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Investigation of Coherent Multicarrier Code Division Multiple Access for Optical Access Networks

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Abstract

Orthogonal frequency division multiplexing (OFDM) has proved to be a promising technique to increase the reach and bit rate both in long-haul communications and in passive optical networks. This paper, for the first time, investigates the use of OFDM combined with electrical CDMA in presence of coherent detection as a multiple access scheme. The proposed multicarrier-CDMA system is simulated synchronously using Walsh-Hadamard codes and its performance is evaluated in terms of bit-error-rate and spectral efficiency. It is shown that the system error slightly increases for greater number of users due to multiple-access interference. BER can be reduced using longer code words for the same number of users at the expense of losing spectral efficiency.

Keywords: *Fiber Optic Communication; Optical MC-CDMA; Coherent Detection; Optical Access Network; OptiSystem*

1. Introduction

The increase in internet traffic has led to increase in demands for optical access networks with higher bit rates that can be used in longer distances. Therefore, exploitation of advance techniques is necessary for future passive optical networks (PONs). Optical orthogonal frequency division multiplexing is a promising technique that has been the subject of interest in recent years. Not only this modulation type benefits from good spectral efficiency due to the overlap of the frequency sub-channels, but it also has the ability to fight chromatic dispersion (CD) in fiber optic channel, improving system performance [1]. OFDM has been used in optical communications either with direct detection [2] or with coherent detection [3] and has shown better receiver sensitivity, spectral efficiency and robustness against chromatic dispersion when used with coherent scheme, but it has a more complex transceiver design [4].

In passive optical networks, OFDM has been studied either as an access scheme (OFDMA) where each subcarrier is subscribed to a certain user, or simply as a modulation where the subcarriers are all dedicated to a single user [5]. Sometimes it has been combined with access schemes such as wavelength division multiplexing (WDM) to meet the requirements of future optical access networks [6-8]. In [9] the use of OFDM in combination with electrical code division multiple access (CDMA) scheme was proposed in fiber optic communications for the first time. The proposed MC-CDMA scheme was implemented in presence of direct detection scheme and was used to synchronously transmit data with an overall bit rate of 15 Gbps over a 70 km single mode fiber (SMF) using Walsh-Hadamard codes. In [10] the performance of the aforementioned scheme was evaluated for asynchronous transmission of data using Gold sequence. In this paper, the use of MC-CDMA in presence of coherent optical receivers is investigated for the first time as a hybrid optical access scheme and is analyzed through spectral efficiency and BER for different number of users in different transmission distances and different launch powers.

In section 2, some background information about OFDM and MC-CDMA is provided. Section 3 describes the designed system and the relating simulations parameters. The simulations have been done by co-simulation of OptiSystem 13 software with Matlab. The results of these simulations and their analysis are presented in section 4. Finally, section 5 is dedicated to the conclusion and possible future works.

2. Technical Background

In this section, optical OFDM and multicarrier-CDMA structures are briefly introduced.

2.1 Orthogonal Frequency Division Multiplexing

In OFDM, the spectrum is divided into overlapping subcarriers. Each subcarrier is transmitted with a slower rate in parallel with other subcarriers. Therefore, OFDM has the ability to reduce the effect of chromatic dispersion in optical fiber communications by extending subcarriers in time domain.

Figure 1 shows the block diagram of OFDM modulator. The input data is the output of an M-ary modulator. Serial input data is converted into parallel by serial to parallel converter. Then IFFT is applied to the parallel data and cyclic prefix is added to each stream. Finally, the digital data is converted to analog using an interpolation technique and the parallel data is converted back to serial. In demodulator, reverse operations are applied. Schematic of OFDM demodulator is shown in figure 2.

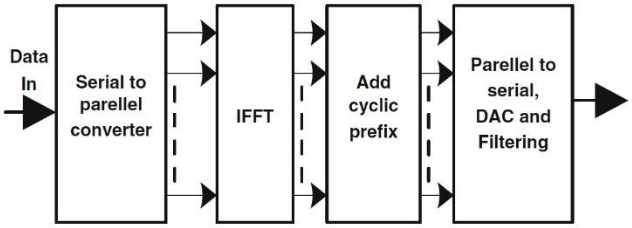

Fig. 1 OFDM modulator [11].

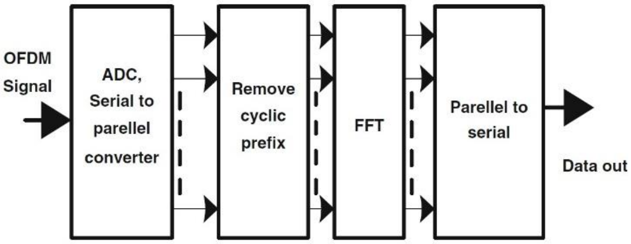

Fig. 2 OFDM demodulator [11]

2.2 Coherent Optical OFDM

A generic coherent optical OFDM (CO-OFDM) system is shown in figure 3. The system can be divided into five parts [4]: (1) electrical baseband OFDM transmitter, (2) electrical to optical up-converter consisting of a pair of Mach-Zehnder modulators (MZM) and a continuous-wave (CW) laser, (3) optical channel, (4) optical to electrical down-converter by a pair of balanced photodetectors and a continuous-wave laser, and (5) electrical baseband OFDM receiver.

Due to differential structure of balanced photodetectors, the common mode noise is reduced and as a result, CO-OFDM has a better sensitivity than direct detection optical OFDM (DDO-OFDM) [4]. Moreover, with appropriate settings CO-OFDM benefits from linear transmission of data between electrical and optical domains which makes OFDM perform better in alleviating channel dispersion [3]. However, DDO-OFDM is less susceptible to phase noise. Besides, it has a lower complexity and therefore, it has been investigated extensively in PONs [12].

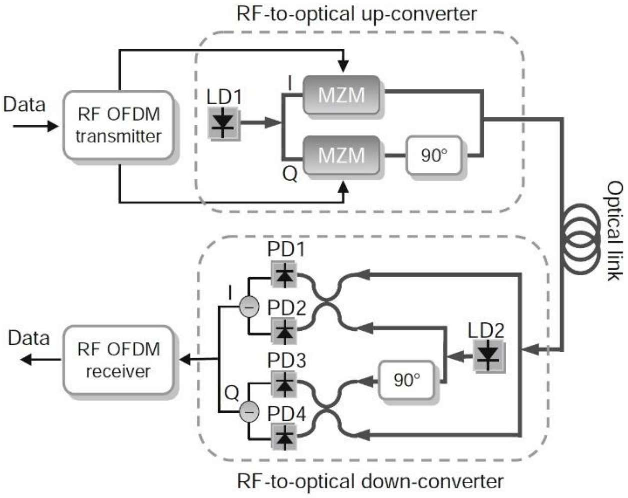

Fig. 3 A coherent optical OFDM system [4].

2.3 Multicarrier-CDMA

Multicarrier-CDMA (MC-CDMA) access scheme is a combination of CDMA and OFDM in which a CDMA signature code is assigned to each OFDM user. As depicted is figure 4, the signature code is multiplied by each of the input symbols at the transmitter before the IFFT block. At the receiver side, the signature code is multiplied by the signal to regenerate the input symbols after the FFT operation.

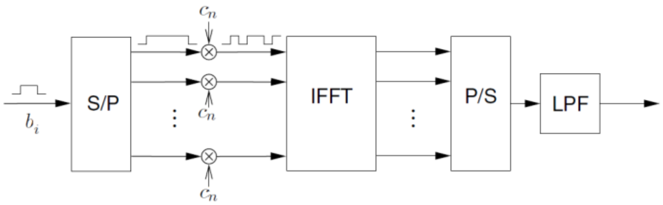

Fig. 4 Schematic of a MC-CDMA transmitter [13].

3. Design Parameters

Our simulations have been performed by co-simulation of OptiSystem 13 and Matlab, where Matlab is used only for simulation of MC-CDMA modulator and demodulator blocks. Figure 4 shows the block diagram of the simulation MC-CDMA system with N users. Each of the transceivers has a structure as shown in figures 3. Walsh-Hadamard codes are employed as signature codes. For each simulation, the length of the code equals the number of users. For each user, a 4-QAM coder is used before MC-CDMA modulator with 512 subcarriers and 1024 FFT points with no cyclic prefix. At the output of the MC-CDMA modulator, the in-phase and quadrature signals are converted into an optical signal and up-converted by a pair of Lithium Niobate Mach-Zehnder modulators and a continuous-wave laser of 193.05 THz with a linewidth of 100 kHz. Here all users have the same laser carrier frequency. Then the signals from all users are combined by an optical power combiner and sent into the channel.

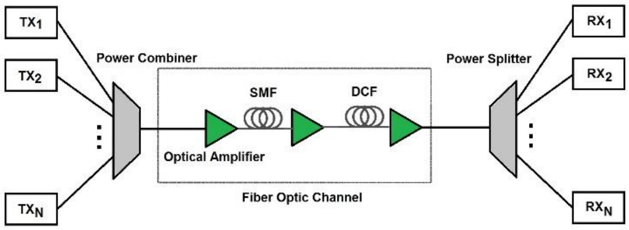

Fig. 5 Block diagram of the MC-CDMA system.

The transmitted signal passes through the channel shown in figure 5. The first optical amplifier acts as a power booster with a gain of 15 dB, while the other two are used for compensation of fiber power loss. The amplifiers have a noise figure of 4 dB. The parameters of optical fibers are shown in table 1.

Table 1: Characteristics of optical fibers in simulated by OptiSystem

Parameter	SMF	DCF
Dispersion (ps/nm/km)	16	-80
Dispersion Slope (ps/nm^2/km)	0.08	-0.4
Attenuation (dB/km)	0.2	0.4
Effective Area (um^2)	80	30
Nonlinear Index of Refraction (m^2/W)	2.6e-20	2.6e-20
Differential Group Delay (ps/km)	0.2	0.2

At the receiver, the signal is split by a power splitter, the output of which is converted to electrical form by a pair of balanced photo-detectors. A CW laser with the same carrier frequency and linewidth as the transmitter one is used as the local oscillator. Each of the PIN photo-detectors has a responsivity of 1 A/W, thermal noise of 100e-24 and dark current of 10 nA. The resulting electrical signal passes through the MC-CDMA demodulator followed by a 4-QAM decoder to regenerate the binary data for each user.

4. Results and Discussion

In figure 6, a comparison has been made between BER performances of MC-CDMA systems with various number of users versus the launch power per user. The systems are simulated with a bit rate of 50 Gbps for each user and the channel length is 240 km. It can be seen that the performance of MC-CDMA deteriorates as the number of users is increased. Figure 7 shows the changes in BER for both systems with various number of users through different values of optical fiber channel length. The system has a bit rate of 50 Gbps for each user and a launch power of -20dBm per user. Figures 6 and 7 are quite consistent with each other regarding the relation between BER performance and the number of users. The performance degradation of the system in each of these cases can be attributed to the presence of multiple-access interference (MAI) in CDMA scheme, which has an overwhelming effect especially for greater number of users.

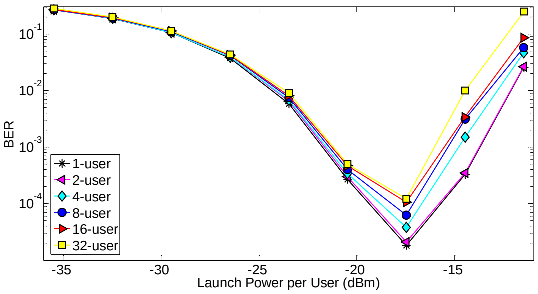

Fig. 6 BER vs launch power per user for MC-CDMA with various number of users.

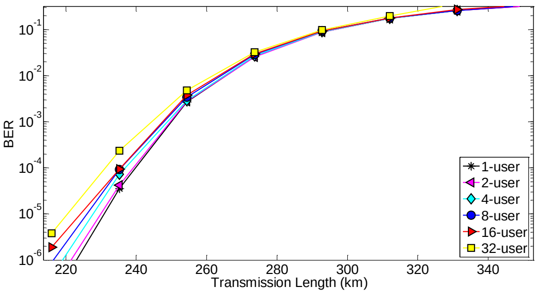

Fig. 7 BER vs channel length for MC-CDMA with various number of users.

Figure 8 shows BER versus channel length for an 8-user MC-CDMA system with various lengths of code words while the simulation settings are the same as those mentioned for figure 7. It can be seen that the system performance improves as longer code words are adopted. However, the increase in the length of the codes causes the signal spectrum to spread more widely and consequently, as depicted in figure 9, it results in a reduction of the system spectrum efficiency.

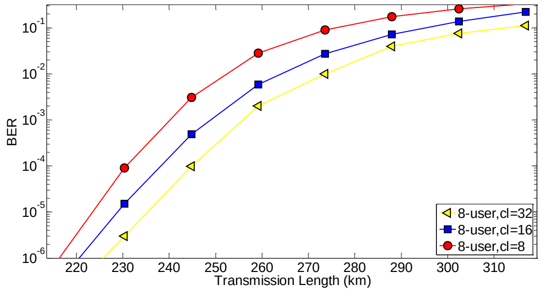

Fig. 8 BER vs channel length for 8-user MC-CDMA with different code lengths.

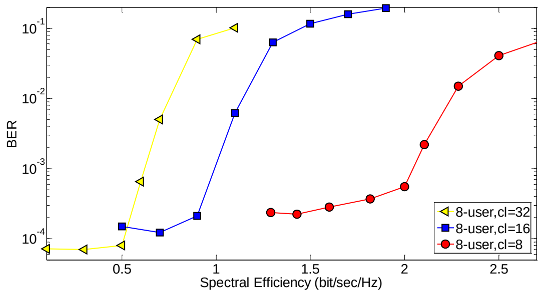

Fig. 9 BER vs spectral efficiency for 8-user MC-CDMA with different code lengths.

5. Conclusion

In this work, we investigated the use of coherent MC-CDMA in optical fiber communications as an access scheme for the first time. It was shown that the performance of the proposed scheme in terms of BER declines as the number of users increases, which is mainly due to the presence of MAI. Then the performance of the MC-CDMA system was evaluated for the code words with various lengths being used as the number of users was constant. Even though increasing the code length led to the system BER mitigation, the spectral efficiency was significantly degraded. Therefore, a compromise can be made between the BER and spectral efficiency of the proposed system using different code lengths. For future work, coherent MC-CDMA can be analyzed in PON structure where asynchronous upstream data transmission is an issue and therefore, non-orthogonal codes such as M-sequence should be used as signature codes. It is noted that performance evaluation of asynchronous MC-CDMA for direct detection systems has been reported by [10].

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