Alamouti Coded Asymmetrically Clipped Optical OFDM for Improved Performance of Multi-Mode Fiber

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Abstract

In this work, Alamouti coded asymmetrically clipped optical orthogonal frequency division multiplexing technique is investigated in a multimode fiber (MMF) transmission. Analysis is carried out on asymmetrically clipped O-OFDM and MMF models. The proposed technique finds significant improvement of bit error rate and received signal to noise ratio compared to conventional optical OFDM technique in MMF transmission.

1. Introduction

Multimode fibers (MMF's) are installed in local area networks (LANs) and found attractive with respect to single mode fibers (SMFs) cable due to its larger core area and numerical aperture for efficient light coupling from semiconductor lasers. MMF offers large mechanical tolerances, cabling and splicing are less stringent compared to SMF counterpart. In many places Gigabit Ethernet backbone LAN requires up-gradation from 1 Gb/s to 10 Gb/s and higher in a cost effective manner. A wide range of solutions have been investigated to enhance the transmission performance of MMFs without altering the existing fiber infrastructure. Few notable techniques to improve transmission capacity in MMF's are coarse wavelength division multiplexing (CWDM), multilevel coding, spatially resolved receivers, electrical equalization in the receiver etc. Performance improvement of MMF-enabled optical datacenter networks with direct detection is an important topic of research [1]

MMF based LAN links performance is mainly affected by the inter-modal dispersion which cause inter-symbol interference (ISI). Modal dispersion of multiple modes in MMF offers frequency selective fading to the transmitted signal. Optical OFDM (O-OFDM) format is a suitable modulation technique against frequency selective fading channel and reduce inter-symbol interference (ISI) by choosing the symbol period of each sub-carrier longer than the delay spread caused by the modal dispersion. Experimental measurements have shown that 10 Gb/s intensity modulation and direct detection (IM-DD) O-OFDM signals is able to transmit over 1000 m in a MMF ink employing a directly modulated distributed feedback laser (DFB) [2]. The main drawback of multi-carrier modulation in systems using intensity modulation (IM) is the requirement of high dc bias so that O-OFDM waveform becomes non-negative. To avoid this high dc biasing problem, an efficient technique asymmetrically clipped O-OFDM (ACO-OFDM) can be used. This technique exploits judicious choice of OFDM data sub-carriers such that impairment from OFDM clipping noise can be avoided. Hermitian Symmetry used in this technique to obtain real valued OFDM output and even subcarrier cancellations to get rid of negative part of the OFDM signal certainly reduce the transmission data rate. This loss of data rate can be compensated by using multiple antennas in transmitter and receiver side of MMFs. In this work, we use transmit diversity by using two laser sources at the transmitter and a photo detector at the receiver. Two laser sources can be combined using space time block code namely, Alamouti code in optical domain. This technique significantly reduce bit error rate (BER) and improves data rate in frequency selective MMFs. Moreover, the Alamouti scheme does not require channel state information (CSI) at the transmitter and yields a low complexity maximum-likelihood decoding algorithm.

2. Alamouti coded optical OFDM system

The proposed Alamouti coded ACO-OFDM transmitter is shown in Fig1. Alamouti block is placed before the IFFT block. Alamouti algorithm works in two time slots. At a given time t, input data streams are segmented which are denoted by d_1 and d_2 in Fig.1. Each data stream is QAM modulated. Complex QAM modulated output is fed to Hermitian Symmetry block which is denoted by D_1 and D_2 in Fig.1. Then IFFT is taken and negative OFDM amplitudes are clipped to zero. Thus ACO-OFDM signal is generated. After adding cyclic prefix the two output sequences are denoted by x_1 and x_2. According to Alamouti algorithm, at time t, x_1 and x_2 sequences are

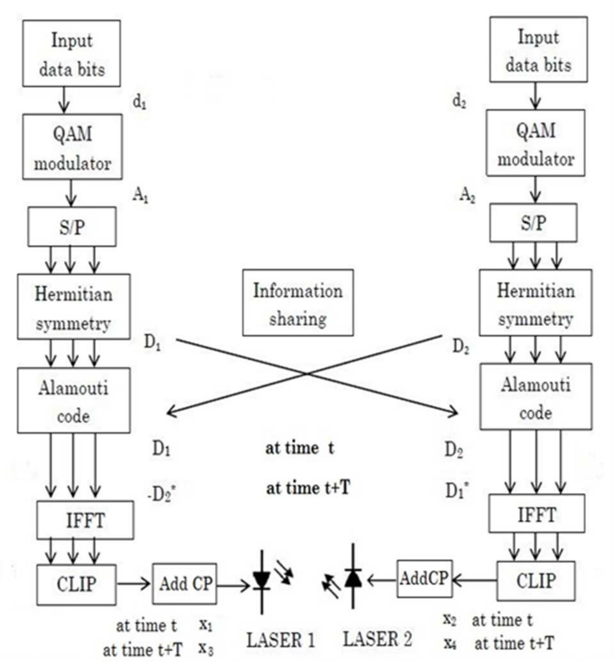


Figure1. Alamouti coded ACO-OFDM transmitter

intensity modulated by LASER 1 and LASER 2 respectively and transmitted over MMF at the same time. In the next time slot (t+T), the two sequences are interchanged to $-D_2^*$ and D_1^* and sent to IFFT block, where '*' denotes complex conjugate operation. Negative amplitude of the output ACO-OFDM is clipped and cyclic prefix is added to it. The resulting sequences are denoted by x_3 and x_4. At time (t+T), x_3 and x_4 sequences are intensity modulated by LASER 1 and LASER 2 respectively and transmitted simultaneously over MMF as shown in Fig.2. Each laser sources launches light into the MMF with different modal power distribution as shown in Fig.3(a). Photo detector (PD) is employed at the MMF output to detect light and electrical signals are further processed in a direct detection receiver.

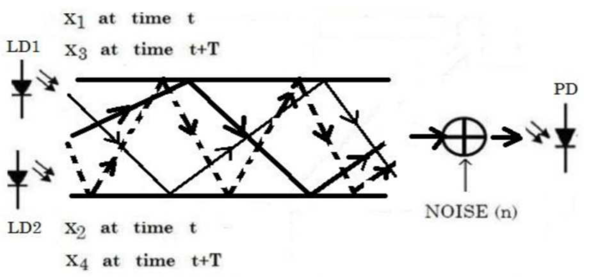
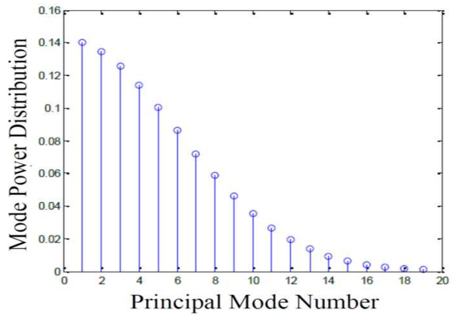


Figure 2. Two modulated laser sources launching power at the same time in a MMF

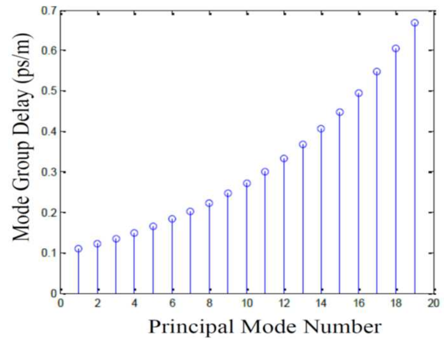
Alamouti scheme [3] is employed to estimate the signals at two time instants t and t+T and decoding is done by maximum likelihood (ML) detector. Then original data is extracted from the Hermitian Symmetric sequences and QAM baseband demodulator.

3. Results

MMF is modeled using statistical techniques and obtained mode power and delay distributions are shown in Fig. 3(a) and 3(b) respectively. 50 µm diameter MMF is considered in the analysis.



(a)



(b)

Figure 3. (a) Mode power and (b) Mode delay distribution in MMF

In this analysis, total number of subcarriers in an OFDM symbol is 128 and 10^4 such QAM modulated OFDM symbols are considered. Alamouti coded optical ACO-OFDM in MMF link employs two configurations.

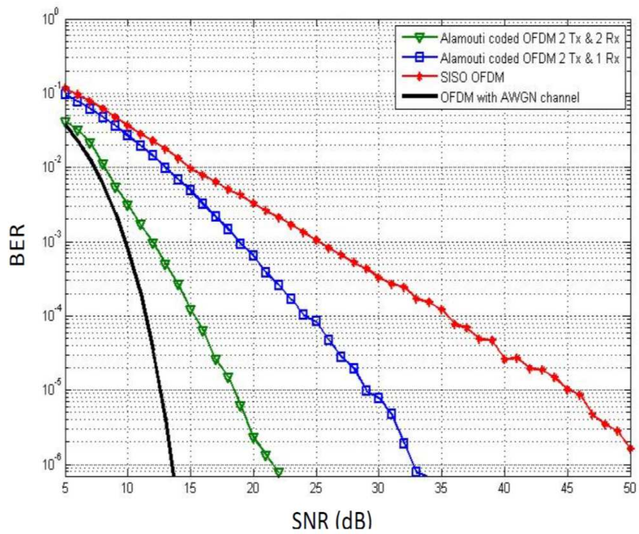


Figure 4. SNR versus BER using 128 OFDM subcarriers and 4 level QAM data

The first one using 2 transmitters and one receiver and the second one using 2 transmitters and 2 receivers. BER versus SNR is studied using Monte Carlo simulation for both the configuration and the result is plotted in Fig 4. The results are compared with the analytical expression given by Eq.(1) [4] for optical OFDM signal only limited by AWGN channel. This plot is shown by solid line in Fig.4.

$$BER = \frac{2\left(\sqrt{M} - 1\right)}{\sqrt{M}\ \log_2 M} erfc\left(\sqrt{\frac{3 * SNR}{2(M - 1)}}\right) \tag{1}$$

A substantial performance improvement in BER and received SNR is noticed in Alamouti coded ACO-OFDM scheme compared to the conventional optical OFDM in MMF transmission. With two receiver technique, the proposed scheme found improvement of SNR about 28 dB compared to the conventional O-OFDM at BER of 10^{-6}.

4. References

1. Zhizhen Zhong, N. Hua, Y. Yu, Z. Wu, J. Li, H. Yan, S. Li, R. Luo, J. Li, Y. Li, and X. Zheng, “Throughput Scaling for MMF-Enabled Optical Data Center Networks by Time-Slicing-Based Crosstalk Mitigation”, Optical Fiber Communication Conference 2018, San Diego, California United States 11–15 March 2018.

2. N. E. Jolley, H. Kee, R. Rickard, J. Tang, and K. Cordina, “Generation and propagation of a 1550 nm 10 Gb/s optical orthogonal frequency division multiplexed signal over 1000 m of multimode fibre using a directly Modulated DFB”, presented at the Optical Fibre Communication Conf. /National Fiber Optic Engineers Conf. (OFC/NFOEC), Anaheim, CA, Mar. 11, 2005, Paper OFP3.

3. S. M. Alamouti, “A Simple Transmit Diversity Technique for Wireless Communications”, IEEE Journal On Select Areas in Communications, vol. 16, no. 8, October 1998.

4. Raed Mesleh, Hany Elgala, and Harald Haas,” On the Performance of Different OFDM Based Optical Wireless Communication Systems”, J. Opt. Commun. Netw./vol. 3, no. 8, August 2011.