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A Review of Recent Advancement in Optical Multiplexing Technologies

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Abstract— Optical fiber communication along with the advanced optical networking technologies and advanced modulation formats is an evolving field of research. The enormous bandwidth and long distance reach of optical networks makes them a suitable candidate to be used in backhaul networks. This paper presents a comprehensive review of various advanced optical multiplexing technologies viz: Wavelength Division Multiplexing (WDM), Orthogonal Frequency Division Multiplexing (OFDM), Time Division Multiplexing (TDM) along with several architectural advancements in these optical multiplexing networks is also discussed in a holistic manner.

Keywords— WDM, RoF, PON, EONs, Orthogonal Frequency Division Multiplexing (OFDM), TDM.

I. INTRODUCTION

Optical communication is a type of communication which uses light instead of electrical current to carry the signal from one point to another via optical fibers. The main drawbacks of our communication networks are capacity, speed, signal losses distortion and power limitation. Fiber optic technology comes out as a great solution to tackle these problems. It has several advantages like high capacity, huge bandwidth, low signal losses and small space requirement [1].

In optical communication, electrical signal is converted into optical signal for transmission through optical fiber by optical transmitter. An optical fiber is a dielectric cylindrical waveguide made of low loss materials. The core of the waveguide has a refractive index a little higher than that of outer medium, so that light pulses is guided along the axis of fiber by total internal reflection [2]. It transmits optical signals from optical transmitter to optical receiver. Received optical signal is converted into original electrical signal by optical receiver. Block diagram of an optical communication system is shown in fig 1.

The organization of the paper is as follows, Section I of the paper gives the introduction to the topic optical fiber communication, Section II of the paper gives a brief about optical multiplexing techniques and state some recent work in field of optical multiplexing, Section III of the paper contains WDM, its types and work related to it, Section IV of the paper shows working of OFDM and recent advancements in the field, Section V of the paper has TDM, its types and work in its field, Section VI contains conclusion of the entire paper.

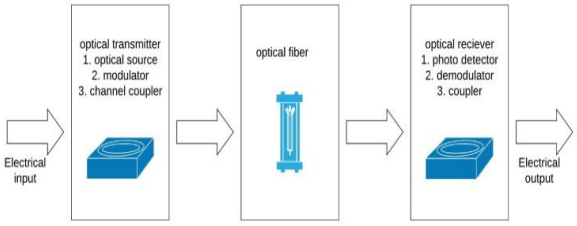

Figure.1. Block diagram of an optical communication system

This paper gives an overview about different optical multiplexing technologies followed by review of recent advancements in it.

II. OPTICAL MULTIPLEXING

Multiplexing is a technique that combines multiple signals into one signal over a channel while de-multiplexing is a technique that divides the combined signal into original component signals. Multiplexers are used at receiving end and de-multiplexers are used at receiving end.

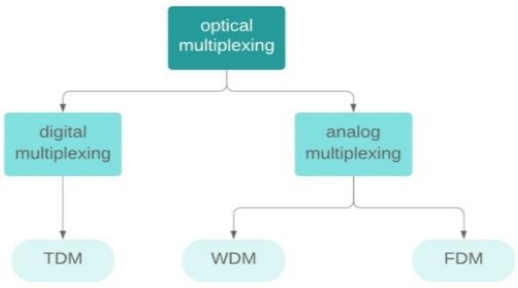

Figure 2. Classification of multiplexing techniques

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There are two types of multiplexers: Analog and digital multiplexers and three main multiplexing techniques: frequency division multiplexing (FDM), wavelength division multiplexing (WDM), time division multiplexing (TDM) which are further divided various types.

The author in [3] carefully examines all technological advancements in use of fiber communication link as a smart channel with large capacity to carry the digital data.

The author in [4] gives review of in vehicle optical networks and also explains current trends and subjects affecting the key devices used.

The authors in [5] explain different techniques, feature and structures. It also discusses applications involved in these multiplexing techniques and advantages and disadvantages. It also makes comparison between FDM, WDM and TDM.

III. WAVELENGTH DIVISION MULTIPLEXING

In WDM, signals having different wavelengths are transmitted in parallel on single optical fiber. This technology is getting popular as users are increasing day by day to use data networks.

WDM increases the transmission capacity and as well as adds flexibility to complex communication systems. So we can say that different data channels can be introduced at different locations in a system, and other channels can be taken out. For such operations, one can use add- drop multiplexers that helps one to add or drop channels based on their wavelengths. In WDM technology, huge opto-electronic bandwidth mismatch is being exploited by requiring that equipment of each user operate only at electronic rate, but several WDM channels of different end users may be multiplexed on same fiber. In WDM technology, the spectrum of transmitting optical signal is divided up into a number of non-overlapping wavelength bands, where each wavelength supports a single communication channel operating at whatever rate one desires. Thus, it allows multiple WDM channels to coexist on a single fiber and with right type of fiber, the device can multiplex de-multiplex and can act as add- drop multiplexer simultaneously [6].

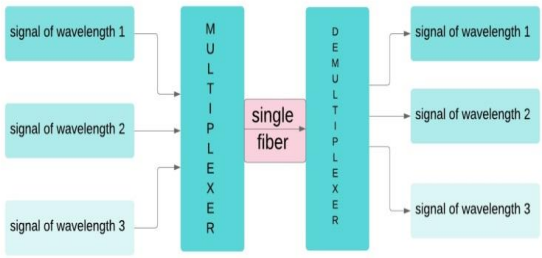

Figure 3. Wavelength Division Multiplexing

There are two different versions of WDM: Course wavelength division multiplexing (CWDM) and Dense wavelength multiplexing (DWDM).

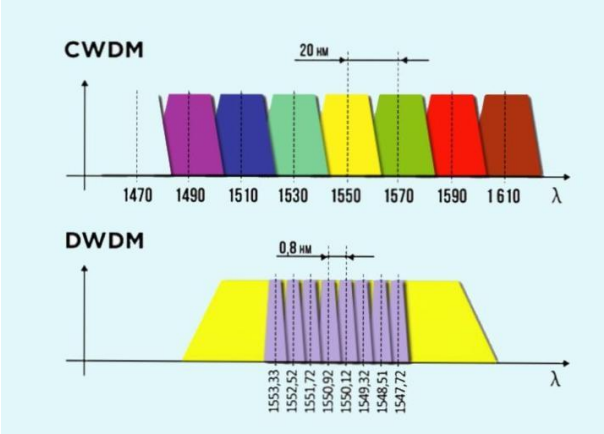

Figure 4. Difference between CWDM and DWDM [7]

CWDM: It uses relatively small no. of channels than DWDM but more than WDM and can transmit up to 18 CWDM wavelengths over one pair of fiber. It has large channel spacing of 20 nm and wavelength range from 1270 nm to 1610 nm. It is a cost effective solution of WDM. It's wavelength tolerance for transmission is fairly large and single channel bit rate: 1- 3.125 Gbit/s.

DWDM: It can transmit up to 96 DWDM wavelengths over one pair of fiber. It can have a channel spacing of 0.8 nm. In this type of multiplexing transmitters have to meet high wavelength tolerances and the wavelength range from 1528 nm to 1563 nm. The optical signals can achieve distances over 1000 km by help of optical amplifier and the single channel bit rate: 1- 100 Gbit/s.

The author in [8] presents a comprehensive review of recent advancement in field of optical communication networks along with recent work presented by literature. It describes optical communication network and compares performance of different channels for different transmission reach. The WDM based optical networks followed by advancement in RoF networks are discussed. It also describes ways to overcome the limitation of

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traditional WDM based networks and for efficient use of resources.

The authors in [9] provides the study of WDM, WDM networking evolution, WDM network constructions and advancements in WDM technology.

The authors in [10] discussed the literature reported which showed the need of improvement in system in terms of noise level and their modified work has enhanced the performance of newly designed simulation model.

The authors in [11] provided a long term solution by proposing EONs to handle exponentially increasing data traffic efficiently and economically in DWDMs.

The authors in [12] studied and evaluated the performance of different dispersion compensation techniques for EDFA based 32 channels DWDM network. By assumed results it is found that if the number of input channels in a DWDM system are varied then the quality of signal received remains almost same showing marginal degradation and the designed system works really well even at high transmission range.

The authors in [13] evaluated the working of EDFA based 32 channel DWDM network using different pumping techniques at variable pumping power at different EDF lengths. The results show that, Q factor increases for both the pumping techniques with increase in pump power.

The authors in [14] evaluated and studied the working of DWDM based 32 channel optical link using EDFA for different modulation formats at variable data rates over different transmission range at different pumping wavelengths. The result shows that the designed system shows significant improvement and works optimally.

IV. ORTHOGONAL FREQUENCY DIVISION MULTIPLEXING

FDM is a multiplexing technique in which all users use common channel at same time (full time) but they are allotted different frequency to prevent any kind of signal interference. So bandwidth is divided among users and time is not divided. Still, there is possibility of cross talk in FDM.

Orthogonal Frequency Division Multiplexing (OFDM) is a digital multicarrier technique which is used in both wireless and wired communication system and also offers several advantages which makes it suitable for high speed data transmission. To overcome linear and non-linear impairments in optical communication systems and to support high speed data transmission orthogonal frequency division multiplexing is introduced. In optical communication the processing at high rates is feasible because OFDM is efficient in making use of FFT techniques for various modulation and demodulation functions implementation [15].

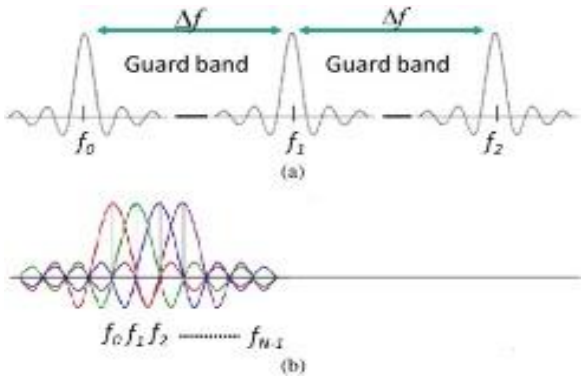

Figure 5. Difference between system carriers in FDM(a) and OFDM(b) [16]

Difference between FDM and OFDM: In FDM systems, the signal carriers are far apart with respect to each other while in OFDM systems carriers are densely packed and are orthogonal to the other carriers. Orthogonal here means that the peak of one carrier occurs at null of the other. Hence OFDM system is more bandwidth efficient as compared to FDM system as orthogonal frequency division multiplexed signals can carry more data in smaller bandwidth. OFDM systems have more Peak to Average Power ratio as compared to FDM system .OFDM system provides higher data rate compare to FDM system in the same bandwidth usage .FDM systems are used in radio, satellite communications and require large amount of guard bands between adjacent frequency bands. OFDM systems are used in LTE and various other technologies requiring higher data rate. In OFDM systems multipath interference is more as compared to FDM systems but can be reduced using high end algorithms. In FDM systems entire bandwidth is used by the user, while in OFDM the bandwidth is divided into many narrow band channels and each narrow band is allocated to user. Hence OFDM supports more subscribers and channels as compared to FDM.

In OFDM transmitter, the randomly generated data bits are converted into QAM symbols which are then converted into the parallel form using serial to parallel (S/P) conversion and pilot symbols are added for synchronization. These are then modulated on orthogonal subcarriers using Inverse Fast Fourier Transform(IFFT) and then a Cyclic Prefix(CP) is added to mitigate Inter-Carrier Interference (ICI) and Inter-Symbol Interference (ISI),then a discrete OFDM signal is generated using parallel-serial conversion and digital to analog (DAC) conversion is done to produce an analog OFDM signal. In-phase and Quadrature-phase (IQ) up-conversion is done to obtain an RF signal which then modulates ECL through an

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MZM and the optical signal thus obtained is transmitted over the optical fiber. At the receiving end, direct detection is done using a photo-detector (PD) to obtain an electrical OFDM signal which is then passed through a low pass filter and then passed through OFDM modem and IQ down-conversion, analog to digital (ADC) and S/P conversion is done [17].

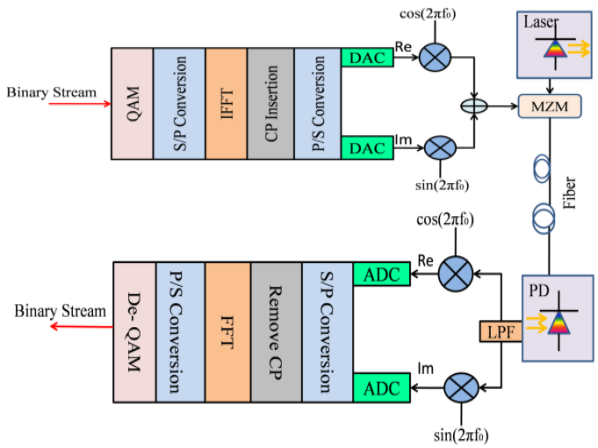

Figure 6. Basic block diagram of OFDM systems

The author in [18] provided a survey of OFDM behaviors, principles and analyzed different techniques that improves performance of OFDM for wireless communications. The author has also explored a brief overview of OFDM applications for wireless communications.

The authors in [19] explain us about OFDM, its architecture, applications of OFDM in various systems, its advantages and disadvantages.

The authors in [20] presented a scheme which enables all optical VPN and ONUs based on OFDM-PON. In proposed optical OFDM-PON system, 16 QAMs are used. The advantage of this system is that subcarriers can be allocated to different VPN and ONU according to user's requirements dynamically, works optimally and enhances the network security.

OFDM systems can be used in various network security systems as they occupy less bandwidth and carry more data. The authors in [21] proposed and analyzed a method of overloading subcarriers by multiple transmitters to secure OFDM in wireless time varying channels. The authors in [22] proposed algorithms for enhancing physical layer security and spectral efficiency of OFDM with index modulation systems. One of the algorithms in proposed paper ensures QoS based communication aiming to maximize spectral efficiency.

V. TIME DIVISION MULTIPLEXING

In TDM, the complete channel bandwidth is allotted to one user for fixed time slot. So the division is in time not in bandwidth. Hence, there is no chance of crosstalk.

Figure 7. Time Division Multiplexing

TDM is of three types: synchronous TDM, asynchronous TDM and interleaving TDM.

In synchronous TDM, each device is given same time slot to transmit the data to the link, whether the device has any data to transmit or not. That's the reason it is referred to as Synchronous TDM. Synchronous TDM requires that the total speed of various input lines should not exceed the capacity of path. Each device places its data onto the link when its time slot arrives *i.e.* each device is given the possession of line turn by turn. I any device does not have data to send then its time slot remains empty. The various time slots are organized into frames and each frame consists of one or more time slots dedicated to each sending device. If there are *n* sending devices, there will be *n* slots in frame *i.e.* one slot for each device. [23]

Asynchronous TDM is also known as statistical time division multiplexing because in this type of multiplexing, time slots are not fixed *i.e.* the slots are flexible. Here, the total speed of input lines can be greater than the capacity of the path. In asynchronous TDM, if we have *n* input lines then the frame contains not more than *m* slots, with *m* less than *n* ($m < n$).

In this the number of time slots in a frame is based on a statistical analysis of number of input lines. In this system slots are not predefined, the slots are allocated to any of the device that has data to send. The multiplexer scans the various input lines, accepts the data from the lines that have data to send, fills the frame and then sends the frame across the link. If there are not enough data to fill all the slots in a frame, then the frames are transmitted partially filled.[21]

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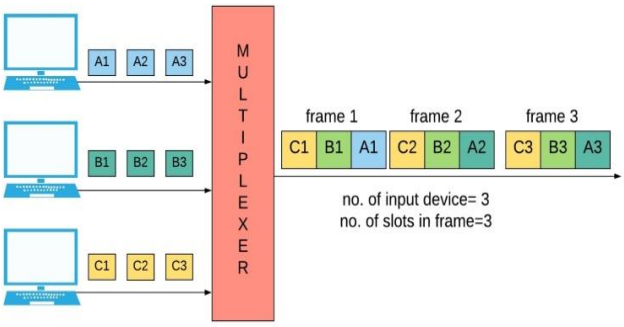

Figure 8. Synchronous TDM

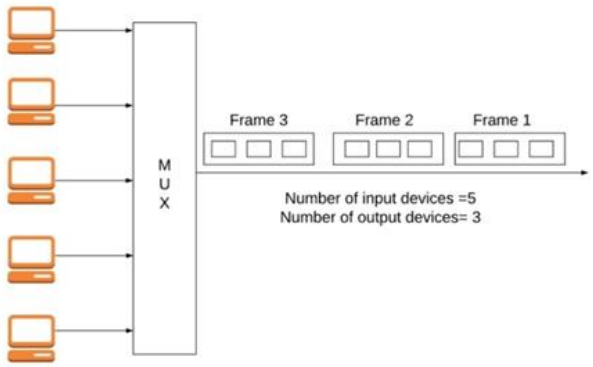

Figure 9. Asynchronous TDM

Interleaving TDM is of two types: bit interleaving and packet interleaving.

If the data stream can be transmitted in form of bit (on bit by bit basis), then it is known as bit interleaving and if the data stream can be transmitted in form of packet (on packet by packet basis), then it is known as packet interleaving. In both bit and packet interleaved case, framing pulses can be used. In packet interleaved case, framing pulses mark the boundary between packets. In bit interleaving case, if n input data streams are to be multiplexed, a framing pulse is used every n bits.[24]

The authors in [25] have done a detailed study on time division multiplexing and its applications in high-speed optical communications. The authors in [26] have presented model of TDM based on PONs with multiple channels that use different coding schemes and transmit data over non linear fiber in an efficient manner with optimum use of resources. The authors in [27] designed a model of bidirectional TDM PON.

VI. CONCLUSION

In this review paper we have presented a comprehensive review of the latest advancement in the field of optical multiplexing techniques and the recent work reported in the literature. The paper also gives overview of various optical multiplexing technologies such as WDM, TDM and OFDM along with their advantages and disadvantages. This paper will provide a direction to the researchers to pursue their research in the field of optical multiplexed advanced optical networks efficiently and effectively.

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