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Review on Multiplexing Techniques in Bandwidth Utilization

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Abstract: Multiplexing is a method by which multiple analog message signals or digital data streams, coming from different sources are combined into one signal over a shared medium. In this paper, we present an overview of different multiplexing techniques in bandwidth utilization. We focus on the three well-known multiplexing technique used in bandwidth utilization which are Frequency-Division Multiplexing (FDM), Wavelength-Division Multiplexing (WDM) and Time-Division Multiplexing (TDM). We mainly discuss the multiplexing technique, features and structures. This paper also briefly discuss an applications involved in these multiplexing techniques and the advantages and disadvantages of these three multiplexing techniques. At the end of this paper, we summarize and make a comparison between FDM, WDM and TDM.

Key words: Bandwidth Utilization · Multiplexing · FDM · WDM · TDM

INTRODUCTION

Bandwidth is the numerical difference between the highest and lowest frequencies. It measures the maximum data transfer rate of a network or Internet connection in a given amount of time. For analog devices, bandwidth is measured in hertz (cycles per second). For digital devices, bandwidth is measured in bits per second. While bandwidth is used to describe network speeds, it does not measure how fast bits of data move from one location to another instead of measures how much data can flow through a specific connection at one time. The wider the bandwidth, the faster data can be sent.

Basically, there are two ways of bandwidth utilization which are multiplexing and spreading. Multiplexing combines several channels into one while spreading expand the bandwidth of a channel to insert redundancy. Multiplexing concerned with efficiency while spreading concerned with privacy and anti-jamming.

In this paper, we present a survey on the different multiplexing techniques in bandwidth utilization. We outline the characteristic for each technique and provide a comparison on the significant differences between them.

The rest of the paper organized as follows. In section 2, we take a glance into the background of multiplexing and discuss widely the details of each multiplexing techniques which are FDM, WDM and TDM. Section 3 presents a comparison study between FDM, WDM and TDM technique. Finally, section 4 summarizes the entire article and suggests a future work.

MATERIALS AND METHODS

In order to maximize the utilization of the link, the link can be shared whenever the transmission capacity (bandwidth) of a medium linking two devices is greater than the bandwidth needs of the devices, such as one cable can carry a hundred channels of television [1].

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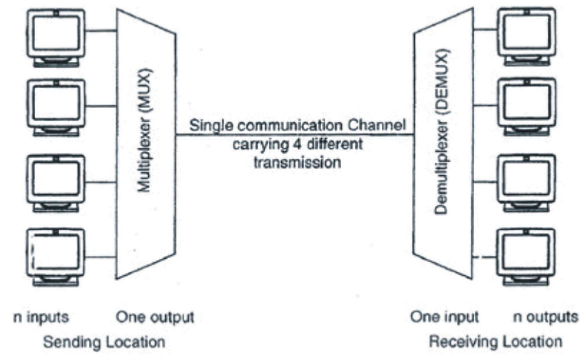

Fig. 1: Multiplexing and demultiplexing

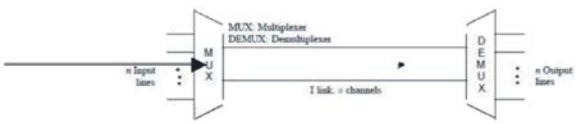

Fig. 2: Multiplexed system

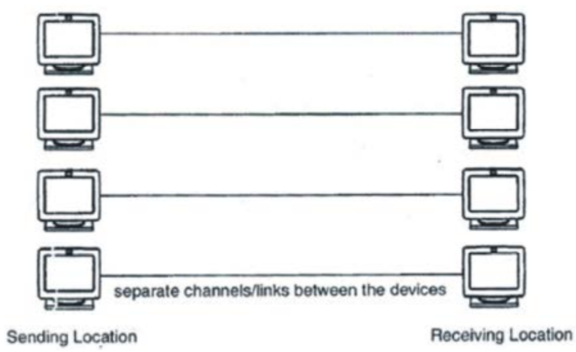

Fig. 3: Communications links without multiplexing

Multiplexing is the process of combining multiple signals (analog or digital), commonly from slow devices, onto one very fast communications link. This sharing is achieved by a device called a Multiplexer (MUX) and Demultiplexer (DEMUX). Multiplexing is performed by combining n input lines to generate one output line i.e. (many to one) by using a device called MUX. This means that MUX has several inputs and one output. By a corresponding device, DEMUX, at the other end separating the signal into several subchannels. Therefore, DEMUX has one input and several outputs.

Figure 1 shows the concept of multiplexing and demultiplexing. MUX takes 4 input lines and diverts them to single output line. The signal from 4 different devices then is combined and carried by this single line. At the receiving side, a DEMUX takes this signal from a single line and separates it back into the original signals and directs them to the 4 different receivers [2].

In a multiplexed system, *n* lines share the bandwidth of one link. Figure 2 shows the basic format of a multiplexed system. The lines of the left direct their transmission streams to a MUX, which combines them into a single stream (many-to-one). At the receiving end, that stream is fed into a DEMUX, which separates the stream back into its component transmissions (one-to-many) and directs them to their corresponding lines. In the figure, the word *link* refers to the physical path. The word *channel* refers to the portion of a link that carries a transmission between a given pair of lines. One link can have many (n) channels [1].

Figure 3 shows if no multiplexing is used between the users at two different sites that are distance apart. Then separate communication lines would be required. This is costly and also become difficult to manage. If multiplexing is used then, only one line is required. This may reduce the line cost and also it would be easier to keep track of one line than several lines.

There are three major categories of multiplexing techniques which are Frequency-division Multiplexing (FDM), Wavelength-division Multiplexing (WDM) and Time-division Multiplexing (TDM). The first two techniques designed for analog signals and the third one is for digital signals.

Frequency-division Multiplexing (FDM): FDM is an analog process. It can be applied when the bandwidth of a link in (hertz) is greater than the combined bandwidths of the signal to be transmitted. FDM works by transmitting all of the signals along the same high speed link simultaneously. Each signal modulates different frequency. These modulated signals are then combined into a single composite signal that can be transported by the link. FDM assigns a discrete carrier frequency to each data stream and then combines many modulated carrier frequencies for transmission. The carrier frequencies have to be different enough to accommodate the modulation and demodulation signals. FDM gives a total bandwidth greater than the combined bandwidth of the signals to be transmitted. Therefore, the link must have sufficient bandwidth to be able to carry the wide range of frequencies required. While transmitting signals, frequency overlap must be avoided for FDM to work properly. In order to prevent signal overlap there are strips of frequency that separate the signals. These are called *guard bands*; a strip of unused bandwidth [3].

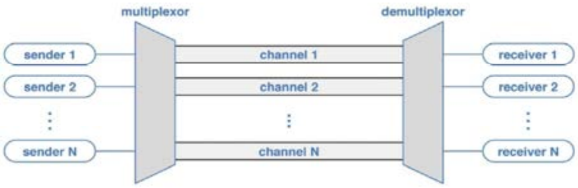

Fig. 4: FDM

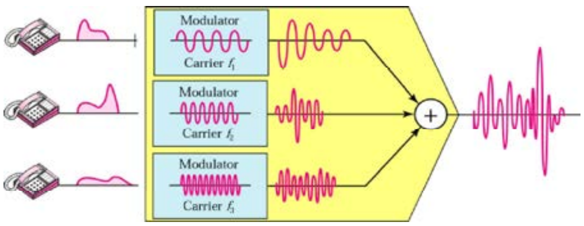

Fig. 5: FDM process

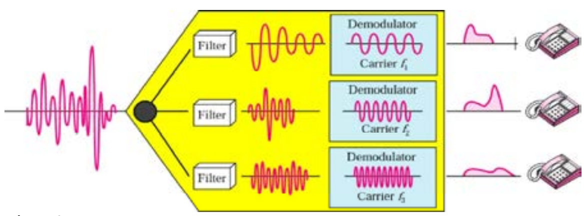

Fig. 6: FDM process

Figure 4 gives a conceptual view of FDM. The transmission path is divided into several parts. Each part represents a channel that carries one transmission. FDM is an analog multiplexing technique that combines analog signals.

Multiplexing Process: Figure 5 is a conceptual illustration of the multiplexing process of FDM. Each source generates a signal of similar frequency range. Inside the multiplexer, these similar signals modulate different carrier frequencies (*f1*, *f2* and *f3*). The resulting modulated signals are then combined into a single composite signal that is sent out over a media link that has enough bandwidth to accommodate it [1].

Demultiplexing Process: Figure 6 is a conceptual illustration of demultiplexing process of FDM. The DEMUX uses a series of filters to decompose the multiplexed signal into its constituent component signals. The DEMUX present at the receiver side works by separating the signals according to the appropriate frequencies. Then each signal is passed to an amplitude demodulation process to separate the carrier signal from the message signal. Then, the message signal is sent to the waiting receiver.

Applications of FDM: One of FDM's most common applications is cable television. Each television channel has bandwidth of 6 MHz. Even though only one cable reaches a customer's home, the service provider can send multiple television channels or signals simultaneously over that cable to all subscribers without interference. To access the desired signal, receivers must tune to the appropriate frequency (channel).

In AM and FM radio broadcasting, air is uses as the transmission medium. AM radio has a bandwidth of 530 to 1700 kHz which is shared to all radio stations. All the stations broadcast the signals simultaneously but on varying frequencies. The signal that goes to the air is a combination of all signals and the receiver is then tuned to receive the signals from the desired station. A receiver receives all these signals, but filters (by tuning) only the one which is desired where a number of different stations will broadcast simultaneously but on different frequencies. Listeners can then "tune" their radio so that it captures the frequency or station they want. Same goes to FM radio; it has a wider band of 88 to 108 MHz because each station needs a bandwidth of 200 kHz.

First generation of cellular telephones also uses FDM. Two 30 kHz channels assigned for each user; one for sending voice and the other one for receiving. The voice signal with a bandwidth of 3 kHz (from 300 to 3300 Hz), is modulated by using FM. FM signal has a bandwidth 10 times that of the modulating signal. This means that each channel has 30 kHz (10 x 3) of bandwidth. Therefore, each user is given a 60-kHz bandwidth in a range available at the time of the call by the base station.

Advantages and Disadvantages of FDM: FDM is a simple technique and inexpensive. This kind of multiplexing is popular used with radio, cable TV and TV. In using cellular telephones, all the receivers do not need to be at the same location. FDM also is not sensitive to propagation delays. Furthermore, it allows maximum transmission link usage.

However in FDM, there is need of filters which are very expensive and complicated to construct design. FDM is a technique for analog signal. Analog signal is having limited frequency range. Sometimes, it is necessary to use more complex linear amplifiers in FDM systems.

Wavelength-division Multiplexing (WDM): WDM is an analog process. It is similar to the FDM. The idea is the same but different in frequency. The frequencies are very

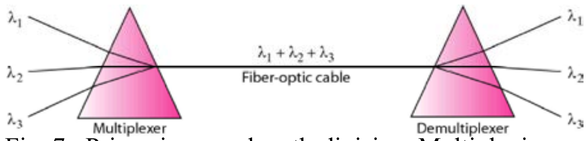

Fig. 7: Prism in wavelength-division Multiplexing and Demultiplexing

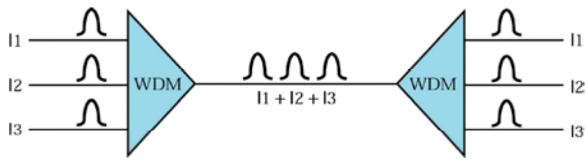

Fig. 8: Wavelength-division Multiplexing

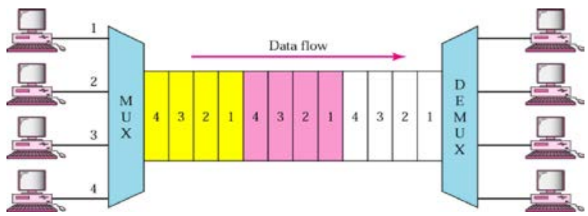

Fig. 9: Time-division multiplexing

high. This technique is combining different signals of different frequencies. But it is specifically used to combine lots of Optical Carrier signals into a single optical fiber. WDM uses fiber optical cable to transmit the signal. An optical fiber is a transparent thin fiber for transmitting information from one point to another by using pulses of lights [4]. The available bandwidth is waste if fiber-optic cable is used for one single line. So, multiplexing is performed to combine several lines into one. In WDM, a large number of optical carrier signals is combined based on a laser that is designed to emit single color of light. Each signal that needs to transmit is attached to the laser that will emit a colored light beam and the color will be different for different signal [5]. These light beams are then sent simultaneously. At the receiving end, the combined colors then splits back into the original individual colors again.

Figure 7 shows the concept of WDM. Combining and splitting light sources are easily handled by a prism. A prism bends a beam of light based on the angle of incidence and the frequency. Using this technique, multiplexing is performed to combine several input beams of light, each containing a narrow band of frequencies, into one output beam of a wider band of frequencies. A DEMUX can also be made to reverse the process.

Figure 8 gives a conceptual view of a WDM multiplexer and DEMUX. Very narrow bands of light comes from different sources are combined to make a wider band of light. The signals are separated by the DEMUX at the receiver side.

Applications of WDM: One application of WDM is the Synchronous Optical Network (SONET) network in which multiple optical fiber lines are multiplexed and demultiplexed. SONET (known outside the US as synchronous digital hierarchy or SDH) is a network technology built around dual fiber-optic rings [6]. If one ring fails, the network is designed to immediately switch traffic to the other ring. WDM is also used in the FTTC Fiber To The Curb (FTTC). Initially, a telephone company used fibers between the end offices to nearly junction box where it met up with twisted pairs from the houses.

Advantages and Disadvantages of WDM: WDM need high cost and complex technique. However, it has very high capacities. Due to its high capacity, WDM maximizes optical bandwidth using different wavelengths. WDM systems can use signals with up to 40 channels, each containing 10 Gbps, and it is predicted that capacity will increase to 80 or more channels. WDM also do not need guard band. In WDM, narrow bands is used that results in closer channel spacing, lower optical power loss, and allow use of optical amplifier. It is also scalable and signals speed can be variety.

Time-Division Multiplexing: TDM is a digital process. In TDM, MUX is uses to collect and store incoming signals from slow lines connected to it by distributing a time slot on the fast link to each in turn [7]. The messages are sent over a high speed one by one. Each transmission has a time slot assigned to it. Theoretically, the available speed of the fast link should at least be equal to the total of all of the slow speeds coming into the multiplexor so that its maximum capacity is not exceeded. They are then received and separated by a DEMUX according to the time slot provided for each signal. The transmission speed of the fast link is equal to the sum of all the slow speed signals coming into the MUX. Basically, TDM is a digital multiplexing technique for combining several low-rate channels into one high-rate one.

Figure 9 shows the conceptual design of TDM. The link is sectioned by time slot rather than by frequency as in FDM. In TDM, we are concerned about multiplexing but not switching. As shown is Figure 9, this means that all the data in a message from source 1 always go to one specific destination, be it 1, 2, 3, or 4. The delivery is fixed

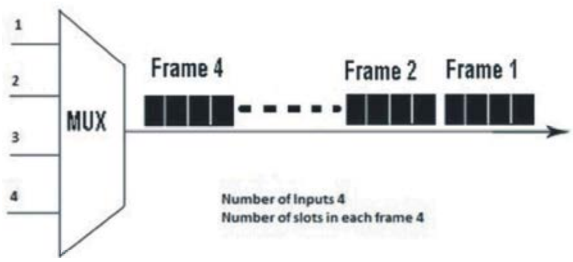

Fig. 10: Synchronous TDM

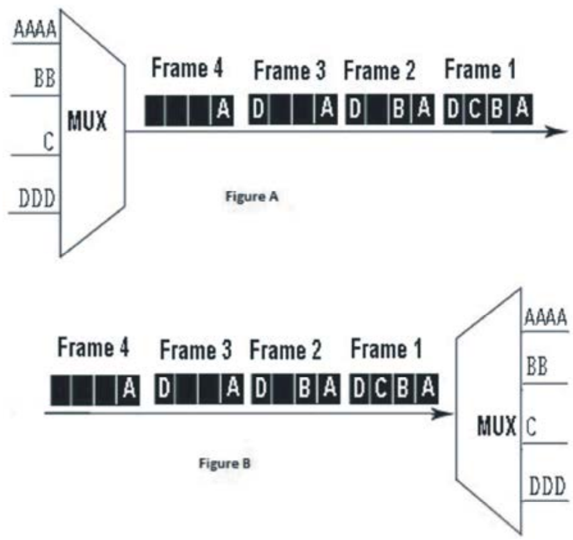

Fig. 11: Synchronous TDM mechanism

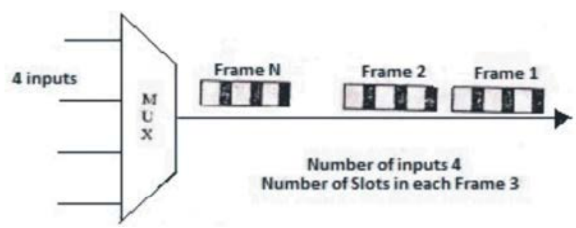

Fig. 12: Asynchronous TDM

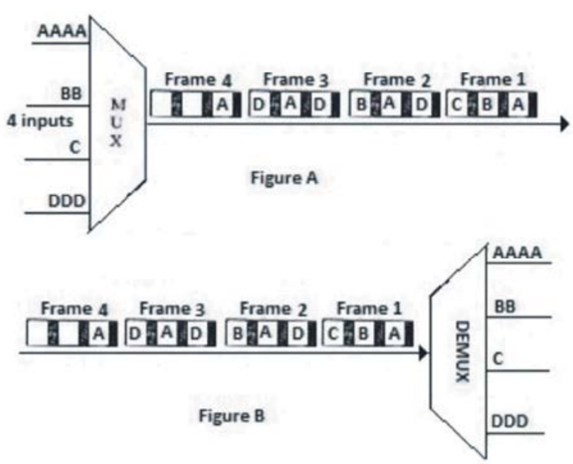

Fig. 13: Asynchronous TDM mechanism

and unvarying, unlike switching. TDM can be divided into two schemes which are *synchronous* and *asynchronous*.

Synchronous TDM: In synchronous TDM, the MUX distribute the equal time slot for each device connected to it. It gives the time slot for the device at all the time whether they are transmitting signals or not. This is wasteful in that there will be many times when allocated time slots are not being used. Therefore, the use of Synchronous TDM does not guarantee maximum line usage and efficiency. In synchronous TDM, the data flow of each input is divided into *units.* Each input occupies one input time slot. A time slot can be in the form of 1 bit, one character, or one block of data. Time slots are grouped into *frames*. A *frame* consists of one complete cycle of time slots; one slot dedicated to each sending device. In a system with *n* input lines, each frame has n slots, with each slot allocated to carrying data from a specific input line. Basically, in synchronous TDM, the data rate of the link is *n* times faster and the unit duration is *n* times shorter.

Figure 10 shows an example of synchronous TDM where number of inputs, n is 4. For example, time slot 1 is assigned to device 1 only and cannot be used by other device.

Figure 11 shows how the synchronous TDM works. Synchronous TDM is not efficient. If a source does not have data to send, there is an empty slot in the output frame of the corresponding data.

Asynchronous/Statistical TDM: Asynchronous TDM is a more flexible method than synchronous TDM. In asynchronous TDM, each slot in a frame is not dedicated to the fix device but time is given for the devices that have data to transmit. Therefore, this technique requires more processing time than synchronous TDM. However, we achieve maximum efficiency and line usage using this technique.

Figure 12 shows an example of asynchronous TDM that has number of inputs, n is 4. Number of slots in each frame is less than the number of input lines. A frame contains a fix number of time slots. As shown in the figure, each slot has an index of which device to receive. A slot needs to carry data as well as the address of the destination. MUX checks each input line in *round-robin* fashion; it allocates a slot for an input line if the line has data to send; otherwise, checks the next line.

Figure 13 shows how the asynchronous TDM works. In the synchronous TDM, some slots are empty because there have no data to send

Table 1: FDM, WDM and TDM comparison

FDM	WDM	TDM
Analog transmission Transmission two or more signals on the same path, but different times	Analog transmission Transmission two or more signals on the same path, by using different frequencies at the same time	Digital transmission Transmission two or more signals over a same path by using a different frequency band for each signal
Total frequencies are divided into several users	Total wavelength are divided into several users	Total available time are divided into several users
The signals multiplexed come from different sources transmitters	A few wavelengths are multiplexed from different sources	Imply partitioning the bandwidth of the channel connecting two node into finite set of time slots
It is not sensitive to propagation delays	It is not sensitive to propagation delays	It is sensitive to propagation delays
Guard bands needed	No need for guard band	No need for guard band

but in this asynchronous TDM, no slot is empty as long as there are data to send by any input line.

Applications of TDM: Synchronous TDM is used in T1 and E1 connections. Telephone companies implement TDM through a hierarchy of digital signals, called Digital Signal (DS) service or digital hierarchy. Europeans use a version of T lines called E lines.

Second-generation cellular telephone companies use synchronous TDM. It divides available bandwidth into 30-kHz bands. For each band, TDM is applied so that six users can share the band. TDM also used in Asynchronous Transfer Mode (ATM) networks, Integrated Services Digital Networks (ISDN) multiplexing and SONET [6, 8, 9].

Advantages and Disadvantages of TDM: TDM is a process for digital signals. It is relatively simple and commonly used in ISDN. The disadvantage of synchronous TDM is wastage of bandwidth when there are time slot although they have no data to transmit.

However for asynchronous TDM, they transmit the data from active workstations only. If the workstation is not active, no space is wasted on the multiplexed streams. Asynchronous multiplexers occupy the incoming data streams and create frames containing only the data to be transmitted. Hence, the Asynchronous TDM or Statistical TDM is designed to avoid this type of wastage of bandwidth.

RESULTS AND DISCUSSION

All discussed features and differences between FDM, WDM and TDM can be summarized in Table 1 [10-12].

CONCLUSION

In this paper, we have investigated about FDM, WDM and TDM. As a whole, we can say that the aim of multiplexing is to share bandwidth among channels that can be done in the time or frequency domain. The different types of multiplexing are very useful to transfer data with a high speed where it saves time and money. Besides that, we can have one link for multiple channels instead of having a link for every channel and have no problems in transmitting and receiving information. They are used in very common areas such as telephone and television. The concept behind WDM is similar to FDM. However, the data rate and bandwidths are much higher. Instead of sharing portion of the bandwidth as in FDM, time is shared in TDM. Future research will be the review on the types of WDM which are Dense Wave Division Multiplexing (DWDM) and Coarse Wave Division Multiplexing (CWDM). Another type of multiplexing technique which is Code Division Multiplexing (CDM) also will be investigated.

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