OPTICAL DOMAIN MULTIUSER INTERFERENCE ESTIMATION FOR SPECTRAL PHASE ENCODING OPTICAL FIBRE CDMA SYSTEMS

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Abstract: In this paper, an effective technique for reducing the multi-user interference (MUI) in spectrally-phase-encoded optical code division multiple access (SPE-OCDMA) systems has been proposed. In this method the effect of MUI signal on the main user's signal has been decreased using multiuser interference detection (MID). Two structures have been introduced for accomplishing MID and degrading its destructive effect on the decoded ultra-short light pulse; temporal multiuser interference estimation (TMIE) and nonlinear multiuser interference estimation (NMIE). Both of these methods utilize two photo-detectors for estimating the MUI signal. In spite of simple structure of these two receivers, their performance analysis shows an improved performances comparing to other receivers.

1 INTRODUCTION

A spectrally-phase-encoding optical fibre code division multiple access (SPE-OFCDMA) system is a system in which a phase encoding has been applied on a coherent ultra-short light pulse with a rectangular spectral pattern (Salehi et al., 1990). Similar to the other kind of optical fibre CDMA systems, the MUI is the main limiting factor on the performance of the SPE-OFCDMA systems (Salehi et al., 1990). The MUI effect in these systems appear as an noise-like signal distributed in the bit period in the vicinity of the ultra-short optical pulse of main user. But because of the slow response time of photo-detectors comparing to the ultra-short pulse duration, a part of the noise-like signals of other users is also gathered by the detector and degrade the performance of the receiver. Some solutions such as using time gating (Lee et al., 2002), second harmonic generation (SHG) (Ni et al., 2007), self phase modulation (SPM) (Ni et al., 2007), and two photon absorption (TPA) detectors (Jamshidi and Salehi, 2007), have been proposed for the fibre OCMDA systems to alleviate the MUI problem.

Multi-user interference estimation has been proposed for decreasing the undesired interference effect of the users in multiple access networks (Brandt-Pearce and Aazhang, 1994). But because all of these methods was in electrical domain, the estimation process takes much time and limits the bit-rate of the system. Also it needs to the information of the other users. In this manuscript we investigate a novel method for declining the MUI effect on the signal of the desired user in SPE-OFCDMA systems. In this approach a interference estimation in optical domain has been used for this purpose. Actually two photo-detectors with different integration times are used to estimate and reduce the MUI destructive effect on desired signal. In the both of the proposed structures for MID the effect of interference is reduced after making an estimation of it. In the TMIE structure, an estimation of the interference is made using the temporal distribution of the MUI signal. Then an estimation of the interfering signal is made using the output of second detector and subtracted from the output of the

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first one. In the second structure, NMIE, the interference has been estimated from the decoded signal and a nonlinear function of it. The simulation results shows the performance of the proposed technique.

2 PRINCIPLES OF SPECTRAL PHASE ENCODING SYSTEMS

In the SPE-OCDMA systems, the bandwidth of the ultra-short optical pulse of each user has been divided into N_0 spectral bins with identical bandwidth and the phase of each bin has been altered according to a specific code sequence of that user. So at the output of the transmitters the optical pulse become as a noise-like signal. At the detector the conjugate of the desired transmitter's code is applied on the received signal. Thus all of the phase alternations removed at the decoder and the ultra-short pulse has been revealed. For the signals of the other users the phase shifts rearranged at the decoder but aren't removed. So the signals of the interfering users remain spread and noise-like. In this study it is considered that users have equal power at the receiver and each bit stream from each user is synchronized. It should be noted that power equality and synchronization are not necessary for the system although we have used them to simplify the analysis and simulation.

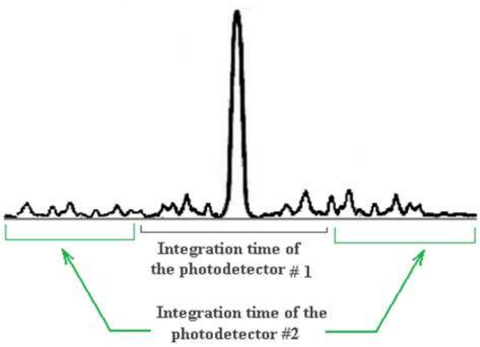

Figure 1: Integration times of the first and second photo-detectors.

The MID receiver can be implemented in two ways. In the first way is to use temporal multiuser interference estimation (TMIE) to lower the MUI effect. This receiver consists of two photo-detectors, one for collecting the main signal in the time duration of T_1 and the other for gathering the interference signal due to the other users in the time duration of T_2. The two detectors can have an overlap in their integration time. The integration time of photo-detectors is depicted in Figure 1. So the output signals of each

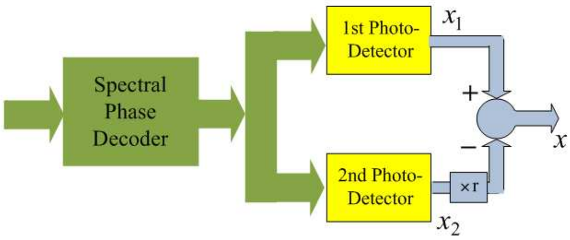

Figure 2: Structure of TIME receiver.

detector can be expressed as

$$X_1 = \int_{-\frac{T_r}{2}}^{\frac{T_r}{2}} P_1(t)dt \tag{1}$$

$$X_2 = \int_{-\frac{T_b}{2}}^{\frac{T_b}{2}} P_2(t)dt \tag{2}$$

We define a new output based on the outputs of the two photo-detectors (Figure 2) as follows

$$X = X_1 - rX_2. \tag{3}$$

where r is defined as the ratio of integration times

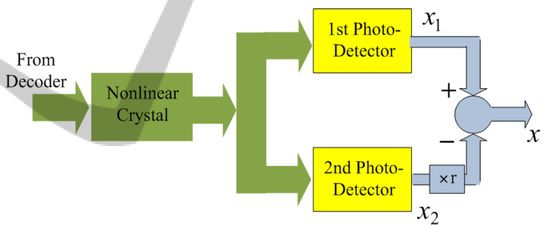

Figure 3: TIME receiver after a nonlinear optical device.

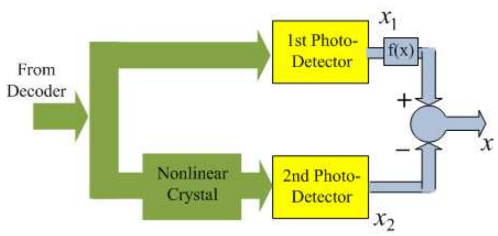

Figure 4: Structure of NIME receiver.

of the first and second detectors, i.e. $r = T_1/T_2$. Regarding the autocorrelation function of the interference signal in SPE-OCDMA systems (Salehi et al., 1990), the mean of the MAI can be eliminated in X but its variance will be increased. So the error probability will be declined.

The TMIE receiver can be used alongside the other nonlinear approaches such as SHG and SPM as illustrated in Figure 3. In this case the received signal passes through a nonlinear media before the detection

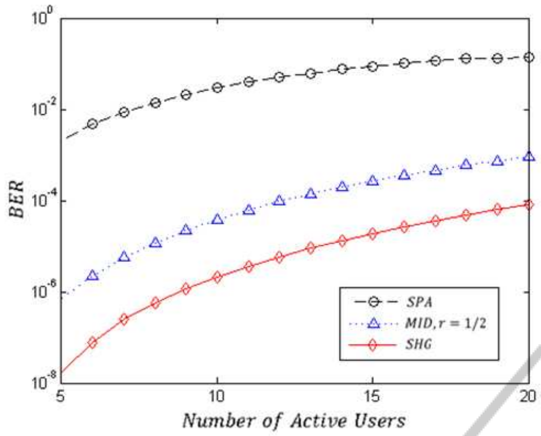

Figure 5: BER versus the number of active users for SPA, MID and SHG receivers.

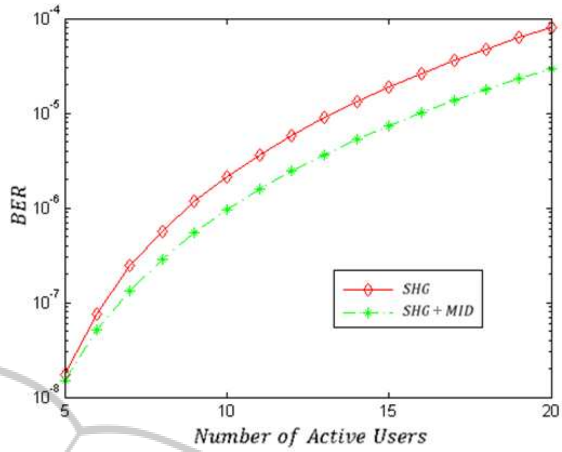

Figure 6: BER versus the number of active users for receivers using SHG and both SHG and MID.

and then TMIE by two photodiodes is used for estimating the Interference signal. Similar to the previous case the mean of the MAI signal can be removed by selecting an appropriate value for the parameter r.

The other type of the MID receiver is Nonlinear Multiuser Interference Estimation (NMIE) as depicted in Figure 4. In this kind of MID receiver two photo-detectors are used for interference estimation as before but with the same integration time. The difference between the photo-detectors is that the first one integrates on the decoded signal but the second one integrates on the decoded signal passed through a nonlinear media. The output of the receiver in the term of the first and second photo-detectors outputs can be expressed as follows

$$X = f(X_1) - X_2. \tag{4}$$

where $f(x)$ is a function for canceling the mean of the MUI signal at the output which depends on the function of the nonlinear media. For example for the receiver with SHG as nonlinear media $f(x)$ is αx^2, where α is a proper coefficient.

3 PERFORMANCE ANALYSIS

In this section, performance analysis of the proposed system will be made and compared with that of SHG and Single Photon Absorption (SPA) codes. MAI has been considered as the main performance degrading factor of the SPE-OCDMA system and the shot noise and thermal noises have been neglected. In our performance analysis, 1Gbps bit rate and 20nm optical bandwidth have been considered. Also, code-length has been supposed to be 500. The results are for the equal probable bit transmitting.

The bit error rates for three different receivers, MID, SHG and SPA, are depicted in Figure 5 versus the number of active users for the 10mW optical peak power for each user. As can be seen the SHG receiver has the best performance comparing to the other receivers. But the interesting part of these results is the performance of the MID receiver. In MID receiver we are able to improve the system performance only by using two photo-detectors and nothing else. Despite the simple structure of the MID receiver, its BER is only one order worse than the SHG receiver. Figure 6 shows the performance of a system when both SHG and MID are used at the receiver. According to these results the performance of the receiver with both SHG and MID is a bit better than that of a receiver with only SHG.

4 CONCLUSIONS

In this paper a novel receiver for SPE-OCDMA systems has been introduced. The proposed system works based on the estimation and reducing the interference signal of the other users. Two different structures, TMIE and NMIE, have been proposed. But of these structures utilize two photo-detectors to make estimation from the MUI signal. The TMIE receiver has an acceptable performance comparing to the SHG receiver regarding its uncomplicated structure.

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