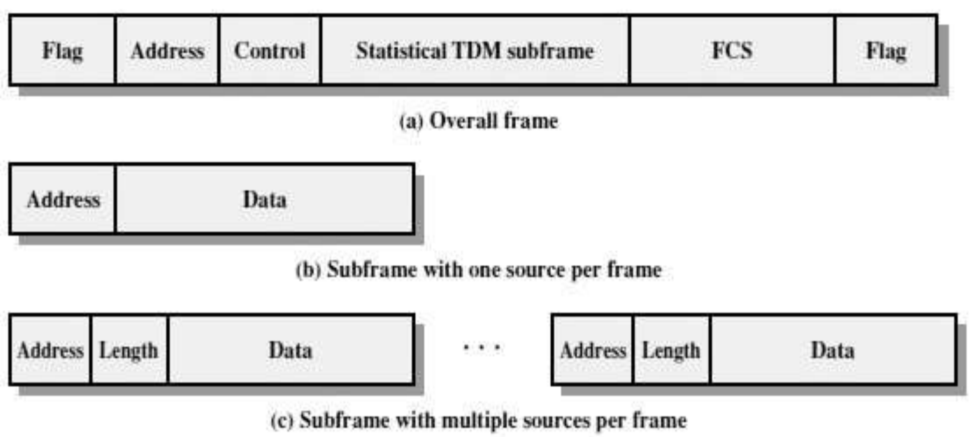

Figure 9.4: Statistical TDM Frame Formats

In the first case, only one source of data is included per frame. That source is identified by an address. The length of the data field is variable, and its end is marked by the end of the overall frame. This scheme can work well under light load but is quite inefficient under heavy load. A way to improve efficiency is to allow multiple data sources to be packaged in a single frame. Now, however, some means is needed to specify the length of data for each source. Thus, the statistical TDM sub frame consists of a sequence of data fields, each labelled with an address and a length. Several techniques can be used to make this approach even more efficient. The address field can be reduced by using relative addressing. That is, each address specifies the number of the current source relative to the previous source, modulo the total number of sources.

Self-Assessment Questions -3

8. In which of the following multiplexing, some of the multiplexed channels can increase their allotted time if other stations are not using theirs to full capacity?
   (a) Frequency division multiplexing
   (b) Wavelength division multiplexing
   (c) Synchronous time division multiplexing
   (d) Statistical time division multiplexing
9. Data frames contain header and trailer information in ____________ transmission.
10. The most common mechanism for framing is known as____________ .
11. Linking a number of terminals to a shared computer port is an application of_______________ TDM.
12. A_________ TDM system will use a synchronous protocol such as HDLC.

5. ASYMMETRIC DIGITAL SUBSCRIBER LINE

Asymmetric digital subscriber line (ADSL) is one of a number of recent schemes for providing high-speed digital transmission of the subscriber line. Table 9.1 shows few important new schemes, which collectively are referred to as xDSL.

Table 9.1: Comparison of XDSL alternatives

	ADSL	HDSL	SDSL	VDSL
Data rate	*1.5 to 9 Mbps downstream 16 to 640 kbps upstream*	*544 or 2.048Mbps*	*544 or 2.048Mbps*	*13 to 52 Mbps downstream 1.5 to 2.3Mbps upstream*
Mode	*Asymmetric*	*Symmetric*	*Symmetric*	*Asymmetric*
Copper pairs	*1*	*2*	*1*	*1*
Range (24-gauge UTP)	*3.7 to 5.5 km*	*3.7km*	*3.0km*	*1.4km*
signaling	*Analog*	*Digital*	*Digital*	*Analog*
Line code	*CAP/ DMT*	*2B1Q*	*2B1Q*	*DMT*
Frequency	*1 to 5 MHz*	*196 kHz*	*196 kHz*	*>=10 MHz*
Bits/cycle	*Varies*	*4*	*4*	*Varies*

UTP = unshielded twisted pair

High Data Rate Digital Subscriber Line (HDSL)

HDSL was developed in the late 1980s by BellCore to provide a more cost- effective means of delivering a T1 data rate (1.544 Mbps). The standard T1 line uses alternate mark inversion (AMI) coding, which occupies a bandwidth of about 1.5 MHz. Because such high frequencies are involved, the attenuation characteristics limit the use of T1 (a T1 line is a fiber optic line that can carry roughly 60 times more data than a normal residential modem) to a distance of about 1 km between repeaters. Thus, for many subscriber lines one or more repeaters are required, which adds to the installation and maintenance expense.

HDSL uses the 2B1Q coding scheme to provide a data rate of up to 2 Mbps over two twisted-pair lines within a bandwidth that extends only up to about 196 kHz. This enables a range of about 3.7 km to be achieved.

Single Line Digital Subscriber Line (SDSL)

Although HDSL is used for replacing existing T1 lines, it is not suitable for residential subscribers because it requires two twisted pair, whereas the typical residential subscriber has a single twisted pair. SDSL was developed to provide the same type of service as HDSL but over a single twisted-pair line. As with HDSL, 2B1Q (Two-binary, one-quaternary line code) coding is used. Echo cancellation is used to achieve full-duplex transmission over a single pair.

Very High Data Rate Digital Subscriber Line (VDSL)

One of the newest xDSL schemes is VDSL. The objective is to provide a scheme similar to ADSL at a much higher data rate by sacrificing distance. VDSL does not use echo cancellation but provides separate bands for different services. Following are some tentative allocation:

- POTS: 0-4 kHz
- ISDN: 4-80 kHz
- Upstream: 300-700 kHz
- Downstream: >= 1 MHz

Self-Assessment Questions - 4

13. One of the recent scheme for providing high-speed digital transmission of the subscriber line is__________ .
14. HDSL uses the 2B1Q coding scheme. State true or false.
    (a) True (b) False
15. ______________ was developed to provide the same type of service as HDSL but over a single twisted-pair line.

6. SUMMARY

Let us recapitulate the important concepts discussed in this unit:

- Multiplexing is about sharing a communications line.
- The device that combines the signals on the sending end of a channel is called a multiplexer and the device on the receiving end that separates them into their original order is called a demultiplexer.
- There are different types of multiplexing such as frequency division multiplexing, wavelength division multiplexing and time division multiplexing.
- Frequency division multiplexing (FDM) is a method of transmission in which numerous signals are combined on a single communication line or channel and a different frequency is assigned to each signal.
- Wavelength division multiplexing is a form of frequency division multiplexing specifically for combining many optical carrier signals into a single optical fiber.
- In time division multiplexing (TDM), multiple data streams are combined in a single signal and transmitted over the same link by allocating a different time slot for the transmission of each channel.
- Synchronous time division multiplexing (or slotted time division multiplexing) is a form of TDM in which the time allocated to a device or workstation is fixed.
- Statistical time division multiplexing (STDM) is a form of TDM that improves sharing efficiency by allowing some of the multiplexed channels to increase their allotted time if other stations are not using theirs to full capacity.
- Asymmetric digital subscriber line (ADSL) is a recent scheme for providing high-speed digital transmission of the subscriber line.

7. TERMINAL QUESTIONS

1. Describe frequency division multiplexing.
2. Explain wavelength division multiplexing.
3. Differentiate between synchronous time division multiplexing and statistical time division multiplexing.
4. Explain different asymmetric digital subscriber line schemes.

8. ANSWERS

Self-Assessment Questions

1. (a) Frequency division multiplexing
2. Guard bands
3. Orthogonal frequency division multiplexing (OFDM)
4. OFDM
5. Wavelength division multiplexing
6. DWDM (Dense wave division multiplexing)
7. 128
8. (d) Statistical time division multiplexing (STDM)
9. Synchronous
10. Added-digit framing
11. Synchronous TDM
12. Statistical TDM
13. Asymmetric digital subscriber line (ADSL)
14. (a) true
15. Single line Digital Subscriber Line (SDSL)

Terminal Questions

1. Frequency division multiplexing (FDM) is a method of transmission in which numerous signals are combined on a single communication line or channel. A different frequency is assigned to each signal within the main channel. (Refer section 2 for detail).

2. Wavelength division multiplexing is the optical equivalent to early carrier system. Wavelength division multiplexing is a form of frequency division multiplexing specifically for combining many optical carrier signals into a single optical fiber. (Refer section 3 for detail).
3. *Synchronous time division multiplexing (or slotted time division multiplexing)* is a form of TDM in which the time allocated to a device or workstation is fixed. This method is popular for digital voice telephone circuits because each voice call delivers data at exactly the same rate. Another category is *statistical time division multiplexing (STDM)*. This is a form of TDM that improves sharing efficiency by allowing some of the multiplexed channels to increase their allotted time if other stations are not using theirs to full capacity. (Refer section 4 for detail).
4. Asymmetric digital subscriber line (ADSL) is one of a number of recent schemes for providing high-speed digital transmission of the subscriber line. (Refer section 5 for detail).

References:

1. Behrouz A. Forouzan, Sophia Chung Fegan, “Data Communications and Networking”, Fourth edition.
2. William Stallings, “Data and Computer Communications”, Sixth edition, Pearson Education, Delhi, 2002.
3. Taub and Schilling, “Principles of Communication Systems”, Tata Mc Graw Hill, Delhi, 2002.
4. S. Tanenbaum, ”Computer Networks”, Pearson Education, Fourth Edition.
5. N. Olifer, V. Olifer, ”Computer Networks: Principles, technologies and Protocols for Network design”, Wiley India Edition, First edition.
6. Simon Poulton (2003), packet switching and X.25 Networking, Pitman publishing.
7. Walrand, P. Varaiya, “high performance communication networks”, Morgan kaufmann.