Performance Improvement of OCDMA System using Optical Normalizer

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Abstract— The need of ultra high speed communication network has encouraged the telecom industry to investigate the hidden potential of Optical Code Division Multiple Access (OCDMA) in LANs. OCDMA is considered as the optimal solution as it provides huge bandwidths as compared to the other existing multiple access systems. However, Multiple Access Interference (MAI) increases with the increase in number of simultaneous users which severely limits the performance of the OCDMA system. MAI can be reduced by using optical hard limiter placed at the front end of the receiver. But the drawback associated with it is that it is not able to handle random signals effectively. To overcome this problem, there is a strong need for the design of new detection scheme that will be proved efficient enough to enhance the performance of the OCDMA system, while reducing the effects of the MAI. A new technique using optical normalizer employing dynamic thresholding is introduced. The performance of system, in terms of BER and Q factor, is compared to the previous technique used to mitigate the effect of MAI.

Key words: OCDMA, MAI, OHL, ON, BER, Q Factor

I. Introduction

The idea of allowing several users to transmit data simultaneously over the communication channel by simultaneously allowing the available bandwidth to each user is called multiple accesses. The available multi access protocols are Wavelength Division Multiple Access (WDMA), Time Division Multiple Access (TDMA), Code Division Multiple Access (CDMA). CDMA implemented in the optical domain give rise to the field of Optical CDMA that supports multiplexing transmission and multiple accesses by coding in optical domain making use of unique signature sequence. Due to its easy access and flexible network structure, it is highly suitable to the multiple access networks instead of Optical Time Division Multiplexing and Wavelength Division Multiplexing. However, the performance of OCDMA system is limited by the Multiple Access Interference (MAI) originating from other users trying to use the medium simultaneously. MAI increases in the conventional OCDMA system with the increase in number of simultaneous users leading to a higher bit error rate and severely limits the user capacity of the system.

In order to mitigate the effect of MAI, very long optical unipolar code sequences can be used [6]. However, this causes very large bandwidth requirement regards to speed limitations of encoding and correlating hardware. To reduce the code length and maintain good performances, one of the possible solutions is to mitigate the MAI by using an interference cancellation receiver. Several interference cancellation methods have been discussed aiming at lowering the Bit Error Rate (BER).

Optical Parallel Interference Cancellation technique can partly cancel the MAI [3]. But cancellation occurs in the receiver side in electrical domain. As a result a delay is generated because of conversion of signal from optical to electrical domain. Another efficient technique is by the use of an Optical Hard Limiter (OHL) placed at the front end of receiver. This technique doesn't require conversion from optical to electrical. Also OHL reduces MAI and helps in improving the BER of the system [1]. But because of random nature of the incoming signal affected with the masking noises and jitters, the optimum threshold voltage cannot be prefixed to a stable constant level, and therefore a need for dynamic threshold adjustments arises. Optical Normalizer is one such technique to implement the concept of dynamic thresholding by making use of variable optical attenuator.

II. Optical Code Division Multiple Access

In Optical CDMA each user is offered full spectrum for the duration of channel access. OCDMA also offers very simple network protocols, simultaneous access for users with maximum bandwidth, inherent data security as unique addresses are allocated to the users. It does not require any time or frequency management and can operate asynchronously without centralized control and does not suffer from packet collisions. The basic block diagram of an OCDMA system is as shown in figure 1 [1].

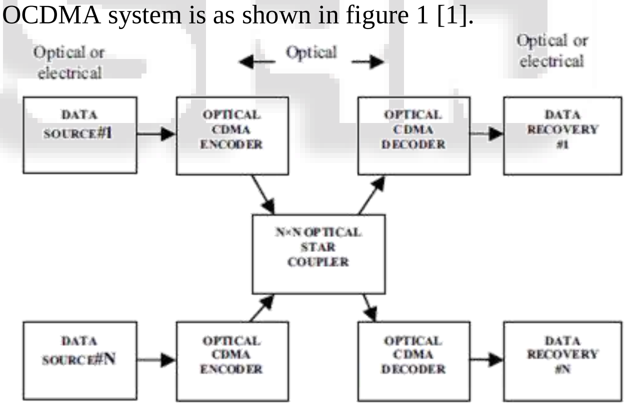


Fig. 1: Block Diagram of OCDMA System

In the transmitter section, analog electrical signal is first converted into narrow optical pulses by narrow band electrical-to-optical converters and then passed on to encoder to generate the required code sequence. Here each bit is divided into N time periods, called chips. Each user of the optical CDMA system has a unique digital signature sequence. The encoder of each transmitter represents each 1 bit by sending signature sequence. However, a binary 0 bit is not encoded and is represented using all zero sequence. Since each bit is represented by a pattern of lit and unlit chips, the bandwidth of the data stream is increased and is then coupled into fiber. The OCDMA encoded data is then sent to an „N x N" star coupler (in local area network) and broadcast to all nodes. Each receiver is given a unique address code from the orthogonal set of codes. Since each receiver is fixed tuned to a unique code sequence, encoder must be tunable to talk to any of the users in the system. On the receiver side, a fixed tuned matched filter recovers the signal in presence of MAI. This is possible because the matched filter de-spreads only the matched filter leaving behind the MAI signal still spread. The appropriate code would be compared to a stored replica of itself (correlation process) and to a threshold level at the comparator for the data recovery. The threshold detected is then converted to electrical form by an optical-to-electrical converter.

The interference from the other channels who are using the same frequency allocation in the same time frame in OCDMA system is known as Multiple Access Interference (MAI). OCDMA system suffers from MAI originating from other active users. Upon increase in the number of active users, the BER performance degrades due to increase in MAI [5]. There occurs reduction in throughput when many users are simultaneously trying to transmit over a common medium, thus producing extreme congestion at high network loads. The data packets and hence the code words overlap and the optical power get added up and optical pulses from one code word can be detected by other receivers tuned to other code words. As a result, a receiver may incorrectly detect other user's code words resulting in packet transmission errors.

III. Optical Parallel Interference Cancellation with Optical Hard Limiter

The technique of Optical Parallel Interference Cancellation with Optical Hard Limiter is successor to Optical Parallel Interference Cancellation. Optical Parallel Interference Cancellation can cancel the MAI to some extent. But cancellation occurs in the receiver side in the electrical domain. As a result a delay is produced due to conversion of optical signal into electrical domain. Another technique is using an Optical Hard Limiter (OHL) [3] at the receiver front end. The key benefit of using this component is that it doesn't require the conversion of signal from optical to electrical domain. OHL reduces Multi Access Interference (MAI) and helps in improving the Bit Error Rate (BER) of the system.

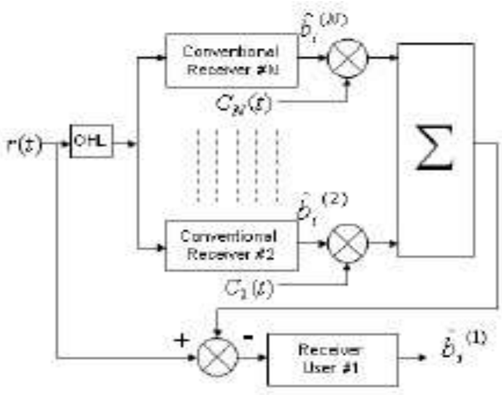


Fig. 2 : Optical Parallel Interference Cancellation with Optical Hard Limiter

To improve the performance of OPIC, OHL has been used in front end of the non-desired users as shown in figure 2. An ideal optical hard limiter is defined as follows:

$$g(x)=\begin{cases}1, & x \geq 1 \\ 0, & 0 \leq x < 1\end{cases}$$

According to the above equation, if an optical intensity is greater than or equal to one, the optical hard limiter would clip the intensity to one. Otherwise, the output of the optical hard limiter would be zero.

The use of optical hard limiter in front of the receiver part results in a performance improvement because it is able to exclude some combinations of interfering patterns from becoming heavily localized in non-zero positions of signature codes. Concurrently, the system yields better performance when the smallest threshold value is used for the desired user which is not the case with conventional OCDMA system. In general OPIC with OHL and lowest threshold values outperforms the conventional OPIC and conventional OCDMA system.

IV. Optical Normalizer Using Dynamic Thresholding

A serious drawback for receivers incorporating optical hard limiter is that due to random nature of incoming bits coupled with noises, optimum threshold voltage can't be prefixed to a stable constant level. Optical Normalizer is one such technique which employs the concept of dynamic thresholding to completely minimize the problem of Multi Access Interference (MAI).

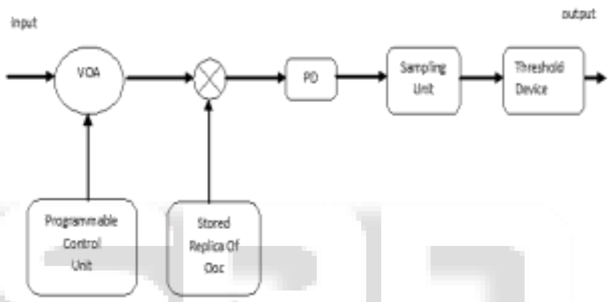


Fig. 3: Optical Normalizer employing Variable Optical Attenuator

The Variable Optical Attenuator is used to optimize the optical power of signals at key points in optical communication networks. Generally, optical power levels are regulated over wide ranges based on configuration of optical communication system. It reduces the excessive optical power above the allowed level at receiver's end with the help of add/drop function to equalize the optical power of channels of OCDMA.

The Optical Power Normalizer normalises the optical signal power by attenuating the input optical signal to the specified average output power level. This is used to attenuate all input optical signal to the same average output power regardless of their different average input power. The other advantage of it is that, it causes the light intensity to be within the dynamic range of photosensitive device, thus provides the safety to the devices from damage due to high light intensity.

Let x_1, x_2, x_3,... x_m be the N samples or power levels of the incoming data at the receiver, then the normalized value is obtained by taking the average of the incoming samples as follows:

$$\text{Normalized Value} = \frac{\sum_{t=1}^{m} x_i}{N}$$

V. Simulation of OCDMA System

The modeling and simulation of OCDMA system is done by using RSOFT OptSim software for different number of users.

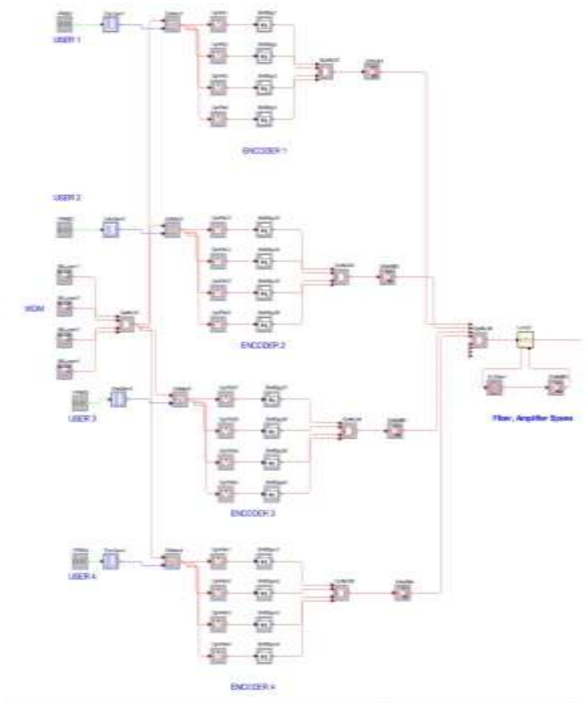


Fig. 4: Encoder Schematic of OCDMA System

The schematic for transmitter section is shown in figure 4. The system uses four mode-locked lasers centered at 1550nm, 1550.4nm, 1550.8nm, 1550.12nm respectively to create a dense wavelength division multiplexed light wave. The encoded data from all the users are multiplexed and passed through the non-linear fiber which introduces loss which can be varied by the user as per the requirement of the system. The multiplexed signal is then passed through an amplifier.

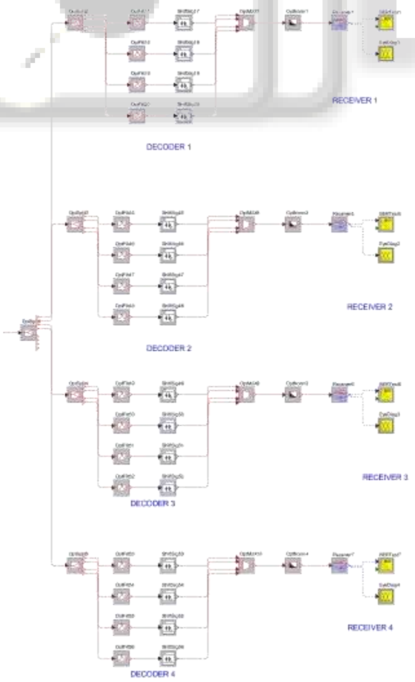
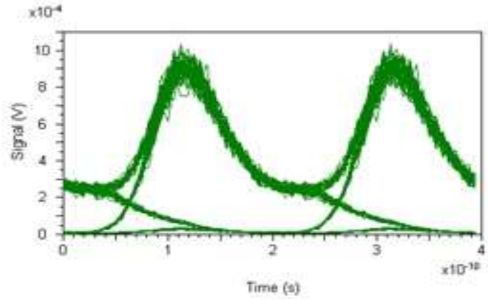


Fig. 5 : Decoder Schematic of OCDMA System using ON

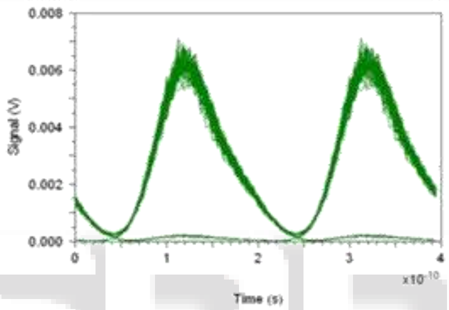
The schematic for receiver section is shown in figure 5. The output signal from the channel reaches the splitter/de-multiplexer. The signal, after passing from splitter, is routed to the respective user's decoder. The decoded signal finally arrives at the optical normalizer and the final signal is passed on to the receiver. The BER and frequency spectrum of the received signal can be observed from the BER analyzer and spectrum analyzer components respectively present in the OptSim.

VI. Results

Results are shown using Eye diagrams and BER values obtained after the simulation of OCDMA system. Optical Normalizer is used in the non-uniform mode so as to mitigate the effect of MAI.

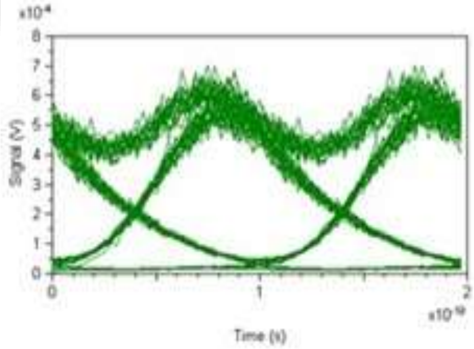


(a)

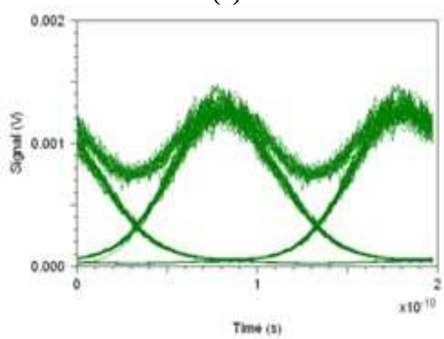


(b)

Fig. 6: Eye Diagram of OCDMA System at 5 Gbps (a) using OHL (b) using ON

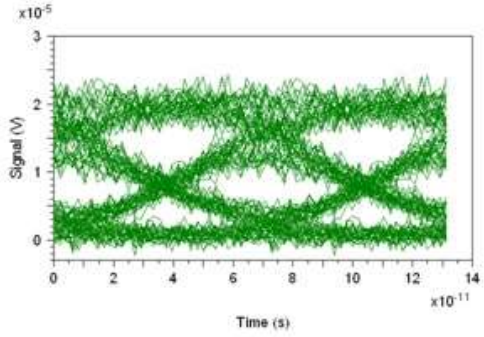


(a)

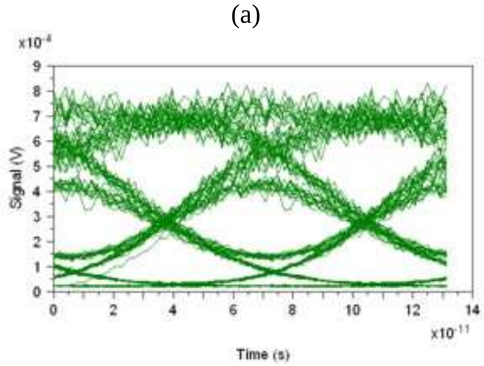


(b)

Fig. 7: Eye Diagram of OCDMA System at 10 Gbps (a) using OHL (b) using ON



(a)



(b)

Fig. 8: Eye Diagram of OCDMA System at 15 Gbps (a) using OHL (b) using ON

Table 1 show BER values of OCDMA system using OHL and OCDMA system using ON for various data rates used. From table 1 it can be observed that OCDMA system using Optical Normalizer performs better than the system using Optical Hard Limiter.

Data rate (Gbps)	**BER**	
	OCDMA using OHL	**OCDMA using ON**
5	3.55e-54	4.68e-58
10	1.92e-47	3.12e-54
12	2.60e-38	2.28e-44
15	2.33e-21	5.01e-31
20	4.26e-08	6.80e-21

Table 1: BER values of OCDMA system using OHL and ON at various data rates

The following graph depicts the variation of BER with Attenuation (dB) for data rate of 15 Gbps. It can be observed that the performance of OCDMA system using Optical Normalizer is way ahead than the system using Optical Hard Limiter.

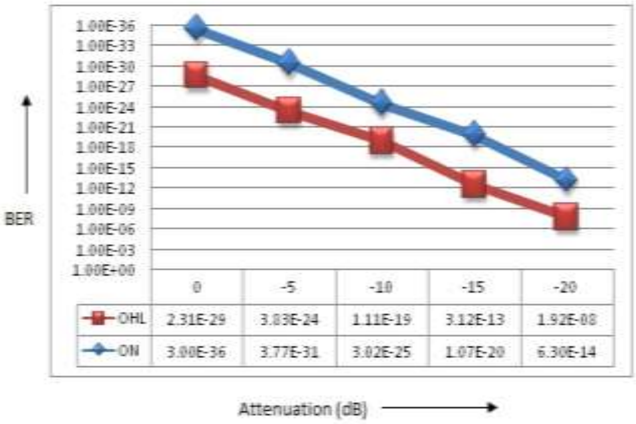


Fig. 7: Variation of BER with Attenuation at 15 Gbps

VII. CONCLUSION

The use of OCDMA technique in optical communication for higher data rate and increased number of simultaneous users is studied. The main drawback of OCDMA system is Multiple Access Interference which limits the user capacity of the system. An optical hard limiter placed at the front end of the receiver can reduce the effect of MAI to some extent. But the limitation of this system is that it cannot handle the incoming random signals efficiently because of the threshold value prefixed to a constant level. The use of optical normalizer overcomes the above stated problem and delivers the signals effectively with very less probability of error. So the overall MAI is reduced to a greater extent which leads to improved QoS of the system. The OCDMA system using ON has the key benefit of low time delay as there is no need for the optical to electrical conversion of the received signal at the time of decoding.

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