New catenated OFDM modulation scheme in zero cross correlation OCDMA at various number of user and effective power

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Abstract. This paper proposes an integration of optical Code Division Multiple Access (OCDMA) with new catenated Orthogonal Frequency Division Multiplexing (OFDM) modulation scheme. This effective combination based on Zero Cross Correlation (ZCC) code can enhanced the system capacity and increased spectral efficiency by fully utilizing the available electrical bandwidth. We investigate the performance of the proposed system for various number of user, number of weight and effective power. The performance assessment is carried out by means of the signal to noise ratio (SNR) and bit error rate (BER) for up to five catenated OFDM bands transmitted simultaneously through optical link at 622 Mbps. More specifically, mathematical expressions for SNR and BER performance are derived. The corresponding numerical results are presented and compared with traditional OCDMA-ZCC system to verified the feasibility of the proposed system. The results show that with OCDMA/catenated-OFDM based on ZCC code provides 86% more number of permissible user for SNR of 15 dB. In addition, this integration provides higher receiver sensitivity; an approximately –22.5 dBm for 20 number of user with 8 number of weight. It is also found that, to accommodate more user, the system requires higher effective power at the receiver.

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1. Introduction

OCDMA plays a vital role in the optical networks as this technology offers an attractive way of sharing massive bandwidth among users. It provides simplicity in all optical systems implementation [1], accurate time of arrival measurements, flexibility of user allocation, ability to support variable bit rate, busty traffic and security against unauthorized users [2]. A key limitation of this technology is the coding scheme. ZCC code is an invention code that can solve many issues in OCDMA including reduction of multiple access interference (MAI), higher permissible number of users, less system cost and reduce the complexity of overall system [3]

Quite recently, considerable attention has been paid to multiband or catenated OFDM technique [4][5] as a suitable solution for realizing next generation of optical access network. This technique transmits asynchronously multiple independent OFDM bands at different frequency. Besides, OFDM itself has several advantages such as high spectral efficiency due to subcarriers overlapping tolerate in the frequency domain [6]. Moreover, the effect of inter-symbol interference (ISI) and inter-carrier interference (ICI) are completely eliminated in OFDM by introducing the concepts of guard time and cyclic extension [7].

In this paper, new method of OFDM called catenated OFDM with ZCC is numerically demonstrated. The proposed system is compared with conventional OOK-ZCC to verify viability of the OCDMA system. In order to avoid interband interference issue, the guard band is introduced. The catenated OFDM signal bands are digitally generated using subband allocation technique in electrical domain. Adder has been used to concatenate more than one bands into electrical available bandwidth at different center frequency. Five bands OFDM signals and ZCC cordwords are used for mathematical analysis at different number of users, effective power and code weight. The results show the improvement in signal to noise ratio for higher number of user as compared to OOK-ZCC method.

The paper is organized as follows. The system description of the ZCC structure and, catenated OFDM and performance analysis are presented in section 2. Section 3 shows the analysis results and discussion and conclusions are presented in section 4.

2. System Description

The proposed of combine catenated OFDM-ZCC/OCDMA network is schematically shown in Fig. 1. It considers a hybrid technology with catenated data signal, ZCC encoder, external optical modulator and optical combiner at transmitter and optical passive splitter, ZCC decoder, photodetector and electrical filter at receiver. At transmitter, the modulated code sequences are multiplexed together by combiner before entering fiber optic channel. Meanwhile, at the receiver part, the code sequences are demultiplexed by splitter. An electrical filter is used to partition each of catenated OFDM band independently. The ZCC code structure and catenated OFDM signal are briefly presented in the next sub-section.

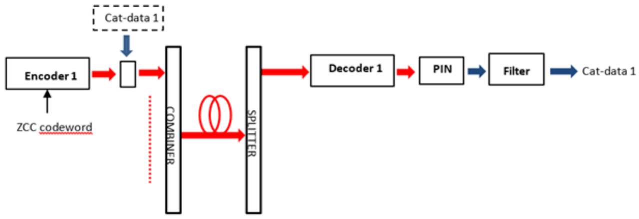

Fig. 1. Proposed network architecture

2.1 Zero Cross Correlation Code

In this section, the construction of ZCC code is explained. The matrix expression in equation 1 is the basic ZCC code

$$Z_w = \begin{bmatrix} A & B \\ C & D \end{bmatrix} \quad (1)$$

where matrix [A] is replication of matrix w-1, matrix [B] is matrix ($w\times 2w$), the diagonal matrix of ones with alternate of zero matrix ($w\times 1$) in between, matrix [C] consists of ($1\times w(w-1)$) matrix of zero and matrix [D] is ($1\times[0\ \ 1]$) which consist of matrix replication for w times [3]. The general equation for basic number of user K_B, weight w and code length L is given by:

$$K_B = w + 1 \quad (2)$$

and

$$L = w(w+1) \quad (3)$$

From Equation 3, the relation between the code weight and the code length is proportional to each other. In order to adapt more users in the networks, the basic code, Z_w is transform into the mapping code, Z_m using mapping algorithm as shown in Equation 4.

$$Z_m = \begin{bmatrix} 0 & Z_{m-1} \\ Z_{m-1} & 0 \end{bmatrix} \tag{4}$$

Equation 5 and 6 are used to relate the number of user K_m, mapped code length L_m and mapping process m.

$$K_m = 2^m (K_B) \tag{5}$$

and

$$L_m = 2^m (L) \tag{6}$$

The structure of ZCC code explained in details in [8].

2.2 Catenated OFDM

The serial input data stream in QAM modulation format is shifted into parallel format. The parallel data is then mapped and transmitted by assigning one symbol for each carrier. An inverse Fourier transform is performed into mapped spectrum to find the corresponding time waveform.[9] To make sure any multipath interference not affected the orthogonality of the data channels, the cyclic prefix (guard period) can be added at the beginning of each symbol [10]. Finally, the parallel data with inphase and quadrature elements is shifted back into the serial symbols which is called OFDM signals.

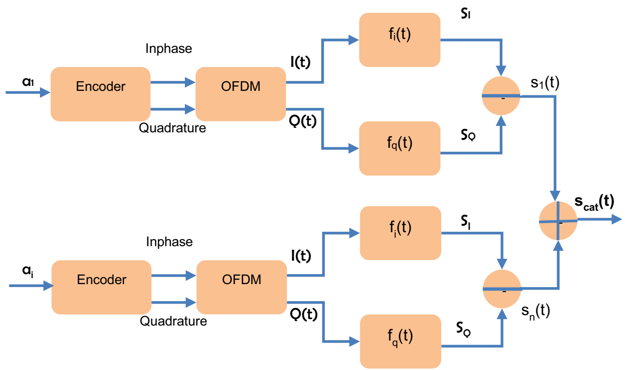

Fig. 2 Schematic design of catenated OFDM

The summed of IFFT modulated baseband OFDM signal is then called catenated OFDM signals [11]. This signal can be written as

$$s(t)_{cat} = \sum_{k=1}^{N-1} X_n[k].e^{(j2\pi f_k t)} \sum_{n=0}^{N_{sb}} m_n.e^{j2\pi n f_m t} \tag{7}$$

where m_n is the modulation index of the nth subband, while n is number of band at n=1, ..., N_{sb} and f_m is the sub-band frequency or also known as center frequency of first band. Here, we assume that the modulation index is identical for all the sub-bands. It calculated using $f_n = nf_m$. $X_n[k]$ denotes the OFDM information symbol and f_k is frequency of kth subcarrier. At the receiver, the detected photocurrent is express as

$$I_r = R.P_r.\sum_{k=1}^{N-1} X_n[k].e^{(j2\pi f_k t)}.\sum_{n=0}^{N_{sb}} m_n.e^{j2\pi n f_m t \, j2\pi n f_m t} \tag{8}$$

where R is the responsivity (R = 0.72) of the photodetector and P_r is the incident light power at the receiver.

2.3 Performance Analysis

The signal to noise ratio (SNR) is given by

$$SNR = \frac{I_r^2}{\sigma_{Total}^2} \tag{9}$$

For the noise variances, we only consider shot noise and thermal noise as written in equation (10).

$$\sigma_{Total}^2 = \sigma_{shot}^2 + \sigma_{thermal}^2 \tag{10}$$

$$\sigma_{Total}^2 = 2eI_r B + \frac{4kTB}{R_L} \tag{11}$$

where e is the electron charge which equal to $1.6x10^{-19} C$, I_r is the signal currents in the photodetector, R_L is load resistance $R_L = 1030\Omega$, T is an absolute temperature (T = *300 K)*, k is the Boltzmann's constant ($k = 1.38x10^{-23} J/K$), and B is the receiver bandwidth (311 MHz). The signal to noise ratio (SNR) is given by

$$SNR = \frac{(R.\frac{P_r w}{L}.\sum_{k=0}^{N_{sc}-1} x_k e^{j2\pi f_k t}.\sum_{n=1}^{N_{sb}} m_n e^{j2\pi n f_m t})^2}{2e(R.\frac{P_r w}{L})B + \frac{4kTB}{R_L}} \tag{12}$$

Thus, the bit error rate (BER) with 16-QAM can be obtained from SNR as below [12]:

$$BER = \frac{\sqrt{16}-1}{\sqrt{16}\log_2\sqrt{16}} erfc\sqrt{\frac{3\log_2 16}{2(15)} SNR} \qquad (13)$$

3. Result and Discussion

In this section, we compare the system performance obtained from theoretical results at 622 Mbps bit rate of the proposed technique with 5 bands to the conventional ZCC OCDMA system. Fig. 3 illustrates the variation of signal to noise ratio according to number of users. The code weight is 4 and effective power is fixed to –10dBm. It is clearly seen that the system with catenated OFDM performs better than the conventional OOK-ZCC system. At SNR of 15 dB, the proposed design has accommodated up to 210 number of user while for the case of OOK-ZCC only 30 number of user is permitted. This improves the SNR performance approximately to 86%. The performance enhancement for catenated OFDM-ZCC design is due to many of OFDM bands transmitted simultaneously for each optical channel, therefore improved the number of user. On the other hand, as many subcarriers used for each band, the signal power increased, thus signal to noise ratio increased. From this result, it is noting that the proposed method is an effective way to improve the capacity of optical channel. Moreover, it has higher spectral efficiency by fully utilizing the available electrical bandwidth for transmitting more bands at same channel.

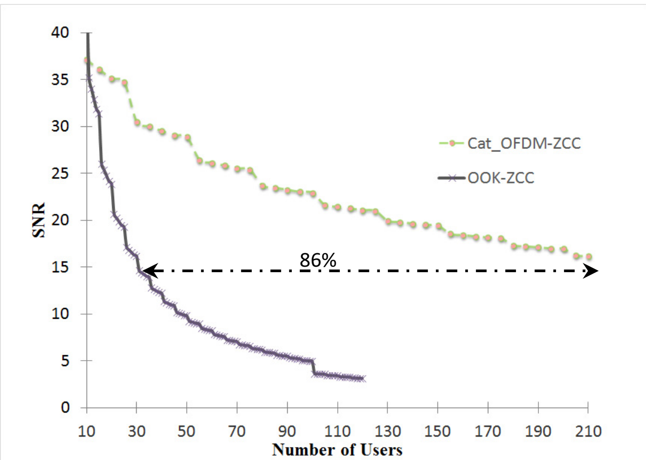

Fig. 3. SNR of catenated OFDM-ZCC and conventional OOK-ZCC according to number of user.

Fig. 4 shows the BER versus received optical power for the catenated OFDM with five bands at code weight, w of 2, 4, 6 and 8, and based on fixed number of user of 20. The acceptable BER limit ($10E^{-9}$) for w=2 reads –16.3 dBm whereas for w= 8 it is −22.5 dBm. This implies a gap of 6.2 dB for the 5 bands catenated OFDM-ZCC OCDMA. The higher the number of weight, the more effective power will be transmitted and less power required at photodetector. The BER declines as the effective power is increased due to the effect of an attenuation and lower magnitude of noise signals.

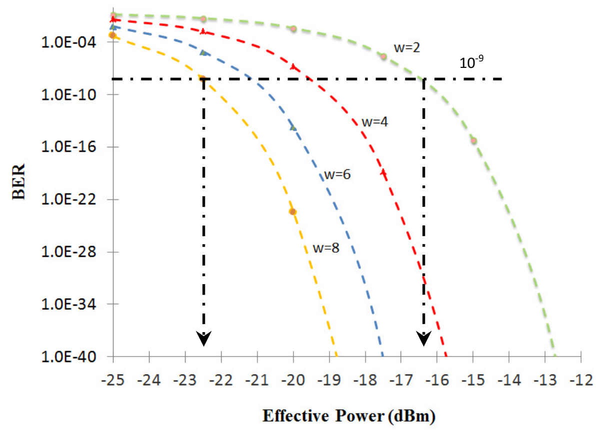

Fig. 4. BER performance with various number of weight according to effective power

In Fig. 5, the BER performance for different number of user is investigated. It is observed that at low effective power, the system with smaller number of user cause lower BER. Besides, as the number of user increases, the code length is increase correspondingly. From the graph, it shows that the effective power is -20 dBm for user = 15, -17 dBm for user = 30, -16 dBm for user = 45 and -14.7 dBm for user = 60. It has been found that, to accommodate more user, the system requires higher effective power at the receiver.

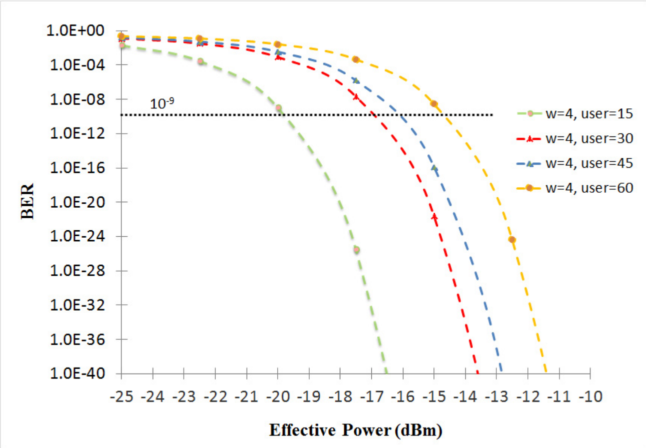

Fig. 5. BER performance according to effective power with different number of user

Conclusion

The effect of multiband OFDM modulation technique leading to a significant increase in total number of users in ZCC optical code division multiple access network. We achieve the high permissible number of user = 210 with five catenated OFDM bands. The improvement is approximately 86% compared to the traditional ZCC system. The receiver sensitivity improves by 6.2 dB at $10E^{-9}$ BER threshold for w = 8 as compared to w = 2 when the number of user is 20. Hence, when varies the number of users with constant code weight, the BER level also varies.

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