Code Development for Simultaneous In-band Transmission of Both SAC-Optical CDMA and WDM Channels

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***Abstract*-Code pulses of spectral amplitude coding (SAC) - optical code division multiple-access (OCDMA) are overlaid onto a multichannel wavelength division multiplexing (WDM) system. Modified quadratic congruence (MQC) codes are developed as the signature codes for the SAC/OCDMA system to avoid the overlapping between signals of both systems. In addition, simultaneous transmission of both optical CDMA users and WDM users on the same band is investigated using a network simulation. Our results are compared to traditional non-hybrid systems. It is concluded that the proposed hybrid scheme achieves performance that is slightly worse than that for the non-hybrid scheme. Furthermore, it provides enhanced data confidentiality as compared to the scheme with SAC/OCDMA only because WDM signals perform a partial masking over encoded signals.**

***Keywords*—** Optical fiber communications, optical networks, optical code division multiple access (OCDMA), spectral amplitude coding (SAC), wavelength division multiplexing (WDM), Modified Quadratic Congruence (MQC).

I. INTRODUCTION

Nowadays, Optical CDMA systems have always been of interest because these systems provide the users simultaneous and asynchronous access to the network with high security [1, 2]. OCDMA can also be overlaid onto the existing WDM networks in order to expand the transmission capacity and to increase the level of security [3, 4]. Modified quadratic congruence (MQC) code of spectral amplitude coding (SAC) for OCDMA is an effective code that can suppress the effects of intensity noise. In addition, this scheme yields a significant reduction in the effects of multiple access interference (MAI) [5].

Recently, the hybrid WDM and SAC/OCDMA scheme have been studied in [6, 7], where each WDM channel can employ the same set of SAC/OCDMA systems. In [8, 9] the transmission of several spectrally phase-encoded OCDMA channels and conventional DWDM channel within the same ITU window has been demonstrated. We have also demonstrated the simulation of hybrid SAC/OCDMA-WDM overlay system using MQC code in [10, 11].

In this paper, we develop a MQC code for simultaneous transmission of several OCDMA channels and WDM channels on the same spectrum band without overlapping. A code shifting technique is used to develop the code. Hence, we investigate the feasibility of transmitting both OCDMA users and WDM users in terms of bit-error rates and of eye diagrams, using a simulation for hybrid and non-hybrid systems. In the following section the MQC code development is presented for our proposed system, followed by the simulation setup, then results and discussions. Finally the conclusion of the paper is provided.

II. MQC CODE DEVELOPMENT

An MQC code for transmission of both SAC-Optical CDMA and WDM channels simultaneously without overlapping has been developed. MQC code families are $\left(p^2+p,\ p+1,\ 1\right)$, with p as a prime number and the properties of MOC codes are mentioned in [5], where an MQC code is denoted by (N ,w ,λ), where N is the number of codewords, w is the code weight, and λ is the cross-correlation. In this code the optimal number of users K equals p^2. Table I shows some binary code sequences, S for parameters $p=5$ and $N=30$.

TABLE I
MQC BINARY SEQUENCES, S WITH p =5 and N =30

S matrix
1 0 0 0 0 0 1 0 0 0 0 0 0 0 1 0 0 0 0 1 0 1 0 0 0 0 0 1 0 0
0 1 0 0 0 0 0 0 0 1 0 0 0 0 1 0 1 0 0 0 1 0 0 0 0 0 0 0 1 0
0 1 0 0 0 0 0 1 0 0 1 0 0 0 0 1 0 0 0 0 0 0 1 0 0 0 0 1 0 0
0 0 1 0 0 0 0 0 1 0 0 1 0 0 0 0 1 0 0 0 0 0 0 1 0 0 0 1 0 0
0 0 0 1 0 0 1 0 0 0 0 1 0 0 0 0 0 0 1 0 0 0 1 0 0 0 0 0 1 0
0 0 1 0 0 0 0 0 0 1 0 0 0 1 0 0 0 0 0 1 0 0 1 0 0 1 0 0 0 0

A new binary MQC sequences, Q is generated based on the old binary MQC sequences, S by using a shifting technique. This technique can be done by multiplication of both S and A_x matrix.

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A basic A_x is given by (3 × 4) matrix where x represents the number of [A] on A_x and it equals $\dfrac{N-(N \bmod 3)}{3}$. A_1 and A_x are illustrated in equation (1a) and (1b), respectively.

$$A_{x=1}=\begin{bmatrix}1000\\0100\\0010\end{bmatrix}_{3\times 4} \qquad \text{(1a)}$$

$$A_x=\begin{bmatrix}[A_1]\ 0000 & \cdots & \cdots\ \cdots\\ 0000\ [A_2]\ 0000 & \cdots 0000 & \\ 0000\ 0000 & \ddots & \cdots\ \cdots\\ \vdots\quad\ \vdots & & \ddots\ \ \cdots\\ 0000\ 0000 & \cdots 0000 & [A_x]\end{bmatrix}_{N\times(N+x)} \qquad \text{(1b)}$$

If S matrix has size $(K \times N)$, then a size of A_x is $(N \times M)$ where $M = N + \dfrac{N-(N \bmod 3)}{3}$, so the result is a new binary code sequences, Q with a size $(K \times M)$. We notice that the number of columns of Q increases one for each old three columns with consideration of integer number. In our proposed system, we assume that the bandwidth of a WDM channel, B_w equals that of a chip of MQC code of SAC/OCDMA, B_s. That is, $B_w = B_s = 25$ GHz. The WDM channels are allocated at every 100 GHz (or equivalently 0.8 nm in wavelength). Therefore, for each 3 elements of MQC chip, there is 1 channel of WDM system. This technique (or method) can be also implemented on any code of SAC-OCDMA.

In this paper, we present as an example; MQC code sequences with p = 5 and K = 25, so the size of S is (25 × 30). Hence, we select the size of A_x (30 × 40). The result; Q = S × A_x with size of (25 × 40). This results lead to have 10 locations for the WDM channels as shown in Table II. This technique is important to avoid the overlapping between signals from both systems in order to get a better performance than that presented in our previous work [10, 11].

TABLE II

MQC BINARY SEQUENCES WITH SHIFTING PROCESS, Q WITH p =5, x =10 and M =40

Q matrix
1 0 0 **0** 0 0 0 **0** 1 0 0 **0** 0 0 0 **0** 0 0 1 **0** 0 0 0 **0** 0 1 0 **0** 1 0 0 **0** 0 0 0 **0** 1 0 0 **0**
0 1 0 **0** 0 0 0 **0** 0 0 0 **0** 1 0 0 **0** 0 0 1 **0** 0 1 0 **0** 0 0 1 **0** 0 0 0 **0** 0 0 0 **0** 0 1 0 **0**
0 1 0 **0** 0 0 0 **0** 0 1 0 **0** 0 1 0 **0** 0 0 0 **0** 1 0 0 **0** 0 0 0 **0** 0 1 0 **0** 0 0 0 **0** 1 0 0 **0**
0 0 1 **0** 0 0 0 **0** 0 0 1 **0** 0 0 1 **0** 0 0 0 **0** 0 1 0 **0** 0 0 0 **0** 0 0 1 **0** 0 0 0 **0** 1 0 0 **0**
0 0 0 **0** 1 0 0 **0** 1 0 0 **0** 0 0 1 **0** 0 0 0 **0** 0 0 0 **0** 1 0 0 **0** 0 1 0 **0** 0 0 0 **0** 0 1 0 **0**
0 0 1 **0** 0 0 0 **0** 0 0 0 **0** 1 0 0 **0** 0 1 0 **0** 0 0 0 **0** 0 1 0 **0** 0 1 0 **0** 0 1 0 **0** 0 0 0 **0**

III. SIMULATION SETUP FOR THE PROPOSED SYSTEM

In a hybrid WDM-OCDMA system, the network traffic consists of narrow-band WDM signals overlaid with optical broadband CDMA signals in the same spectral region. The main idea in the proposed system is to avoid the overlapping between signals of both systems. By using the code shifting technique that was explained in the above section, the overlapping between signals can be attenuated properly.

The setup of the hybrid scheme, illustrated in Fig. 1, has been simulated using OptiSystem software. The non-hybrid system has also been simulated for comparison with the hybrid system. The MQC code for 25 users used in the simulation is (30, 6, 1), while the 4 WDM channels used are 1551.4, 1550.6, 1549.8 and 1549 nm. The system parameters are illustrated in Table III. The simulation is kept as real as possible by activating all attenuation parameters.

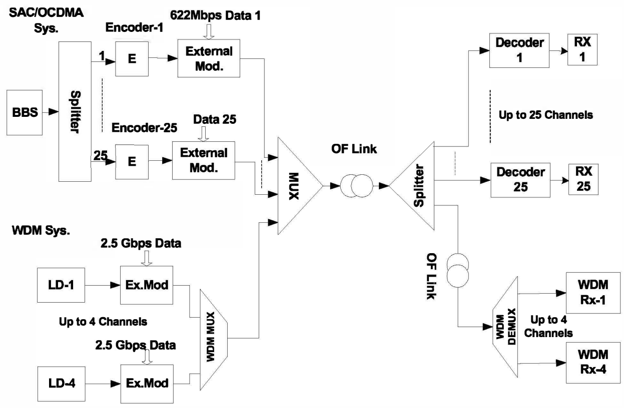


Figure 1. Block-diagram of the hybrid proposed system.

In the hybrid system, the combined signal is transmitted through the optical fiber link and is split into two parts. One part is for the receivers of SAC/OCDMA signals composed of matched decoders, and balance techniques. The other part is for the receivers of the WDM system, composed of narrowband WDM de-multiplexer, to remove the broadband signal that is coming from SAC/OCDMA source, and standard receiver parts of WDM. For the non-hybrid system, each individual system using the same previous parameters were simulated.

TABLE III

TYPICAL PARAMETERS USED FOR EXPERIMENTAL SIMULATION

Broadband source transmitted power for SAC-OCDMA	16 dBm
Laser source transmitted power for WDM	0 dBm
Data bit rates for SAC/OCDMA and WDM, respectively	622 Mbps and 2.5 Gbps
Bandwidth of encoder/decoder filters	25 GHz
Fiber link attenuation	0.2 dB/km
Fiber dispersion	17 ps/nm-km
Dispersion slope	0.075 ps/√km
External modulator extinction	30 dB
Dark current	5 nA
Thermal noise coefficient of the photodetector for SAC/OCDMA and WDM, respectively	1×10^{-22} W/Hz and 1.8×10^{-22} W/Hz
Number of SAC/OCDMA users	25
Number of WDM users	4

IV. RESULTS AND DISCUSSIONS

The bit-error rate (BER) performance of the system is evaluated prior and after hybridization. Fig. 2 shows the BER for user of SAC-OCDMA system with various received optical power for both hybrid and non-hybrid schemes. The BER for the hybrid scheme is slightly worse than that for the non-hybrid scheme because of the effects of filters. All users of SAC-OCDMA system have approximately equivalent BERs. It has been shown that the difference of values between the hybrid and non-hybrid system is very small.

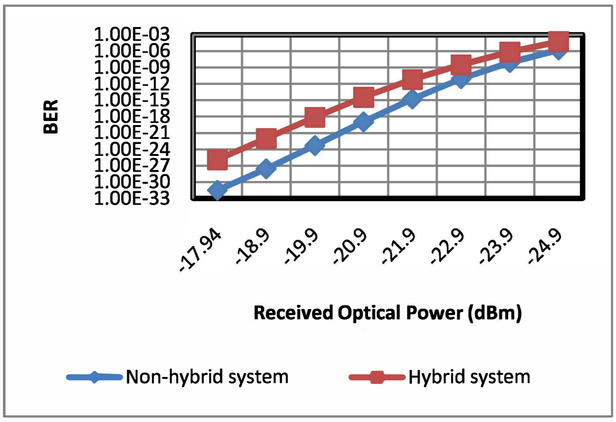
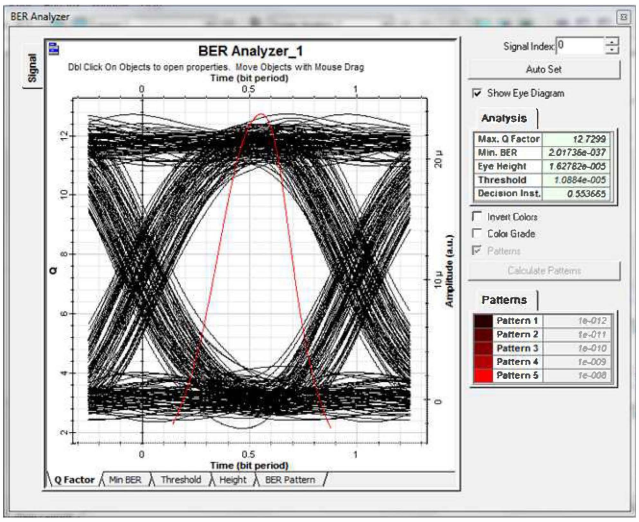
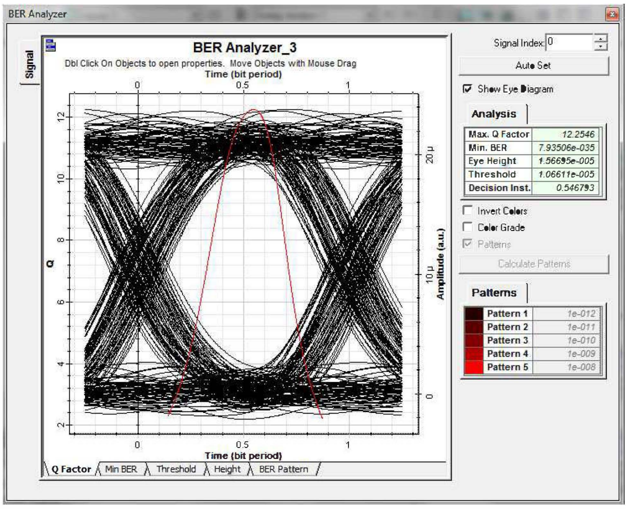


Figure 2. BER versus received optical power for SAC-OCDMA user for both hybrid and non-hybrid systems.

The performance of the WDM system under a hybrid SAC-OCDMA-WDM scheme and lone WDM scheme is shown in Fig. 3 in terms of eye diagrams. These eye diagrams are obtained when a data rate of 2.5 Gbps is transmitted and the received optical power is -19.0 dBm where Fig. 3(a) is the WDM system in the non-hybrid case and Fig. 3(b) is the WDM system in the hybrid case. The BER is found to be 2.0E-37 for setup as in Fig. 3(a) and 7.9E-35 for setup as in Fig. 3(b). It is obvious that the performance for both systems is near to each other.



(a)



(b)

Figure 3. Eye diagram for a WDM user with -19.0 dBm received optical power, (a) WDM system; (b) Hybrid SAC-OCDMA-WDM system.

V. CONCLUSION

The separation process between different techniques has been presented by developing the MQC code of SAC. The simultaneous in-band transmission of both OCDMA and WDM channels has been investigated. In addition, simulation of both hybrid and non-hybrid schemes have been performed with different design parameters. Our results indicate that although both OCDMA and WDM users use the same band of transmission, an acceptable performance can still be achieved and the difference of values between the hybrid and non-hybrid system is very small. In general, our system provides enhanced data confidentiality as compared to that of SAC/OCDMA scheme only because WDM signals perform a partial masking over encoded signals.

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