Performance of SAC-OCDMA system utilizing subcarrier multiplexing technique for High Capacity Access Network

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Abstract- In this paper, the implementation of subcarrier multiplexing technique in spectral amplitude coding (SAC) optical code division multiple access (OCDMA) network using Zero Cross Correlation code is developed and investigated. Theoretical analysis is done to determine the signal-to- noise ratio of such network and analysis of the performances in term of bit error rates are presented. Simulations are done using Optisys software version 6.0. Motivation to this research is driven to take advantage of both the low implementation cost of the SCM technology which uses the exixting RF/microwave devices; and the attractive SAC which reduce the Multiple Access Interference (MAI) in OCDMA system. The use of ZCC code can eradicate phase induced intensity noise (PIIN) which will contribute to better BER. For typical error rate of optical communication system of 10e-9, it has been observed fro theoretical results that the new hybrid SCM/OCDMA system provide better spectral efficiency and accommodate more users simultaneously with less code length and thus lower cost of implementations than the traditional OCDMA network utilizing the ZCC code. Thus this system could be one promising solution to the symmetric high capacity access network with high spectral efficiency, cost effective, good flexibility and enhanced security, which makes an attractive candidate for next generation broadband access network.

Keywords: Spectral Amplitude Coding (SAC), Zero Cross Correlation (ZCC), Subcarrier Multiplexing (SCM)

I. INTRODUCTION

Demand for more flexible bandwidth creation at lower cost is causing service providers to look at alternative and complementary technologies to the popular OCDMA systems. The fiber-to –the –home technology opt for a more reliable system with reduced cost and affordable implementation for each end users. The large gap between the user requirement and the capacity offered in the optical domain has forced the need for channel sharing mechanisms that would allow more than one user to share the channel capacity provided by each code. Subcarrier multiplexing (SCM) provides an additional dimension of multiplexing to increase the efficiency and flexibility of optical transport networks. SCM is an existing technique that has been used in radio, satellite, and cable-TV applications at much lower data rates for many years, providing low-cost, highly bandwidth-efficient physical-layer transport. Among the use of SCM technology is in the CATV technology [1, 2] and local area networks as proposed in [3, 4].

In the optical part, various techniques and schemes have been proposed to utilize fiber optic capacity in the access and backbone of the network, which includes the development of many new codes design, detection schemes and hybrid architectures in pursuit of optical channel capacity optimization. This paper introduce a hybrid multiplexing technique in the OCDMA network design which combines two step of modulation in the RF domain and optical domain to accommodate more users with reduced system cost. The idea behind the system consideration is that components and equipment of the RF/microwave domains are more matured and far less expensive than their counterparts in the optical domain.

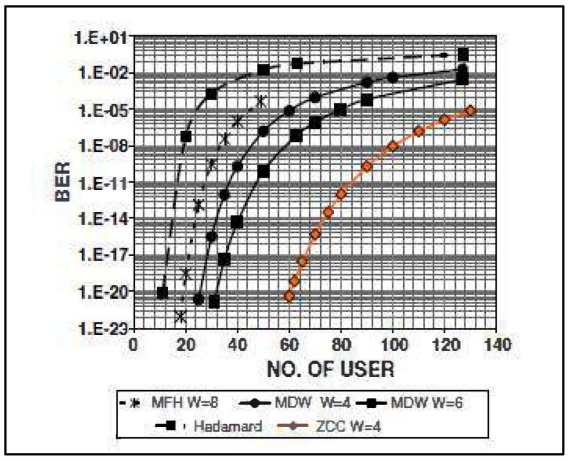

Figure 1: Comparison BER performance of ZCC code with other codes. [5]

In order to get an optimized performance of the system, a good choice of code design is an essential parameter that needs to be taken into account. A good set of codes is the one having the maximum number of codes with maximum weight and minimum length with the best

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possible autocorrelation and cross-correlation properties [6]. Many codes have been proposed for OCDMA [6–8]. This paper utilizes a new unified code construction in the Spectral Amplitude Coding (SAC) OCDMA family named Zero Cross Correlation (ZCC) code [9]. Figure 1 show that the ZCC code has been proven to provide a better performance compared to the system encoded with Hadamard and MFH codes. The detailed of ZCC construction and performances compared to other codes have been presented in [9]. This paper is divided into five sections, after introduction in Section 1; Section 2 discusses simulation set up and theoretical analysis, Section 3 gives results discussions followed by conclusion in Section 4.

II. THE SYSTEM CONFIGURATION

A. Simulative analysis

The block diagram of a basic architecture of the subcarrier multiplexed OCDMA system code utilizing direct detection technique is shown in Figure 2. The system was designed and simulated using OptiSystem Ver. 6, which is widely used for optical fiber simulations. The simulations were carried out with ZCC code with varying numbers of RF domain subcarriers as the SCM channels. The performance of the newly proposed system is also analyzed with different number of code sequences in for the optical channel. The bit rate of each channel is 155Mbps (STM-1). The transmission medium is the ITU-T G.652 standard single mode optical fiber. Each optical channel has a spectral width of 0.8nm. The attenuation and dispersion were set at 0.25dB/km and 18ps/nm-km, respectively. The nonlinear effects were activated and specified according to the typical industry values to simulate the real environment as close as possible. The performances of the subcarrier multiplexed SAC-OCDMA system were characterized by referring to the bit error rate (BER) and eye diagram for direct detection techniques. A basic diagram of direct detection technique is illustrated in Figure 3.

The transmitter consists of microwave mixers and combiner, optical external modulator (OEM) and the generated code sequences. The receiver consists of optical decoder, photodetector, splitter; bandpass filters (BPF), microwave mixers and low-pass filters (LPF). At the transmitter, data with independent unipolar digital signal is mixed by a different microwave carrier (f_i). The subcarriers are combined and optically modulated onto the code sequence (k_i) using an optical electrical modulator (OEM). Then n modulated code sequences are multiplexed together and transmitted through the optical fiber. In this hybrid system, each user is assigned a subcarrier frequency f_i, and a particular code sequence k_i, where the pair (k_i, f_i) is unique with respect to every other user. At the receiver, an optical demultiplexer is used to separate different modulated code sequences. Only the intended receiver is able to correctly demodulate the detected signal. Every receiver is matched to a pair (k_i, f_i). Via the decoder, the received signal can be decoded by using a matched code sequence and the unmatched components will be filtered out.

Then, the decoded signal is detected by the photodetector. A splitter and an electrical BPF are used to split the subcarrier multiplexed signals and reject unwanted signals, respectively. In order to recover the original transmitted data, the incoming signal is electrically mixed with a microwave frequency f_i and filtered using LPF. Therefore, for the transceiver scheme, it is important for the transmitter and receiver to generate and tune to the right code sequence and right RF subcarrier frequency to ensure the receiver recovers the desired data, while other signals are rejected. Therefore this enables the hybrid scheme to support high transmission rate with high level of security.

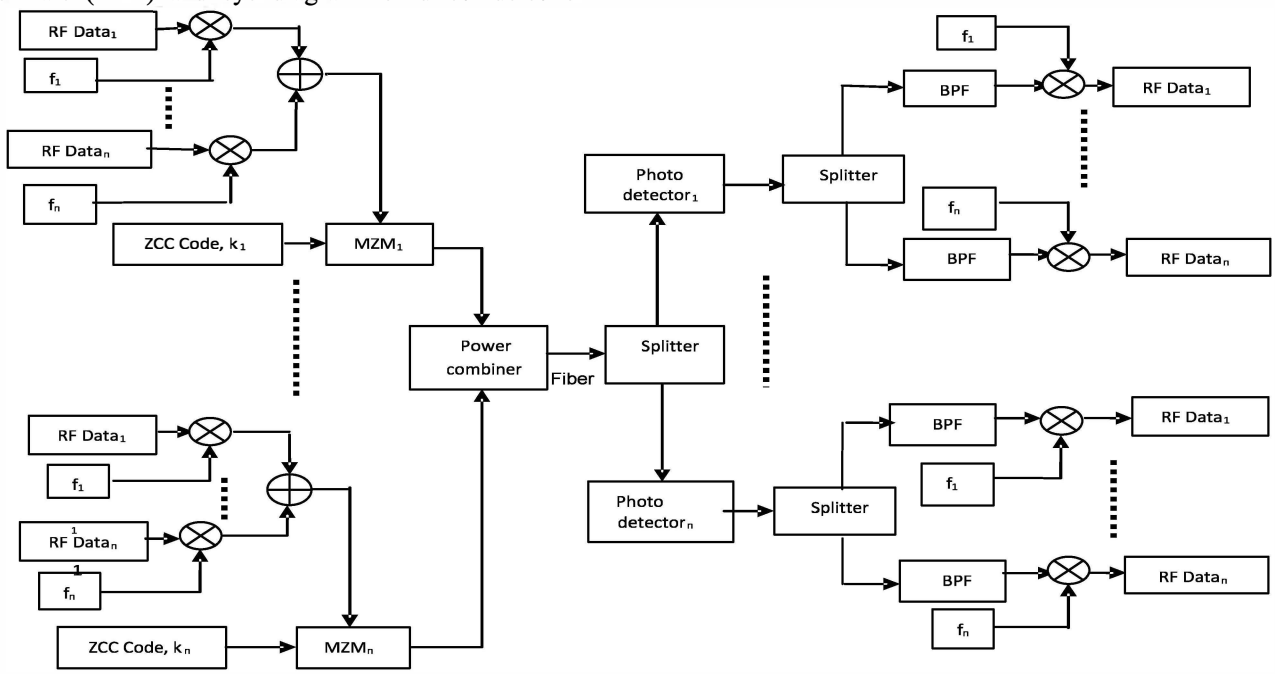


Figure 2: The block diagram of a basic architecture of the subcarrier multiplexed OCDMA

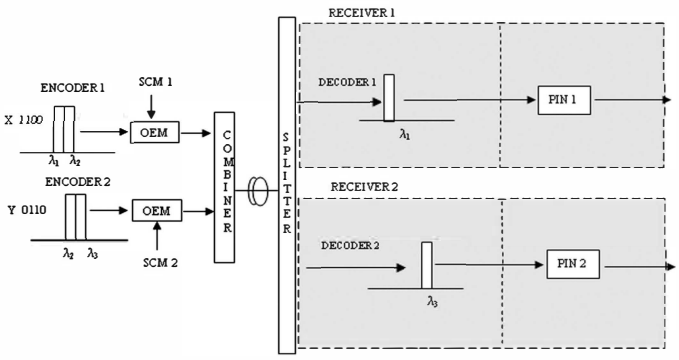


Figure 3: Direct detection technique

B. *Theoretical analysis*

In the analysis of this hybrid SCM/OCDMA system, we have considered the effect of shot noise, thermal noise and also the inter-modulation distortion of subcarrier channels on the photo detector. The PIIN is ignored due to the zero cross correlation condition and no overlapping of spectra from different users. To simplify our analysis, Gaussian approximation is used for all [10-11]. PIN photo detectors are used and the dark current is assumed to be negligible. The spacing of optical carriers is assumed to be sufficiently wide so that the effect of crosstalk from adjacent channels is negligible [12]. The subcarrier channels are equally spaced. Thus, the noise variances at the photo detector due to detection can be denoted as:

$$\langle i^2 \rangle = \langle I_{shot}^2 \rangle + \langle I_{thermal}^2 \rangle + \langle I_{IMD}^2 \rangle \qquad (1)$$

Where I_{shot} denotes the shot noise, $I_{thermal}$ is the thermal noise and I_{IMD} is the inter-modulation distortion noise due to the subcarrier channels.

The total noise here can then be expressed as

$$\langle i^2 \rangle = 2eB\frac{\Re P_{sr} W}{L} + \frac{4K_B T_n B}{R_L} + P_{SR}^2 \Re^2 m_{n,k}^6 \left[\frac{D_{111}}{32} + \frac{D_{21}}{64} \right] \qquad (2)$$

L is the ZCC code length; P_{sr} is the effective power of broadband source at receiver; $m_{n,k}$ is the modulation index of the nth subcarrier of the kth code, $\Re$ the responsivity of the photodetector, D_{111} is the three tone third order inter-modulation at $f_i + f_k - f_l$; D_{21} is the two tone third order modulation at $2f_i - f_k$ and W is the weight of the ZCC code sequence.

The SNR of the hybrid scm/ocdma using ZCC code can be written as

$$SNR = \frac{\langle I \rangle^2}{\langle i^2 \rangle} = \frac{\frac{\Re^2 P_{SR}^2 W^2}{L^2} m_{n,k}^2}{\frac{2eBP_{SR}\Re W}{L} + \frac{4K_B T_n B}{R_L} + P_{SR}^2 \Re^2 m_{n,k}^6 \left[\frac{D_{111}}{32} + \frac{D_{21}}{64} \right]} \qquad (3)$$

$$BER = \frac{1}{2} erfc\left(\sqrt{\frac{SNR}{8}} \right) \qquad (4)$$

Table 1 summarized the typical parameters used in the BER calculation in this study.

TABLE I

TYPICAL PARAMETERS USED IN THE PERFORMANCE ANALYSIS

Symbol	Parameter	Value
η	Photodetector quantum efficiency	0.6
Δv	Linewidth broadband source	3.75THz
λ_0	Operating wavelength	1550nm
B	Electrical bandwidth	311MHz
R_B	Data bit rate	622Mbps
T_n	Receiver noise temperature	300K
R_L	Receiver load resistor	1030 Ω
E	Electron charge	$1.6x10^{-19}$ C
H	Planck's constant	6.66 x 10^{-34}Js
K_B	Boltzmann's constant	1.38 x 10^{-23} J/K

III. RESULT AND DISCUSSION

C. *Theoretical Results*

The Figure 4 and Figure 5 show comparison between the number of users that can accommodate the OCDMA system and the hybrid SCM/OCDMA system with weight 4. For an acceptable BER threshold of $10e^{-9}$, we can see that both systems can accommodate more than 80 users in their system. However, it should be noted for that amount of users, SAC OCDMA system using ZCC code needs 80 code sequences which requires 80 optical channels with about 320 code lengths. For the same amount of users, an OCDMA system utilizing SCM system only needs 8 optical channels occupying about only 37 code lengths. Long code lengths are

considered disadvantageous in its implementation since either very wide band sources or very narrow filter bandwidths are required. In optical CDMA systems using Spectral Amplitude Coding, the length of the code is an important parameter. It is desirable to have smaller code length as this will required smaller bandwidth. Moreover, code with smaller length will require less number of filters at the encoder as well decoder. Thus the purposed hybrid system has shown better performances in terms of design implementation and spectral efficiency. Lower cost of implementation is also a contributing advantage as less optical components are required in the system while more electrical parts which is less expensive is more desirable in the SCM/OCDMA system.

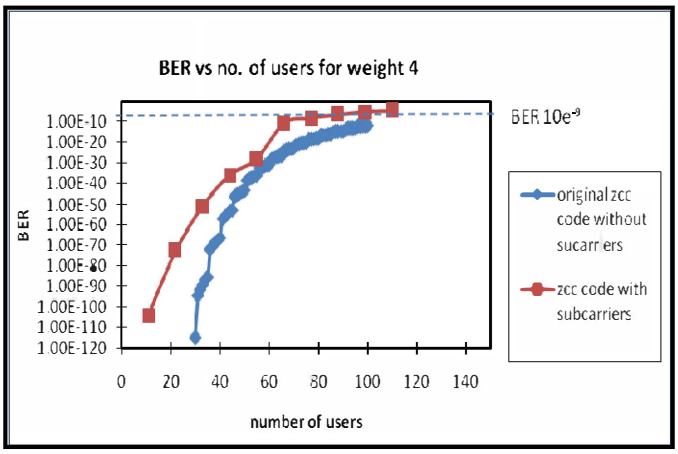


Figure 4: Comparison of BER versus number of users

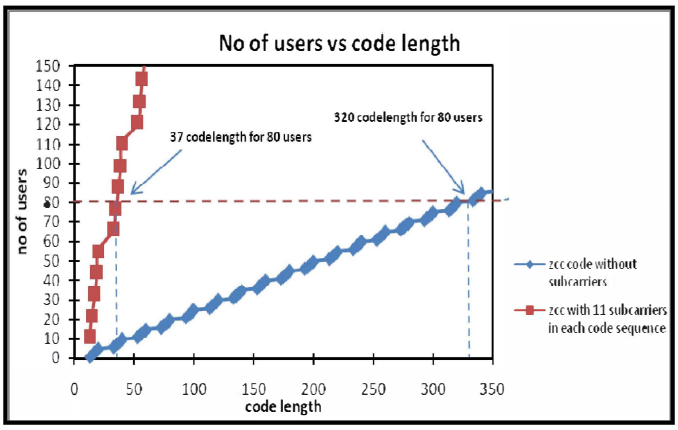


Figure 5: Comparison of number of users versus code lengths

D. *Simulation result*

The Figure 6 below shows an example of an RF spectrum of 6 subcarriers at the input of the encoder. The RF subcarriers are equally spaced and ranged between 5.1GHz to 10.1GHz. The Figure 7 shows an input of NRZ data source at 155 Mbps at the first subcarrier for the first optical channel/code sequence for a system at weight two, four optical channels utilizing ZCC code, and six RF subcarriers. Figure 8 depicts an output signal measured at its decoder end of the first subcarrier channel at the first optical channel/code. It can be observed that the signal can still be recovered with a BER of $10e^{-44}$.

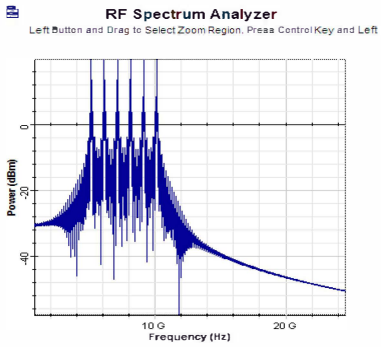


Figure 6: RF Spectrum of 6 Subcarriers

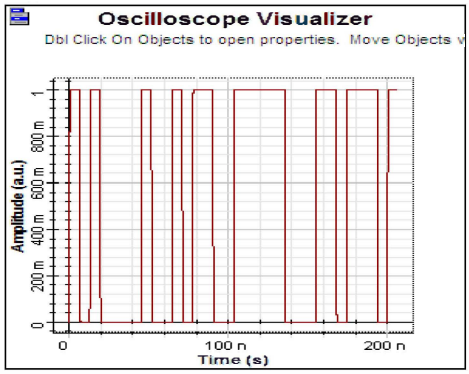


Figure 7: The Input Signal

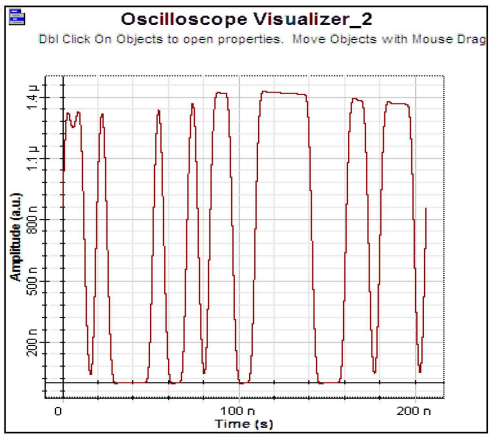
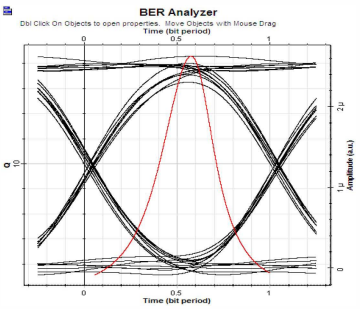


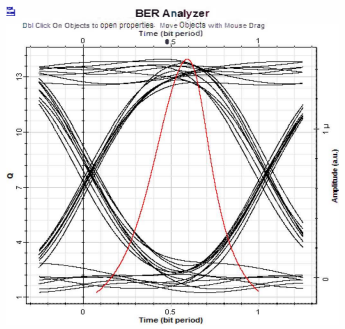
Figure 8: The Output Signal

E. Eye diagram

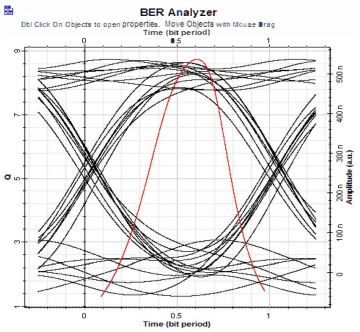
The Figure 9 shows the eye diagram of the signal measured at the output of the first subcarrier on the first code sequence of a system with weight two, transmitting four optical channels (code sequence) with each of the channel occupying (a) 4 RF subcarriers, (b) six RF subcarriers and (c) twelve subcarriers. We can observe that the eye opening becomes closer as the number of subcarriers increase. For this system, up to twelve subcarriers can be transmitted per optical channel with an acceptable BER of $10e^{-18}$.



(a)



(b)



(c)

Figure 9: Eye Diagram (a) 4 RF subcarriers BER=2.13e-77 (b) 6 RF subcarriers BER 1.1e-44, (c) 12 RF subcarriers BER =1.2e-18

IV. CONCLUSION

We demonstrate that by introducing the subcarrier multiplexing technique into the existing OCDMA system using ZCC code not only preserves the capability of suppressing MAI, but also improves the channel data rate of the system with reduced cost. Thus for low data rates applications, it is a profitable alternatives to apply subcarrier multiplexing in the OCDMA network designs and architecture to ensure bandwidth efficiency in a reduced cost and eased of implementations. Larger amount of simultaneous users can benefit from the large bandwidth, higher security and low propagation loss offered by the optical communication networks; a suitable candidate for the fiber-to-the home applications and small segment network

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