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Tributary Mapping Multiplexing an Efficient Technique for High Speed Fiber Optic Communication

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***Abstract*- A novel technique of multiplexing called Tributary Mapping Multiplexing (TMM) is applied to a single channel wavelength division multiplexing system and performance is monitored on the basis of simulation results. To elaborate the performance of TMM in this paper, a 4-User TMM system over single wavelength channel is demonstrated. TMM showed significant tolerance against narrow optical filtering as compared to that of conventional TDM at the rate of 40 Gbit/s. The above calculations are made by optical filter bandwidth and dispersion tolerance that was allowed at minimum. The spectral efficiency achieved by this TMM was 1 b/s/Hz and it was executed by using transmitters and receivers of 10 Gbit/s without polarized multiplexing. The high spectral efficiency, high dispersion tolerance and tolerance against strong optical filtering makes TMM an efficient technique for High Speed Fiber Optic Communication.**

Keywords: Fiber Optic Communication, Tributary Mapping Multiplexing, Spectral Efficiency, Optical Filtering, Wave Length Division Multiplexing and Dispersion.

I. Introduction

The demand for high date rate is increasing day by day. The latest applications used these days require high capacity along with data rate, in this regards the researchers are working day and night to innovate new techniques, which can increase the capacity of optical fiber communication network. Bandwidth is major issue these days and efforts are being made to save the bandwidth by making its utilization better. The demand for high speed communication systems is increasing tremendously and an increment of 40 % per annum is observed. Fiber optic communication is expensive in the aspect that it's laying, operation and maintenance is costly. But on the other hand its capacity and data rate are much higher than other communication links. Also Optical fibers are

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very less susceptible to different type of losses, which are very common in copper cables; these losses include electromagnetic interferences and some other undesirable factors because of such advantages, optical fibers are used for Long Haul Communication [1].

The requirement for high capacity is root cause of important inventions done in 1990's i.e. optical amplifiers. EDFA (Erbium Doped Fiber Amplifier) is one of them and that different optical multiplexing techniques were invented as well like Wavelength Division Multiplexing (WDM). The WDM is the multiplexing technique that utilizes the bandwidth provided by the optical communication link by combining the multiple optical carries with different wavelength for each user. Nowadays WDM system is used by every optical communication network because of which the data rate is enhanced tremendously.

The capacity of wavelength division multiplexing (WDM) communication network can either be enhanced by increasing the number of channels or by the higher signal bit rate of time division multiplexing (TDM) [2]. In long haul high speed optical communication systems, the multiplexing techniques always play a significant role. Strong optical filtering is applied at the process of demodulation and only spectral efficient technique will perform well. As to counter the effect of distortion due to filtering, compact spectrum is required. The system performance and its efficiency depend on the multiplexing format used [3].

II. Literature Review

To enhance the capacity and efficiency of transmission by WDM different ideas were proposed. Among all these methods the advancement in the modulation technique is reported as the best solution to the problem [4, 5]. A lot of multi-level multiplexing techniques are introduced such as AM-Phase Shift Keying polybinary, polyquaternary and M-ary and they responded quite well against chromatic dispersion because of narrow spectral width [6], but there is a major disadvantage of multilevel coding techniques that they reduce the receiver sensitivity [7].

Pulse position modulation is another modulation format in the field of fiber optic communication. The logic behind this coding technique is to divide the symbol duration into small fragments. The symbols are sent during these small intervals by the transmitter. The amplitude and width of the Signal remains constant. Each pulse position is changed with respect to repeated pulse position. PPM required wider bandwidth and less optical power as compared to RZ or NRZ [8].

A new technique that can be used for optical communication called multi slot amplitude coding is introduced recently. This technique behaved significantly well at the time of clock recovery because initially zero level is used for all symbols. But the main limitation of this technique is the reduced receiver sensitivity [9]. The improvement in performance is reported by use of return-to-zero (RZ), but with reduced spectral efficiency [10,11].

But in common that modulation format is best for high speed long-haul communication links using WDM, which shows high spectral efficiency and better tolerance against dispersion [12]. So from previously discussed techniques it is concluded that there is still a need for new multiplexing format for fiber optic communication to handle all issues like better bandwidth utilization, complexity of the system, cost reduction and limitation of communication like dispersion tolerance, spectral efficiency and optical filtering.

III. Problem Statement

Currently, gain bandwidth of EDFA is limiting the maximum number of channels in WDM [12]. To enhance the capacity within the gain bandwidth limitations needs improvement in the spectral efficiency. To acquire the desired results optical filter with high stability along with narrow optical filtering are needed. A problem is associated with narrow optical filtering because it blocks the major part of the signal spectrum and that is distortion [13-18]. The solution to this problem, which is caused by narrow optical filtering, is high spectral efficiency achieved by reduced spectral width of the transmitted signal.

IV. Proposed Multiplexing Technique

A novel mapping multiplexing technique also called Tributary Mapping Multiplexing (TMM) can accommodate a lot of users per WDM channel [19]. Narrow optical filtering can be implemented by use of this technique ,which provides an opportunity to increase the number of channel within the allocated bandwidth to enhance the capacity. In this article a comparison of TMM and conventional TDM using RZ signaling with 50% duty cycle is made. The bit rate that is used per wavelength is 40 Gbit/s. For ease of discussion throughout the article conventional TDM using RZ with 50% duty cycle is referred to as TDM. Also the tolerance against chromatic dispersion is computed and discussed. We demonstrated that TMM perform much better in terms of spectral efficiency, dispersion tolerance and tolerance against narrow optical filtering.

V. TMM Unique Symbol Format

TMM is an efficient alternative technique for 40 Gbit/s optical transmission systems. TMM is a unique transmission technique that divides whole bit duration into two slots and different levels of amplitudes for data from different users over a single fiber. Number of users determines the number of amplitude levels [19].

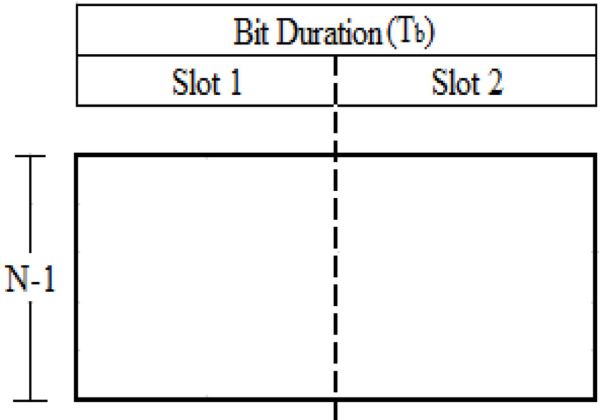


Figure 1. TMM general symbols format

Figure 1 is the representation of TMM general symbol format. Using TMM symbol formatting if N is the number of users then number of amplitude levels will be N-1 and two slots. Each slot duration is explained in [19].

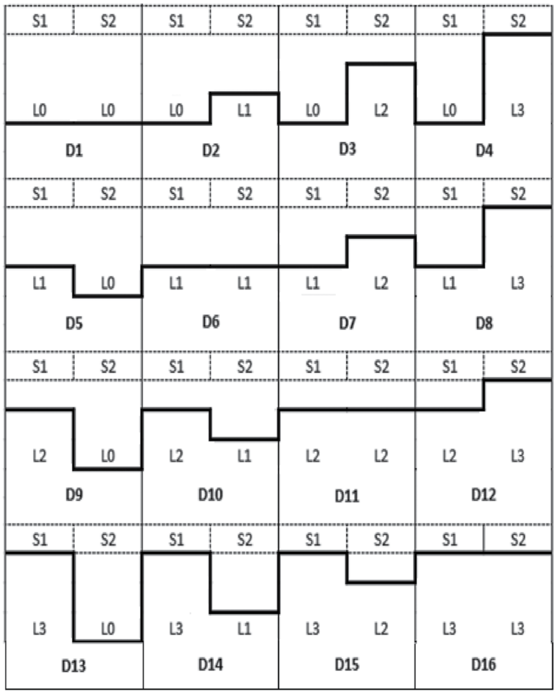
$$T_s = T_b / 2 \tag{1}$$

Where Tb represents the whole bit duration (1/bitrate). For sake of multiplexing different user by TMM technique a method known as mapping method is used. This mapping method coverts the data from different users into unique TMM symbols [19]

The 4-User Transmission system by using TMM as multiplexing method is represented by Figure 2. All possible combinations (D1 to D16) for 4-user multiplexed by TMM is shown is Figure 2 (a). The unique symbol of TMM is generated by mapping each of these possible combinations [19].

Case	U1	U2	U3	U4
D1	0	0	0	0
D2	0	0	0	1
D3	0	0	1	0
D4	0	0	1	1
D5	0	1	0	0
D6	0	1	0	1
D7	0	1	1	0
D8	0	1	1	1
D9	1	0	0	0
D10	1	0	0	1
D11	1	0	1	0
D12	1	0	1	1
D13	1	1	0	0
D14	1	1	0	1
D15	1	1	1	0
D16	1	1	1	1

(a)



(b)

Figure 2. (a) 16 possible combinations for 4-Users TMM System, (b) Unique TMM symbols associated to D1-D16

VI. Simulation Setup for Proposed Model of TMM System

In this research professional software tools, OptiSystem and MATLAB are used to evaluate the system performance. The evaluation of the system performance is used on Bit Error rate (BER), reported in [20].

A. Single Channel 40 Gbit/s TMM System

Figure 3 represents the implementation of 4-User TMM system over single wavelength channel. Each user is an RZ signal with 50% duty cycle and is transmitting at a rate of 10 Gbit/s. Data is generated by random bit sequence and in this way, U1, U2, U3 & U4 data is generated. This is done with the aid of Pseudo Random Bit Sequence (PRBS) of 210-1 along with RZ having 50% duty cycle.

As reported in [19] the multiplexer generates 16 unique symbols for four users by mapping algorithm. This algorithm is based on the combination of bits shown in Figure 2 (b).

At transmitting end, the generated symbols are modulated by Laser Diode (LD) at 1550 nm wavelength and Mach-Zehnder modulator (MZM).

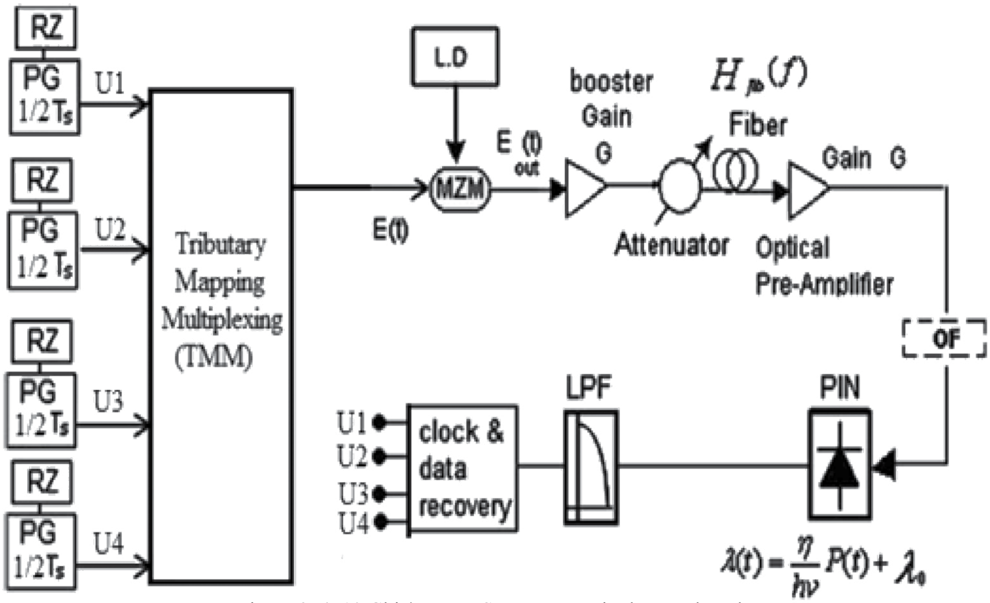


Figure 3. 4x10 Gbit/s TMM Setup over a single wavelength

Shown in Figure 3 a linear band pass system represented by a low-pass equivalent is used to modulate the fiber in which the dispersion of the fiber depends upon the nonlinear phase response of the transfer function of the fibers, reported in [21].

B. Data Recovery Rules

At receiving end photodiode is used to detect the optical signal. The received signal then passed through a low pass-filter (LPF) and then it is further passed from a Clock-and-Data-Recovery (CDR) unit to recover the received data [19]. Figure 4 represents the eye diagram of the output of the modulator.

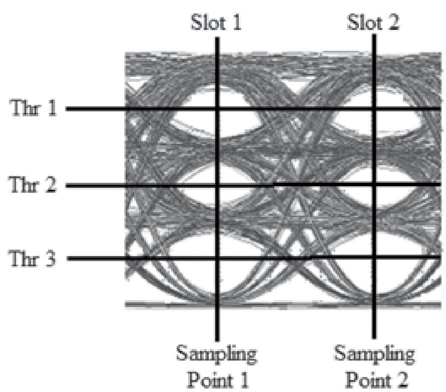


Figure 4. TMM Eye Diagram, including three thresholds and two sampling points

In CDR unit the detected signal is passed into the sampling circuit. In every symbol there are two slots, samples are taken at two sampling points S1 and S2 at each slot (Table 1). Sampling circuit outputs are fed in to the decision and regeneration unit. In this unit the sampled values are measured against three pre-defined threshold values, thr1, thr2 and thr3 (Table 1) and decisions are made on the basis of process defined in the Table 1:

TABLE I
TMM User Recognition Rules

Number	Rules			U1 U2 U3 U4
1	if S1 < thr1	then	S2 < thr1	0 0 0 0
			thr1 < S2 < thr2	0 0 0 1
			thr2 < S2 < thr3	0 0 1 0
			S2 > thr3	0 0 1 1
2	if thr1 < S1 <thr2	then	S2 < thr1	0 1 0 0
			thr1 < S2 < thr2	0 1 0 1
			thr2 < S2 < thr3	0 1 1 0
			S2 > thr3	0 1 1 1
3	if thr2 < S1 < thr3	then	S2 < thr1	1 0 0 0
			thr1 < S2 < thr2	1 0 0 1
			thr2 < S2 <thr3	1 0 1 0
			S2 > thr3	1 0 1 1
4	if S1 > thr3	then	S2 < thr1	1 1 0 0
			thr1 < S2 < thr2	1 1 0 1
			thr2 < S2 < thr3	1 1 1 0
			S2 > thr3	1 1 1 1

The original data by each user is reconstructed by data recovery unit, which uses the rules defined in table. For example, the regenerated data for U1 is binary 0 when the value taken at sampling point S1 is less than thr2 and sampling point S2 is greater or less than thr1, thr2 and thr3. Similarly, the regenerated data for U1 is binary 1 when the value taken at sampling point S1 is greater than thr2 and sampling point S2 is greater or less than thr1, thr2 and thr3. Similarly, data for U2, U3 and U4 can be regenerated [19].

VII. Results and Discussions

A. Spectral Efficiency

Figure 5 shows the comparison between the optical spectra of TMM and conventional TDM at a bit rate of 40 Gbit/s. The spectral efficiency is an important tool that gives an idea about the capacity of digital communication systems. As represented clearly that main lobe of TMM signal is much narrower than conventional TDM signal and side lobes are compressed significantly. This is because TMM divides the whole bit duration into two equal slots and number of levels depending on the number of users. Thus TMM requires a null-to-null spectral width of 2x [No. of Slots x single channel bit rate]/No. of Levels per slot, whereas, TDM requires 2 x [2 x aggregate bit rate]. The narrow spectral width of TMM gives a lot advantages when implemented on WDM system. These advantages are discussed in upcoming sections.

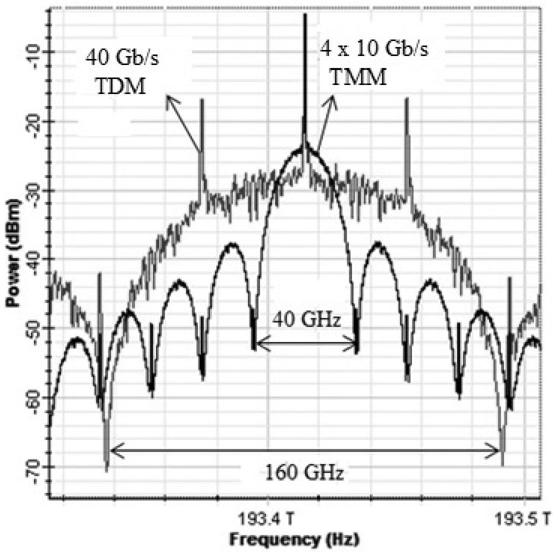


Figure 5. Optical Spectrum of 4 x 10 Gbit/s TMM vs 40 Gbit/s TDM

B. Tolerance against Narrow Optical Filtering

In the case of the communication systems working at an aggregate bit rate of 40 Gbit/s with broader optical spectrum the effect of optical filtering is an important issue. In the de multiplexing process of WDM strong optical filtering is applied. In this section the performance of TMM and TDM under strong filtering condition at 40 Gbit/s is observed.

The spectral width of TMM is narrow, because of which narrow band pass optical filter can be applied for de multiplexing process. Narrow filtering provide space and number of channels can be increased. But very narrow band pass optical filter is used, it blocks the major part of the signal spectrum and this causes the degradation of optical signal.

To compute the effect of distortion because of narrow filtering on optical signal, study measure the power penalties. The figure 6 shows the comparison between the TMM and TDM at 40 Gbit/s. In this figure power penalties are plotted against the optical filter bandwidth at a BER 10-9.

As shown by the Figure 6 the TMM is more robust to narrow optical filter as compared to conventional TDM. For 40 Gbit/s TMM system an optical filter with a bandwidth of 30 GHz can be used for 1 dB penalty. But for TDM optical filter bandwidth should be greater than 78 GHz.

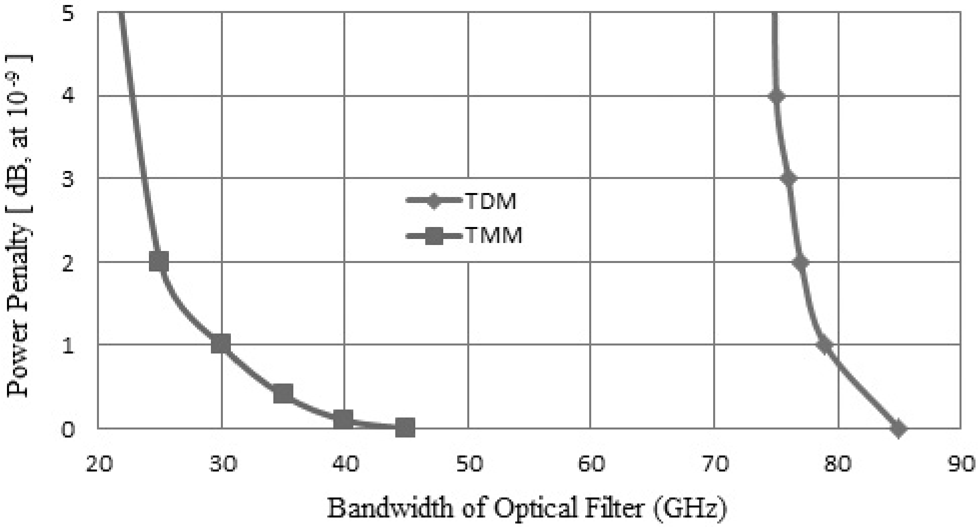


Figure 6. Tolerance against narrow optical filtering

C. Dispersion Tolerance

Here the comparison between the dispersion tolerances of TMM and conventional TDM is performed at aggregate bit rate of 40 Gbit/s. Figure 7 shows the positive and negative dispersion tolerances of TMM and TDM.

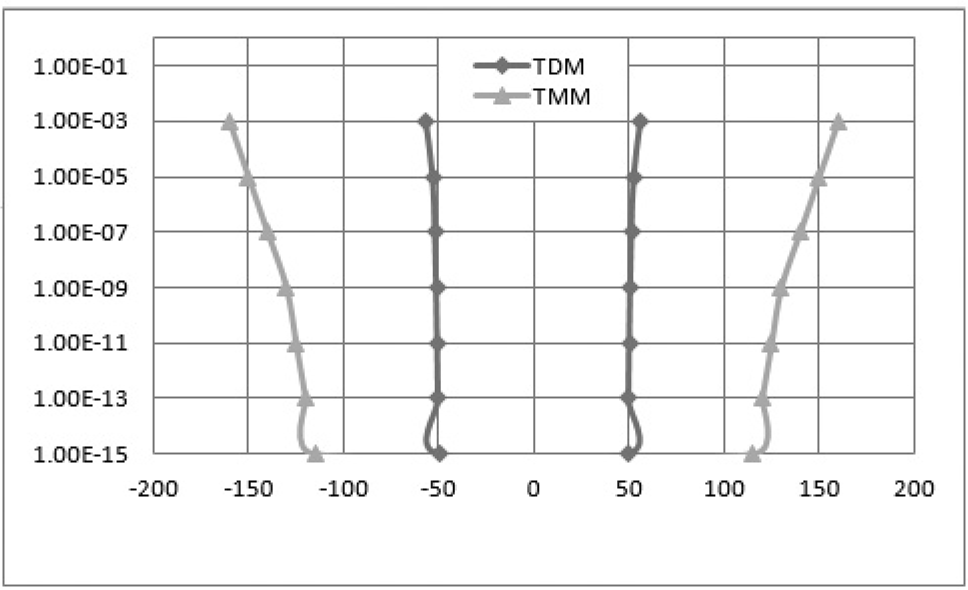


Figure 7. Chromatic dispersion tolerance of 4 x 10 Gbit/s TMM and 40 Gbit/s TDM at same received power

As demonstrated clearly that chromatic dispersion of TMM is ± 130 ps/nm and TDM is ± 51 ps/nm. So it is obvious that TMM is more robust to dispersion as compared to conventional TDM. The reason behind this tolerance is the smaller spectral width of TMM. The spectral width of TMM is 40 GHz, whereas the spectral width of TDM is 160 GHz. So if the spectral width will be smaller system will be more immune to Chromatic Dispersion.

VIII. Conclusion

The performance of 40 Gbit/s TMM and TDM over single channel WDM systems are demonstrated in this paper. The narrow optical spectrum of TMM provides tolerance against strong optical filtering applied at de-multiplexing process of WDM. The possibility of using an optical filter as narrow as 40 GHz for 40 Gbit/s TMM signal was confirmed. The high and symmetrical dispersion tolerance of ±130 ps/nm was obtained for TMM system, which is very attractive in high-speed WDM transmission systems. Based on the simulation results TMM system demonstrated a better spectral width and tolerance against optical filtering in comparison with conventional TDM at 40 Gbit/s bitrate. So, it is concluded that by using TMM signal format the performance and capacity of WDM transmission system can be enhanced significantly.

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