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Performance Analysis of Hybrid OCDMA/WDM System for Metro Area Network

Abstract: In this study a hybrid spectral amplitude coding for optical code division multiple access (i.e., called OCDMA) over wavelength division multiplexing (WDM) network is proposed to support large number of subscribers. The proposed system combines two different techniques, namely OCDMA and WDM. The modified double weight (MDW) code is used as a signature address for designing the system. This code has numerous advantages such as this code can accommodate more number of simultaneous active users under considerable standard bit error rate (e.g. $\leq 10^{-9}$) and shorter code length. The proposed system can enhance the network capability to support high number of users. Therefore, this system can be considered as a promising solution for Metro Area Network (MAN).

Keywords: modified double weight (MDW) code, SAC-OCDMA, WDM and FBG

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1 Introduction

In late 1980 the optical code divission multiple-access (OCDMA) techniques were proposed for optical access network to support more spectral bandwidth, large number of users, mitigating conection and provide flexible provisioning [1]. So, in recent time OCDMA become popular research topic which provides many advantages [2]. However, Most of the research in this area has based on code development and system performance [3, 4]. Last few years, number of SAC codes such as Hadamard [5], M-sequences [6], Balanced Incomplete Bloc Design (BIBD) [7], Modified Quadratic Convergence (MQC) [8], Modified Frequency Hopping (MFH) [9], Random Diagonal Code (RD) [10] and Zero Cross-Correlation (ZCC) [11] are proposed to improve the system performance but when a large numbers of users transmit signal, the system performance is always degraded due to multiple access interference (MAI) So, SAC technique was introduced to eliminate the influence of MAI by using codes with fixed in-phase cross-correlation λ [9]. The SAC-OCDMA is a spread spectrum technique, which increases the physical bandwidth of the channel by applying a spread code. In OCDMA system the data is encoded into OCs by the encoder at the transmitter side and multiple users share the same transmission by using a power splitter/combiner. At the receiver side, the system decoder recognizes the OCs by performing match filtering. The main advantages of SAC-OCDMA system are that the number of active users can larger than the number of available wavelengths. Furthermore, this system provides more attractive solution for burst and asynchronous environments [12].

On the other hand, wavelength division multiplexing (WDM) has been one of the most successful techniques in current fiber optical communication network systems. It offers an enormous bandwidth of optical fibers and can be used for providing multiple parallel channels at low data rates [13]. Due to low spectral efficiency and limited network capacity of OCDMA system, the new system called hybrid system (OCDMA overlay WDM) is proposed by many researchers [14] in the past few years. However, due to the complex code (e.g. frequency-hopping codes) [9] the system performance is always degraded. Therefore, the Modified Double Weight (MDW) code is used for OCDMA system for our study and combined with WDM in a single network to fulfill the subscriber's demand of transmitting high data traffic for FTTH network [14]. The main reason to choose the MDW code is that this code can successfully suppress the MAI effect using complementary subtraction technique. In this paper, we designed a hybrid SAC-OCDMA over WDM system based on non-return-to-zero (NRZ) modulation format, which satisfy the subscriber's current demand of transmitting high data rate enabling coexisting of two different technologies.

The remainder of this paper organized as follows. In Section 2, we review the code construction of MDW code and AND subtraction detection technique. Section 3 shows proposed system architecture. Network simulation setup is shown in Section 4. In Section 5, we discuss the

Table 1: MDW code ideal cross-correlation with different group where weight ($W = 4$)

Kth	C_{18}	C_{17}	C_{16}	C_{15}	C_{14}	C_{13}	C_{12}	C_{11}	C_{10}	C_9	C_8	C_7	C_6	C_5	C_4	C_3	C_2	C_1
1	0	0	0	0	0	0	0	0	0	0	0	0	0	1	1	0	1	1
2	0	0	0	0	0	0	0	0	0	0	1	1	0	0	0	1	1	0
3	0	0	0	0	0	0	0	0	0	1	1	0	1	1	0	0	0	0
4	0	0	0	0	1	1	0	1	1	0	0	0	0	0	0	0	0	0
5	0	1	1	0	0	0	1	1	0	0	0	0	0	0	0	0	0	0
6	1	1	0	1	1	0	0	0	0	0	0	0	0	0	0	0	0	0

results and finally some conclusions are drawn in Section 6.

2 Modified double weight code (MDW) properties

The MDW code is a modified version of DW code family and both DW and MDW code properties are the same except that the MDW has a weight more than two or any even number. Since the code weight increases the signal power of the system then the signal to noise ratio (SNR) for MDW code is high [14]. The MDW code can be represented by $\boldsymbol{K} \times \boldsymbol{N}$ matrix. The basic matrix for MDW code with weight 4 consists of a $[6 \times 18]$ matrix. The significant properties of MDW code is that the ideal cross-correlation is one ($\lambda = 1$) and sometime zero ($\lambda = 0$). An example of basic matrix construction for MDW code with chip sequences is presented in Table 1, where K is the number of users and C is the column number of the codes and represents the spectral position of the chips.

In MDW code sequence construction, the spectral position of four weights $C_{1,K}$ for the first user weight and $C_{9,K}$ for the last user. The *Kth* user is given as $C_{4k} = C_N$ and $C_{1K} = C_{N-1}$. The MDW code possesses numerous advantages including high efficient, easy code construction, simple encoder/decoder design, existence for every natural number $\boldsymbol{n}$ and optimized code length. The MDW code is used as SAC code of each user group in our proposed scheme and the phase cross-correlations of resulting codes will be no more than ones from the original MDW codes. A simple technique will be used for hybrid system channel representation. For WDM signal, two wavelengths will transmit signal for six active users in a single system. The MDW code comparison between different codes in terms of number of active user against BER is shown in Fig. 1. The system parameters are based on a number of previously published papers.

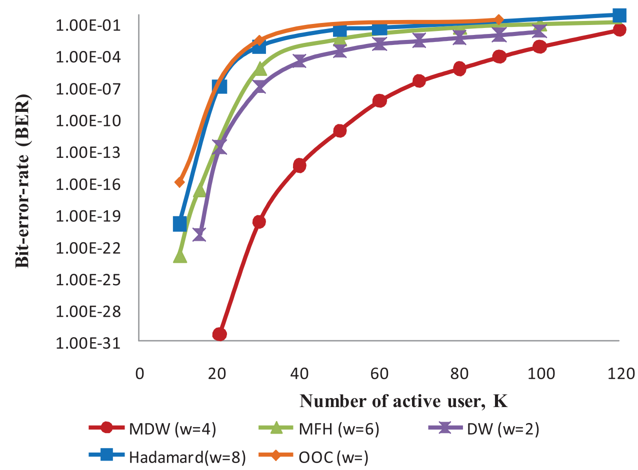

Fig. 1: Number of simultaneous users against bit-error-rate at 622 Mb/s bit rate

3 AND subtraction detection technique

In AND subtraction technique, the cross-correlation $\theta_{\overline{X}Y}(k)$ is substituted by $\theta_{(X\delta Y)Y}$, where $\theta_{(X\delta Y)}$ represents the AND operation between sequences X and Y. For example, let $X = 0110$ and $Y = 1100$ and therefore (X AND Y) = 0100. Figure 2 is shown a AND receiver detection technique.

At the receiver,

$$Z_{AND} = \theta_{XY}(k) - \theta_{(X\&Y)Y}(k) = 0 \tag{1}$$

Equation (1) shows that, with AND subtraction technique, the multiple access interference or the interference from other channels can also be cancelled out. However, in terms of architecture, the AND subtraction technique requires less number of filter in the decoder side. As shown in Fig. 2. AND subtraction detection technique only four filters are needed for decoders of the receivers. The SAC-OCDMA system performance is improved significantly due

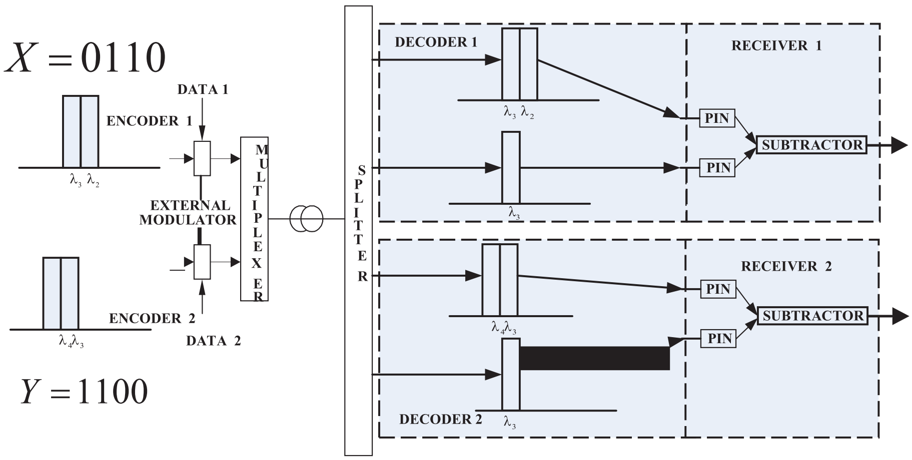

Fig. 2: Implementation of the AND subtraction technique

to the less number of filters in the AND subtraction and the total power loss can be reduced at the same time.

4 Proposed system architecture

In designing the proposed OCDMA over WDM scheme based on MDW code for optical networks, it is assumed that the scheme is implemented by 6 × 6 multiplexer/demultiplexer. Figs. 3 and 4 illustrate the simple block diagram of proposed scheme and its decoder details, respectively. The both system chip has a spectral width of 0.8 nm. The transmitted signal is sliced by multiplexer and splitter. Then the signal is modulated by a modulator (NRZ) and combined using demulltiplexer. The standard single-mode optical fiber (SMF) is used for transmitting the signal to the receiver side. The Fiber Bragg Grating (FBG) spectral phase decoder is used that operates to decode the data at data sub matrix.

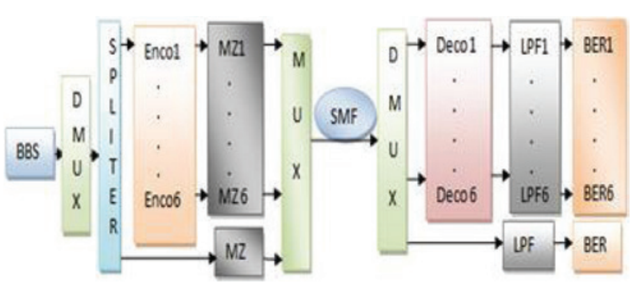

Fig. 3: Overall system block diagram of hybrid system where six OCDMA and one WDM users

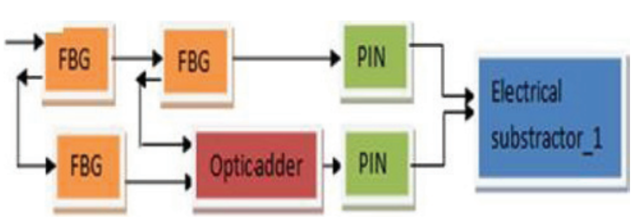

Fig. 4: Overall hybrid system decoder architecture

In the receiver decoder, the complementary subtraction detection technique is used to detect the signal. The detected signal is then decoded by a photo-detector (PIN) followed by a 0.75 GHz low-pass filter (LPF) and error detector respectively. The transmitted power is between 0 to 10 dBm out of the broadband source. The random and uncurled noise is generated in the receiver side. The dark current value is 6 nA, and the thermal noise 1.8×10^{-21} W/Hz for each of the photo detectors. Each user light source is assumed to be unpolarized and carries the spectrum flat bandwidth ΔV Hz. The average optical power for each photo detector per user at the time of the desired user transmit bit “1”.

5 Network simulation setup

The simulation was conducted by the simulation software, OptiSystem Version 7.0, accordance with the system architecture as show in Fig. 3. We run the simulation on the system of 30-km ITU-T G.652 standard single-mode optical fiber (SMF) under NRZ modulation format at 622 Mb/s bit rates. All fiber parameter such as attenuation, group delay, group velocity dispersion, dispersion slop, and non-liner effects are activated during simulation. The average fiber loss is about 0.2 dBm including the splicing loss. The system insertion loss including multiplexer/demultiplexer is taken in the account 0.25 dBm and 2 dBm respectively. All the attenuation α (i.e., 0.25 dB/km), dispersion (i.e., 18 ps/nm km), non linear effects such as four

Table 2: Summary of system specifications

Data rate of OCDMA user	622 Mb/s
Data rate of WDM channel	1 Gb/s
Channel spacing	0.8 nm
Insertion loss	0.25 dBm
Mux/Dmux insertion loss	2 dBm
Fiber attenuation	0.25 dB/km

wave mixing and self phase modulation were activated and specified according to the typical industrial values to simulate the real environment as close as possible. The system specifications listed in Table 2 were used throughout the simulation.

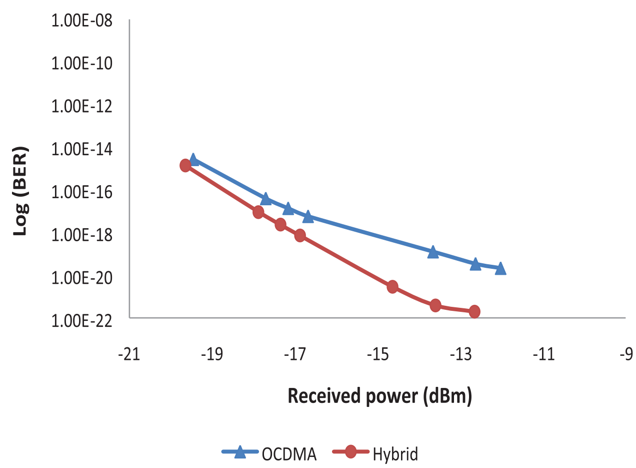

Fig. 6: Measured BER against received optical power for hybrid and OCDMA system

6 Results and discussion

The bit-error-rate (BER) and Q-factor performances are evaluated for each optical wavelength of MDW code. The comparison result of signal between the hybrid system and the conventional OCDMA system is shown in Fig. 5. As seen from Fig. 5 that, the BER performance of the hybrid system is better than the conventional OCDMA for the total length (30 km) of the fiber. The main reason of better signal of hybrid is, the WDM carries higher data rate and combined with OCDMA users, whereas conventional OCDMA system only carries single data rate. As seen in Fig. 5, the error-free transmission value (BER 10^{-19} and $10e^{-16}$) is obtained by the proposed hybrid system and OCDMA respectively.

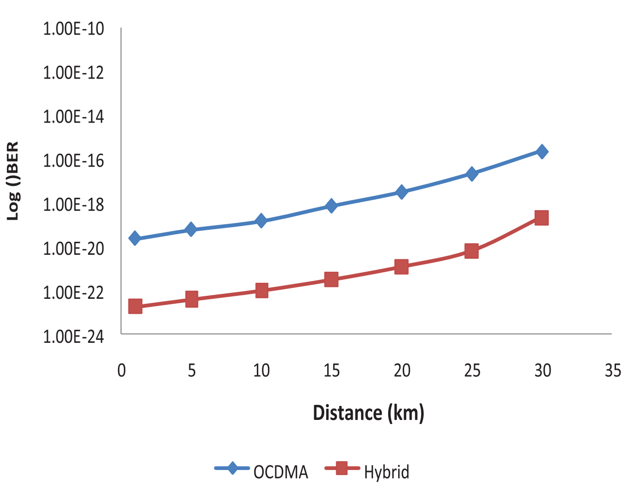

Fig. 5: Variation of BER with fiber distance for hybrid and OCDMA system

The measured BER against received optical power for both the hybrid system and the conventional OCDMA system is shown in Fig. 6. The average received power for first user and last user of hybrid system is about –13 dBm to –20 dBm, whereas the average received power for conventional OCDMA system is –11 dBm to –17 dBm. We ascertained from eye diagrams as shown in Fig. 7 that the signal quality of the hybrid system is much better than conventional OCDMA system.

7 Conclusion

In this study, we proposed a new hybrid SAC-OCDMA over WDM scheme employing MDW code for optical access networks. The new system is more flexible, confidential, and scalable than the conventional OCDMA system. The system bit-error-rate (BER) performance has been investigated against various lengths of the fiber, and different optical received power. Furthermore, We also investigate the signal quality of the hybrid system by eye diagrams. The performance of the proposed hybrid system was compared with the conventional OCDMA system. The comparison results reveal that the hybrid system signal performance is better than the OCDMA system. Hence, the hybrid system can be a promising solution to the local area network, which are offering flexibility, high spectral efficiency, cost effective and ensured security.

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(a)

(b)

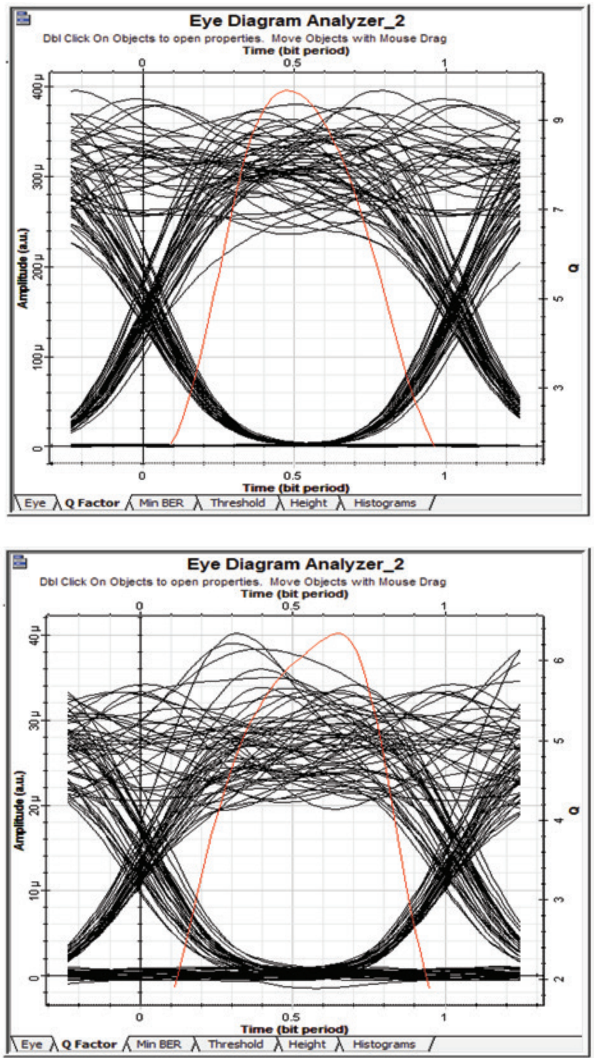

Fig. 7: (a) Hybrid channel, (b) OCDMA channel.

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