Modified-AND Subtraction Detection Technique Based on Weight-Division for SAC-OCDMA Systems

Hamza M. R. Al-Khafaji, S. A. Aljunid, and Hilal A. Fadhil

Abstract—In this paper, we investigate the use of the modified-AND subtraction detection to assuage the intensity noise in spectral-amplitude coding optical code-division multiple-access (SAC-OCDMA) systems. This detection approach is based upon reducing the received power to the decoders by dividing the weight of the utilised code sequence. The proposed technique has the ability to suppress the influence of multiple-access interference (MAI), in addition to alleviate the intensity noise effect. We simulate the system performance of the proposed detection technique using OptiSystem software Version 9.0. The software considered the entire practical impacts in the system, such as nonlinear effect, dispersion, and attenuation in the fiber. The simulation results based on the modified quadratic congruence (MQC) code show that the modified-AND subtraction detection offer best bit-error rate (BER) performance compared to traditional AND subtraction detection.

Index Terms—Optical code-division multiple-access, spectral-amplitude coding (SAC), Modified-AND subtraction detection, multiple-access interference, intensity noise.

I. INTRODUCTION

Optical code-division multiple-access (OCDMA) has attracted great attention, due to its desirable features, such as asynchronous access, soft-capacity, good security and so on [1], [2]. It takes advantage of sporadic use of channels by allowing simultaneous connection of multiple users to the network [3]. Therefore, it has been proposed for flexibly implementing the optical access networks, such as passive optical networks (PONs), in current and future communication and computer networks [4]. On the contrary, the influence of MAI is considered as the main reason of performance degradation in conventional OCDMA systems [5]. In MAI environments, each receiver receives all the signals from all active encoders in OCDMA system. While the matching channel signal is recovered by a decoder, all other unmatched channel signals play the role of noise, which can produce MAI noise [6]. Among all OCDMA techniques, SAC has the advantage of eliminating the effect of MAI by using subtraction detection techniques at the receiver side with fixed in-phase cross-correlation codes [7].

Incoherent broadband sources such as light emitting diodes (LEDs) or an erbium doped fiber source are the most obvious choice in SAC-OCDMA system because they are low-priced as compared to coherent sources [8], [9].

However, the intensity noise considered as the main limitation of these sources. This noise is power dependent so that increasing the signal strength at the detection side does not improve the signal-to-noise ratio (SNR) [10]. As such, the need of an appropriate detection technique compatible with fixed in-phase cross-correlation codes to lessen the influences of intensity noise is justified.

Among SAC codes, MQC ($L = p^2 + p$, $K = p^2$, $w = p + 1$, $\lambda = 1$) is parameterized with a prime number p and is characterized by unity cross-correlation value yields an ideal cross-correlation [11], [12], where L is the code length, K is the number of users, w is the code weight, and λ is the cross-correlation value between any two codes of the family. The residue of this paper is organised as follows. Section II presents the design of modified-AND subtraction detection technique. Next, in Section III we simulate the SAC-OCDMA system using and compare the resultant eye diagrams. And finally, the paper is concluded in Section IV.

Fig. 1. SAC-OCDMA receiver based on modified-AND subtraction detection technique.

II. MODIFIED-AND SUBTRACTION DETECTION

The SAC-OCDMA receiver diagram of this technique is depicted in Fig. 1 [13], [14]. The received optical power is split by splitter 1 into two parts; one to the upper decoding branches (decoder 1 and decoder 2) and the other to the decoder 3 through an attenuator. The 3-dB attenuator ensures that the interference signal has an equal power incident on each photo-detector in the case of inactive user. The upper decoders (decoder 1 and decoder 2) are placed in a parallel configuration to divide the weight of the used code and reduce the optical power level during the decoding process. The upper decoders have a spectral response match with the active user, while decoder 3 has the overlapped bins from different interferers. These overlapped bins can be represented mathematically by AND operation between the active user and interferers [15]–[17]. This technique is implemented by using the fiber Bragg-gratings (FBGs) to decode the received signal due to its low insertion losses, good spectral resolution and low material costs [18]. The

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photo-detector is composed of two photodiodes (PD 1 and PD 2), which are connected electrically in opposition to provide an electrical signal that is proportional to the power difference of the two optical inputs. The equivalent passband resulting from the filtering is chosen to equal $0.75 \times R_B$, where R_B is the bit rate.

III. SIMULATION SETUP AND RESULTS

Fig. 2. Simulation setup of SAC-OCDDA using modified-AND subtraction detection technique; (a) Transmitter; (b) Receiver.

The system was designed and simulated using OptiSystem software Version 9.0, which is widely used for optical fiber simulations. A simple schematic diagram for two users is illustrated in Fig. 2. The simulation was carried out using MQC code (Weight, $w=4$) for up to five active users at the bit rate of each user $R_B = 622$ Mb/s (STM-4). The ITU-T G.652 standard single-mode optical fiber is employed for a 20 Km optical transmission. Each chip has a spectral width of 0.8 nm. The attenuation and dispersion were set at 0.25 dB/km and 18 ps/nm-km, respectively. The nonlinear effects were activated and specified according to the typical industrial values to simulate the real environment as close as possible. The noise generated at the receivers was set to be random and totally uncorrelated. The dark current value was set at 5 nA, and the thermal noise coefficient was 18×10^{-24} W/Hz for each of the photo-diodes at the detection part. The performance of the system was characterized by referring to the BER and eye pattern. Further, it will be assumed that the transmitted power of the light source is limited. However, to overcome this limitation an erbium doped fiber amplifier (EDFA) is used with optimum EDFA gain of 3 dB. The eye pattern of three users for the modified-AND subtraction detection is shown in Fig. 3. It can be seen from Fig. 3 that the average BER value of the three users is 1.63×10^{-18} , while it is 1.15×10^{-16}

for the previous AND subtraction detection. Fig. 4 shows the system performance in terms of BER for MQC code using both detection techniques. It is clearly seen from Fig. 4 that the performance of modified-AND subtraction detection is much better compared to AND subtraction detection.

Fig. 3. Eye diagram results for three active users of MQC code using modified-AND subtraction detection.

Fig. 4. BER variation against the number of active users for both detection techniques using MQC code.

IV. CONCLUSIONS

We have presented a modified-AND subtraction detection for SAC-OCDMA systems to eliminate the MAI effect and mitigate the intensity and shot noise impacts. This technique is based on decreasing the received signal strength to the decoding branches by dividing the spectrum of the utilised code sequence. In order to simulate the real environment as close as possible, the influences of fiber nonlinearities, dispersion and attenuation were considered in the simulation according to the typical industrial values. We ascertained that the modified-AND subtraction detection improves SAC-OCDMA system performance significantly as compared with the conventional AND subtraction detection. An interesting direction for future research lies in analysing the spectral efficiency and BER performance related to the new proposed technique using different SAC codes.

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