COMPREHENSIVE STUDY ANALYSIS OF NOVEL MAPPING MULTIPLEXING (NMM) TECHNIQUE FOR LONG HAUL OPTICAL FIBER TRANSMISSION SYSTEMS

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Abstract

A new multiplexing technique based on mapping method called Novel Mapping Multiplexing (NMM) is proposed and well demonstrated. It is reported that spectral width occupied by 40 Gb/s NMM is 40 GHz with spectral efficiency of 1bit/sec/Hz that shows a clear advantage over the conventional NRZ-OOK and RZ-OOK with same data rate of 40Gbits/sec having spectral efficiency of 0.5bit/sec/Hz and 0.25bit/sec/Hz respectively. This technique features better chromatic dispersion (CD) tolerance and Q-Factor because of its narrow spectral width.

Keywords: Novel Mapping Multiplexing (NMM), Spectral Width, Spectral Efficiency, Chromatic Dispersion (CD), Quality Factor (Q-Factor)

I. Introduction

Multiplexing techniques play a very vital role in high speed and long haul optical fiber communication systems. There are Different types of techniques have been used for maximum efficient utilization of a bandwidth so as result cost could be reduced. Network Design determines the types of multiplexing and modulation techniques that both can be used at same time has also been studied in (C.W. Chow et al, 2004) (D. J. Richardson, 2010) (J. Li et al, 2010).

Various multiplexing techniques such as optical time division multiplexing (OTDM), wavelength division multiplexing (WDM) show high potential to support larger bandwidth has also been demonstrated in (T. H.

Wood et al, 1999) (G. Charlet et al, 2002) (A. H. Gnauck et al, 2004).Various kind of signaling such as M-Ary, AM-PSK ploybinary, Polyquantenary have examined for their better chromatic dispersion (CD) tolerance because of narrow spectral width (A. Malekmohammadi et al, 2009).Recently, multi slot amplitude coding (MSAC) has been reported that offer better clock recovery as a result of its symbols that have initial zero level. The basic problem in MSAC system is degradation in receiver sensitivity that has also been investigated and studied in (R. Talib et al, 2011) (CVIJETIC M, 2004).There is need to develop a new multiplexing and mapping method for high speed optical communication system to perform better to reduce cost, chromatic dispersion tolerance, complexity and spectral efficiency.

In this paper, a new multiplexing technique called Novel Mapping Multiplexing (NMM) has been comprehensively demonstrated for high speed optical transmission networks. NMM uses multilevel amplitudes and fixed 50% duty cycle (DC) with unipolar signaling. Author demonstrates a 40Gb/s NMM optical transmission system and compared it with conventional RZ-OOK and NRZ-OOK.

II. Working Principle

NMM uses multi level amplitudes and slots with unipolar signaling to distinguish the number of users. To transmit the bits, users transmit multi level amplitude voltages.NMM user's data is represented in half of the symbol duration, T_s. On the basis of the uniform distribution of duty cycle, that is 50% for all the users. NMM user to transmit bit, T_i is

$$T_i = T_s/2 \qquad (1)$$

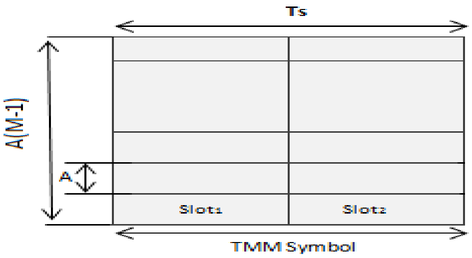

Fig. 1. NMM Symbol Format

Ts, A and M represent symbol duration, amplitude level and number of levels respectively. Multiple users transmit their data on a single communication channel in the same time period, carrier wavelength, duty cycle but different amplitude levels and slots. In NMM transmission, four bits cluster is divided into two bits clusters, where the first two bits (b1, b2) define the slot$_1$ where as the second two bits (b3, b4) define the slot$_2$.Mapping process is shown in the fig.2.

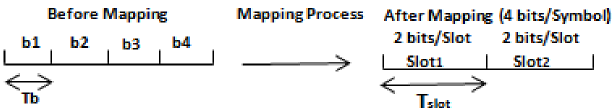

Fig. 2. General Format of Mapping NMM Symbol

$T_{b,\ Tslot}$ represents the bit duration and slot duration respectively.

To recognize the data at the receiver, unique amplitude levels and slots are used [10]. In table I, all possible combination of four NMM users is shown, that are from D_0 to D_{15}. Y0 &Y1 represents User1 (U1) & User2 (U2) and similarly Y2 & Y3 represents User3 (U3) & User4 (U4), respectively at 50% duty cycle. The process ends up by creation of unique symbols that is based on the 2^ncombination Fig. 3.a. NMM signal with multi level amplitudes; different slots and same duty cycle make it unique to APDCDM where each user data recovery is based on unique duty cycle.

Table I . Sixteen possible combinations of bits for four users

Case	D0	D1	D2	D3	D4	D5	D6	D7	D8	D9	D10	D11	D12	D13	D14	D15
U1	0	1	0	1	0	1	0	1	0	1	0	1	0	1	0	1
U2	0	0	1	1	0	0	1	1	0	0	1	1	0	0	1	1
U3	0	0	0	0	1	1	1	1	0	0	0	0	1	1	1	1
U4	0	0	0	0	0	0	0	0	1	1	1	1	1	1	1	1

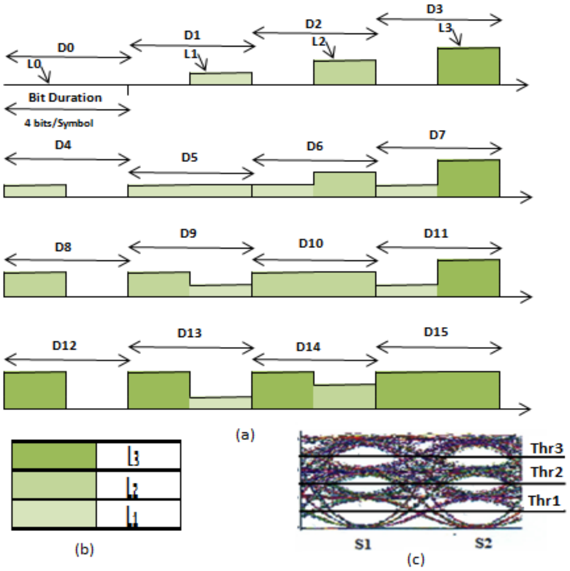

Fig. 3. (a) unipolar multiplexed NMM signal. (b) Colors represent levels for NMM Symbol. (c) NMM eye diagram

III. Simulation Setup

Optical system performance is access by the use of Matlab and optical communication system design software OptiSystem.Q-Fctor is used for performance valuation of the optical system. Figure 4 shows the OptiSystem simulation setup for four NMM user data,

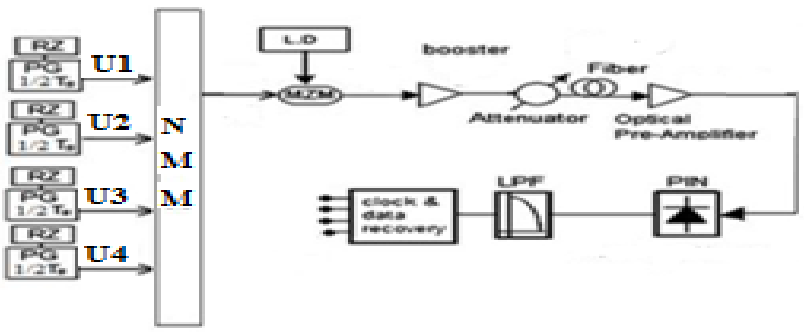

Fig. 4. Simulation Setup

Each at data rate of 10 Gbps with PRBS 2^{10} - 1 are stamped with individual RZ pulse stamps at 50% duty cycles. Each user has the same voltage at the input of the multiplexer. Each user data with bit duration of Tb = 1×10-10 sec is multiplexed via electrical multiplexer to form 4 bits multiplexed cluster then it is mapped to produce a specific symbol of duration Ts =0.1nsec and a slot duration Tslot = 0.05nsec.Laser diode which operates at 0dBm is used to modulate the NMM signal. To avoid the frequency chirping, Machzhender modulator is used. At the output of the modulator, eye diagram is shown in Fig (3.c).

Optical signals at receiver side is detected by the photodiode and than for the filtering process pass through low pass filter (LPF) .To suppress noise that is carried from photodiode, therefore it is required to optimize the bandwidth of Gaussian LPF in the reference to the original signal pulse width. Finally the filtered output signal is fed to the sampling circuit where samples of the NMM signal are taken at sampling points of S1 and S2 in every symbol. Sampling circuit generated outputs fed to decision and regeneration unit to recover original data. In this unit, all NMM sampled values are compared with three threshold value of thrl, thr2 and thr3 Figure 3.c and this decision process is depicted in the Table 2. This Table has the rules to recover four NMM user data.

Table II. NMM Data Recovery Rules

Number	Rules		Decision
1	if S1 < thr1 then	S2<thr1	0000
		thr1<S2<thr2	0001
		thr2<S2<thr3	0010
		S2>thr3	0011
2	if thr1 < S1 <thr2 then	S2<thr1	0100
		thr1<S2<thr2	0101
		thr2<S2<thr3	0110
		S2>thr3	0111
3	if thr2 < S1 < thr3 then	S2<thr1	1000
		thr1<S2<thr2	1001
		thr2<S2<thr3	1010
		S2>thr3	1011
4	if S1 > thr3then	S2<thr1	1100
		thr1<S2<thr2	1101
		thr2<S2<thr3	1110
		S2>thr3	1111

For 40Gb/s system aggregate date rate, spectral width of NMM, NRZ-OOK and RZ-OOK is observed 40GHz, 80GHZ and 160GHz respectively (A. Malekmohammadi et al, 2012) and shown in Fig. 5.

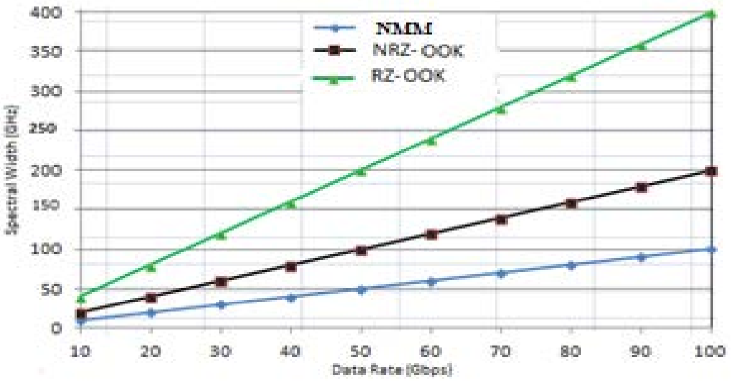

Fig. 5. NMM Spectral Width Comparison with NRZ-OOK & RZ-OOK

NMM symbol eye diagram in Fig. 6 shows clear visual view with greater dispersion tolerance compared with NRZ and NRZ because of its narrow spectral width.

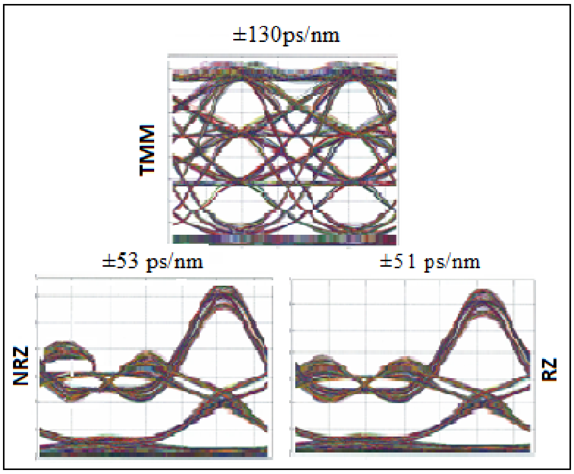

Fig. 6. Dispersion Tolerance of NMM, NRZ and RZ at $^{10-9}$.

TMM six eyes symbol with their respective Q-Factor is show in Fig. 7.

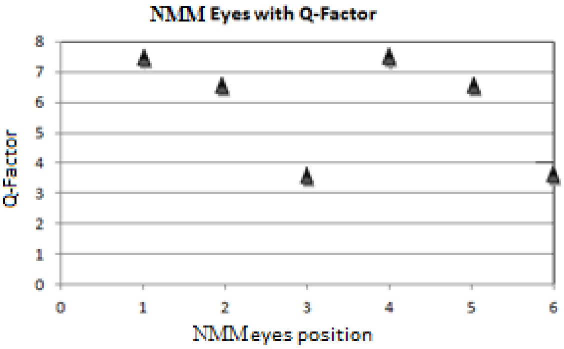

Fig. 7. NMM symbol eyes position with Q-Factor values

IV. BER Estimation

A practice for the BER approximation as deliberate in (MALEKMOHAMMADI A et al, 2008), which is mentioned as Probability of Error (P_E) approximation, is established for every NMM multiplexed users, based on rules used for data recovery, considering four NMM users shown in fig. 3.a, the multi amplitude level signal including noise at the input of the NMM generate a multi amplitude level analog waveform at the output of processing circuit stated as

$$R0(t) = \left\{ \begin{array}{l} R00(t) \text{ for S1, level 0} \\ R01(t) \text{ for S1, level 1} \\ R02(t) \text{ for S1, level 2} \\ R03(t) \text{ for S1, level 3} \end{array} \right\}$$

And similarly,

$$\mathrm{R1(t)} = \left\{ \begin{matrix} \text{R10(t) for S2, level 0} \\ \text{R11(t) for S2, level 1} \\ \text{R12(t) for S2, level 2} \\ \text{R13(t) for S2, level 3} \end{matrix} \right\}$$

where R0(t) and R1(t) are random variables that have continuous distribution. For the ease all through this paper, R0(t) and R1(t) are considered to be as R0 and R1 respectively.

Let we assume to calculate the Probability Density Functions (PDFs) for the eight random variables R0 = R00, R0 = R01, R0 = R02, R0 = R03 for sampling point $S_1$and similarly R1 = R10, R1 = R11, R1 = R12and R1 =R13for sampling point S_2 respectively. These conditional PDFs depend on these two sampling points S_1 and S_2 each transmitted with their corresponding Levels i.e. Level0 Level1, Level2 and Level3. Therefore, when R0 = R00, at S_1, the PDF sent the Level 0 which is denoted as f(**R0S1Level 0**), and when R0 = R01at S_1, PDF sent the Level 1 which is denoted as f(**R0S1Level 1**),and when R0 = R02 at S_1, it sent the Level2 which is denoted as f(**R0S1Level 2**), and when r0 = r03at S_1, the PDF sent the Level 2 which is denoted as f(**R0S1Level 3**).Similarly when R1 = R10at S_2, the PDF sent the Level 0 which is denoted as f(**R0S2Level 0**)and when R1 = R11at S_2,,the PDF sent the Level 1 which is denoted as f(**R0S2Level 1)** and when R1 = R12at S_2, it sent the Level 2 which is denoted as f(**R0S2Level 2**) ,and when R1 = R13 at S_2 the PDF sent the Level 3 which is denoted as f(**R0S2Level 3**).all These conditional PDFs are shown in Fig. 8.Gaussian shapes are illustrated for explanation purpose .

In the formation of BER formula, the polarity of the processing circuit of the receiver is assumed to be set like if the pure signals were existed at the input of the receiver. For S1, R0> Vthr3 when 3rd Level (Level 3) is sent; Vthr3> R0> Vthr2 when 2nd Level (Level 2) is sent; Vthr2> R0> Vthr1 when 1st Level (Level 1) is sent; and R0< Vthr1 when lowest Level (Level 0) is sent. Similarly for S2, R1> Vthr3 when 3rd Level (Level 3) is sent; Vthr3> R1> Vthr2 when 2nd Level (Level 2) is sent; Vthr2> R1> Vthr1 when 1stLevel (Level 1) is sent; and R1< Vthr1 when lowest Level (Level 0) is sent; comparator circuit that is built inside the decision circuit have three threshold voltages,Vthr1, Vthr2 and Vthr3.

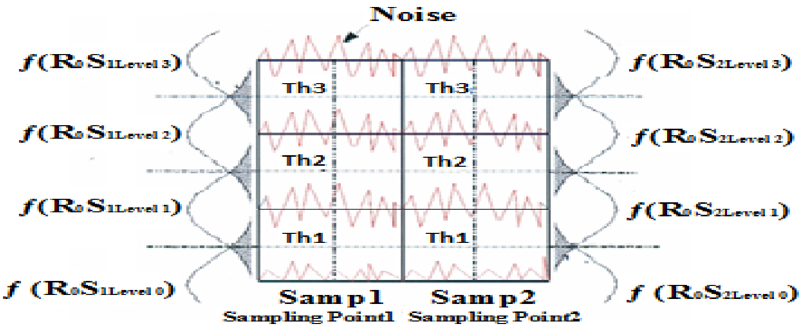

Fig. 8. Probability of error (P_e) of NMM

V. Conclusion

Principle of NMM technique, data recovery rules and BER estimation are discussed.NMM system shows better tolerance to chromatic dispersion and Q-factor because of its narrow spectral width compared to RZ-OOK and NRZ-OOK techniques with same capacity. These results encourage NMM as novel multiplexing technique for long haul high speed optical fiber communication systems.

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