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A Review of Various MAI Reduction Techniques in Optical CDMA System

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Abstract— The demand for high speed networks has motivated the communication industry to investigate enormous potential of Optical Code Division Multiple Access (OCDMA) in local area networks. OCDMA is considered as the strongest candidate for the future ultra-high speed optical networks due to the huge bandwidth offered by the system. OCDMA is a technology which supports multiple simultaneous transmissions in the same time slot and the same frequency to realize multiplexing transmission and multiple accesses by coding in the optical domain. One of the major drawback of the multiuser system is the Multiple Access interference (MAI) that can occur due to the false detection of incoming signals by the user at the receiver side. MAI increases with the number of simultaneous users, leading to higher bit error rate and limits the maximum number of simultaneous users in the OCDMA system. Several techniques have been discussed aiming to reduce the effect of MAI. Optical Parallel Interference Cancellation (OPIC) has been extensively studied with Optical Hard limiter (OHL) being used in front of the receiver side to reduce MAI.

***Index Terms*—OCDMA, MAI, OPIC, 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 major multiple 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 Optical CDMA that supports multiplexing transmission and multiple accesses by coding in optical domain through the assignment of unique signature sequence. Due to its easy access and flexible network structure, it is highly suitable to the multiple access network rather than Optical Time Division Multiplexing and Wavelength Division Multiplexing. However, the performance of OCDMA system is limited by the Multiple Access Interfernce (MAI) originating from other users trying to use the medium simultaneously. MAI increases in the conventional OCDMA system with the number of simultaneous users leading to a higher bit error rate and severely limits the capacity of the system.

In order to reduce the MAI impact, very long optical unipolar code sequences can be used [7]. However, this requires a too large bandwidth 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 in the literature aiming at lowering the Bit Error Rate (BER).

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II. OPTICAL CODE DIVISION MULTIPLE ACCESS

Optical CDMA offers full spectrum to each ser for the duration of channel access , 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].

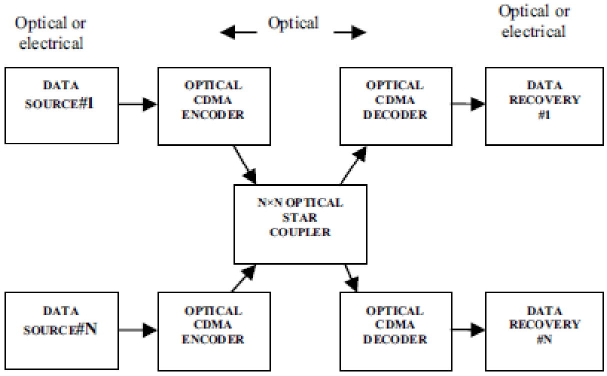

Figure 1 : Block diagram of OCDMA system

On the transmitter side, data bits contained in the electrical form are converted into narrow optical pulses by narrow band electrical-to-optical converters and then fed into an encoder to generate the required code sequence. Here each bit is divided into N time periods, called chips. Each user on the optical CDMA system has a unique 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) or '1 x N' coupler (in an access 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, CDMA 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

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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.

III. Multi Access Interference

The Co-channel interference from other users who are using the same frequency allocation at the same time is known as Multiple Access Interference. OCDMA system suffers from MAI originating from other active users. As the number of active users increases, 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.

A. Conventional Correlation Receiver

Each user employs an on-off keying (OOK) modulation to transmit independent and equiprobable binary data upon an optical channel. A sequence code is impressed upon the binary data by the encoder. The sequence code is specific to each user, in order to be able to extract the data at the end receiver, by comparison with the sequence code [7].

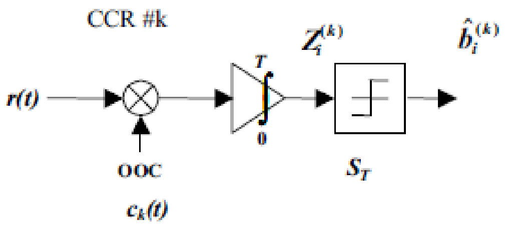

Figure 2 : Conventional Correlation Receiver

The data spreading is realized with OOC. These quasi orthogonal unipolar codes are defined by (F,W,λ_a, λ_c) where F is the sequence length , and W the weight which corresponds to the number of "chip one" in the sequence. The auto and cross correlation constraints λ_a and λ_c are equal to one. At the receiver end, the electrical signal r(t) is the sum of the user's signal.

$$r(t) = \sum_{j=1}^{N} b_i^{(j)}\, c_j\,(t) \qquad (1)$$

where c (t) is the sequence code of the j^{th} user, and b_i(j) is the i^{th} data bit of the j^{th} user. In a Conventional Correlation Receiver (CCR), the received signal r(t) is multiplied by the code sequence corresponding to the desired user $C_k(t)$, and then the result is integrated (Fig. 2). We get the decision variable value as

$$Z_i^{(k)} = \int_0^T r(t).\,c_k(t)dt$$

$$= W.\,b_i^{(k)} + \sum_{j=1, j\neq k}^{N} b_i^{(j)}.\int_0^T c_k\,(t).\,c_j\,(t)dt \qquad (2)$$

The second term in (2) is the interference due to all the non-desired users (MAI).

B. Optical Parallel Interference Cancellation

Optical Parallel Interference Cancellation (OPIC) is adopted from wireless Parallel Interference Cancellation (PIC). OPIC is more complex as compared to PIC but more efficient ion terms of interference suppression because of its ability to remove the non desired user's contribution [3].OPIC operates by estimating the interference due to all undesired users. Then the estimation $\hat{b}_i^{(j)}$of non-desired user #j is spread by corresponding code sequence. The estimated interference is then rebuilt and removed from the received signal r(t).

$$r(t) = \sum_{k=1}^{N} b_i\, C_k(t-\tau_k) \qquad (3)$$

where τ_k is the time delay associated with k^{th} user and b_i is the i^{th} bit of k^{th} user.

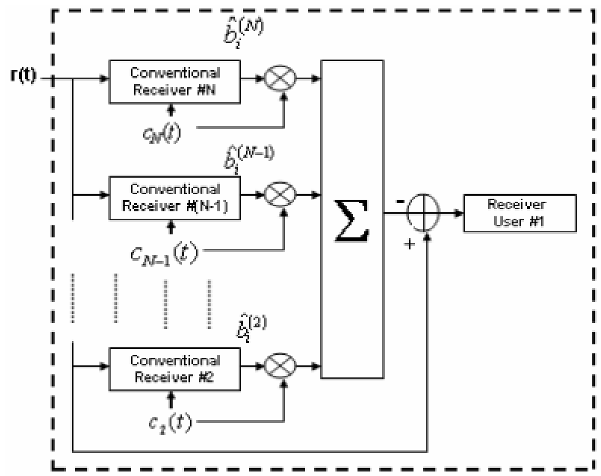

Figure 3 : Optical Parallel Interference Cancellation

The bit sent by the desired user is then extracted by the conventional OCDMA receiver. The signal applied to the entry of desired user receiver (let's assume the desired user is user #1) can be written as follows

$$s(t) = r(t) - \sum_{j=2}^{N} \hat{b}_i^{(j)}\, c_j\,(t) \qquad (4)$$

Where $\hat{b}_i^{(j)}$ and c_j (t) are the estimated data and code sequence of user #j respectively. The next step is detection and estimation of desired user's data using the conventional OCDMA receiver. The decision variable for the desired user #1 is

$$Z_i^{(1)} = W.\,b_i^{(1)} + \sum_{j=2}^{N}(b_i^{(j)} - \hat{b}_i^{(j)}) \int_0^T c_1\,(t).\,c_j\,(t)dt \qquad (5)$$

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In the above equation the second term is called the Interfering term and referred to as I. Errors in the OPIC are due to this term. Unlike CCR, here error occurs only if the desired user sends data equal to 1 and the interference due to other simultaneous user cause an error. On the other hand, I is always negative (if we have wrong detection for the non-desired user i.e if the non-desired user sends data 0) or null (if there are no errors during the extraction of non-desired user's data). In particular, one interfering user produces an interference of "-1". Then, I is an integer number corresponds to the number of interfering users.

C. One Stage Optical Parallel Interference Cancellation

OPIC can be used for N simultaneous users and in order to extract the data of user #1, the data of N-1 non-desired user need to be extracted. Conventional OPIC can reduce the effect of MAI but it is not hardware efficient. However, a receiver with less hardware complexity is needed. One Stage Optical Parallel Interference Cancellation (OS-OPIC)is an optimum choice for the above stated problem.

The idea behind OS-OPIC is quite simple and very effecient in term of cost and complexity. Unlike the OPIC in which we have to extract the data of all non-desired user in order to recover the desired user's data, OS-OPIC operates by providing the estimation $\hat{b}_i^{(k)}$ of only one non-desired user referred as user #k. Then the estimated data is spread by corresponding code sequence, i.e., $c_k(t)$ and removed from the received signal r(t). The bit sent by the desired user is then extracted by conventional correlation receiver. The signal applied to the entry of the receiver can be written as follow:

$$s(t) = r(t) - \hat{b}_i^{(k)} c_k(t) \qquad (6)$$

Where $\hat{b}_i^{(k)}$ and $c_k(t)$ are the estimated data and the code sequence of non-desired user #k respectively.

The signature sequence parameters for OOC are : length F, weight W and the auto-and cross-correlations bounded by 1 for N simultaneous users. Let us assume that user 1 is the desired user and user k is the non-desired user and all the users have same transmitting energy so there is no strong interference.

The signal applied to the entry of the desired user can be written as follow:

$$s(t) = r(t) - \hat{b}_i^{(k)} c_k(t)$$
$$= b_i^{(1)} c_1(t) + b_i^{(k)} c_k(t) + \sum_{j=2,\neq k}^{N} b_i^{(j)} c_j(t) - \hat{b}_i^{(k)} c_k(t)$$
$$= b_i^{(1)} c_1(t) + (b_i^{(k)} - \hat{b}_i^{(k)}) c_k(t) + \sum_{j=2,\neq k}^{N} b_i^{(j)} c_j(t)$$

Before the last detection bloc, the decision variable for the desired user is:

$$Z_i^{(1)} = W.b_i^{(1)} + (b_i^{(k)} - \hat{b}_i^{(k)}) \int_0^T c_k(t).c_1(t)dt + \sum_{j=2,\neq k}^{N} b_i^{(j)} \int_0^T c_j(t).c_1(t)dt$$
$$= W.b_i^{(1)} + H + I \qquad (7)$$

The second term appears in (7) is the non-desired user #k detected by the OS-OPIC receiver referred as H and the third term is due to the undetected users referred as I.

D. Optical Parallel Interference Cancellation with Optical Hard Limiter

The technique of 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) [4] 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.

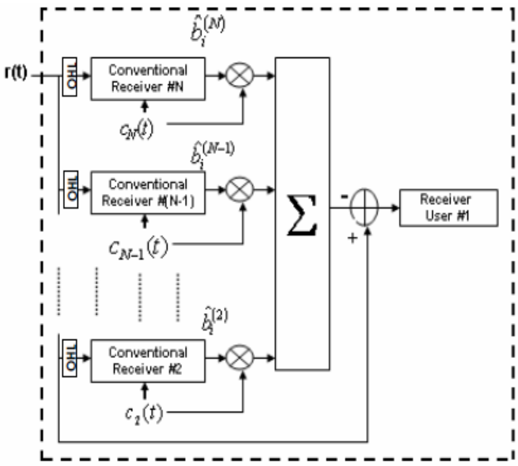

Figure 4: OPIC + OHL

To improve the performance of OPIC, OHL has been used in front end of the non-desired users (fig. 8). 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 localised 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. RESULTS

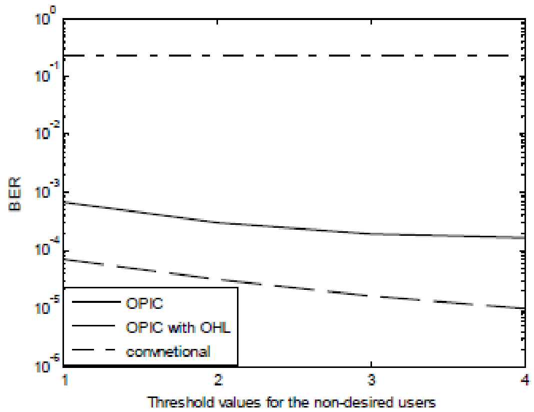

Figure 5 : BER for the CCR, OPIC, OPIC + OHL for 8 users [4]

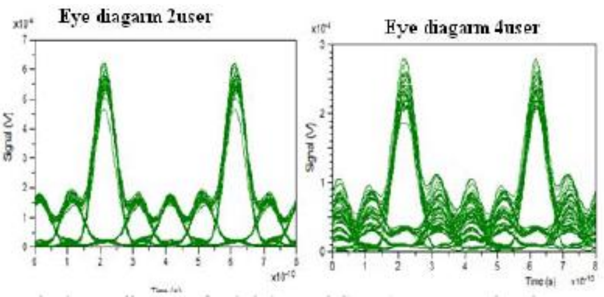

Figure 6 : Eye diagrams of 2 and 4 user OCDMA system using OHL [1]

From figure 5 it is observed that by using OHL with OPIC in front of the non-desired users, the performance of the system is improved [5]. Figure 6 clearly explains that as the number of simultaneous users increases the performance of the system degrades to large extent.

Table 1: Analysis of OCDMA system with OHL in terms of BER and Q Factor [1]

No of users	BER	Q Factor
2 users	1.4005e-048	2.328 e+001
4 users	1.3755e-010	1.604e+001
6 users	3.7302e-006	4.997e+000
8 users	2.1394e-002	4.855e+000

V. CONCLUSION

The use of OCDMA in optical communication networks is studied. OCDMA has got numerous advantages over the other multiple access techniques but it suffers mainly from the problem of multiple access interference which severely limits the capacity of the system. OPIC can remove the non-desired user's contribution to some extent from the desired signal but it is not effective in certain cases. An OHL placed at the front end of the receiver can cancel the MAI to a large extent and can increase the capacity of the system.

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