Experimental Demonstration of Multicarrier-CDMA for Passive Optical Networks

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Abstract

Optical multicarrier-CDMA is experimentally demonstrated for the first time. The system supports up to 256 users at a total bit rate of 15-Gb/s with almost no penalty after 70-Km transmission.

Introduction

Orthogonal frequency division multiplexing (OFDM) alleviates the need for in-line compensation in optical links since the channel's bandwidth is divided into several narrower sub-channels and high speed signals are transmitted over multiple lower rate subcarriers, enabling a very simple equalization in electrical domain [1,2]. Dividing the spectrum into several narrow sub-channels is based on fast Fourier transform (FFT) algorithms which can be simply implemented by commercially available FFT chips. Despite OFDM is new in optical communications, results show that it can be a promising transmission technique [2].

In [3], orthogonal frequency multiple access (OFDMA) was introduced as a technique for sharing the channel in passive optical networks (PONs) that has the advantages of OFDM. This scheme is a subcarrier multiplexing (SCM) technique in which depending on the required bandwidth of an optical network unit (ONU), a number of subacrriers is assigned to that ONU. The disadvantage of this method is that the bandwidth of the channel is not effectively consumed when some ONUs are not operating in the network because each ONU has a predetermined frequency range that other ONUs are unable to use.

In code division multiple access (CDMA) networks, multiple users transmit data at the same time and over the same spectrum in a shared medium. This feature allows users to efficiently utilize the available bandwidth since unlike TDMA or WDM, a time slot or a frequency range is not allocated to a certain user that can potentially be inactive from time to time. Moreover, flexibility, increased security, and plug-and-play functionality have made CDMA a promising candidate for PONs [4].

Multicarrier-CDMA (MC-CDMA) is the combination of CDMA and OFDM, thus taking the advantages of both techniques [5]. This multiple access method has been studied and demonstrated in wireline and wireless radio communications and in this paper for the first time we demonstrate MC-CDMA in optical fibers.

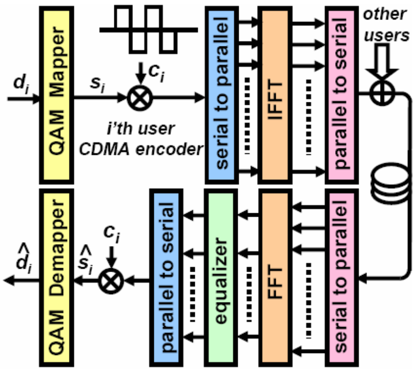

Figure 1: Block diagram of MC-CDMA, upper part is the transmitter and lower part is the receiver

Concept of Multicarrier-CDMA

The general concept of MC-CDMA for one user is presented in Fig. 1. At the transmitter, data of user *i*, d_I, is mapped to QAM symbols, s_I. Then the user's unique signature code, c_I, encodes the symbols into chip sequences. The serial to parallel converter receives a chip sequence of length *N* and copies them to its output and then the Inverse FFT (IFFT) block performs inverse Fourier transform, generating *N* equally spaced subcarriers at its output. Finally, the parallel to serial converter places the subcarriers side by side in time domain.

At the receiver, the reverse processes plus equalization are performed on the signal. The equalizer is a memoryless block that multiplies each input (subcarrier) by a complex number. This number is the inverse of the channel response at the subcarrier frequency and it can be obtained using a preamble sequence and channel estimation. This simple equalization is inherent of OFDM and it is based on the fact that subcarriers bandwidth is very narrow [1]. Finally, each user correlates the output of the equalizer with its own signature code, and since each pair of codes has a low cross-correlation, any user is able to recover its symbols from other users. In this paper we have used Walsh-Hadamard (WH) codes that are completely orthogonal to each other in synchronous systems; therefore, this demonstration is suitable for downlink

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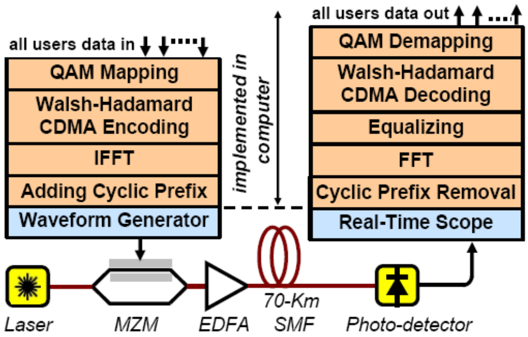

Figure 2: Experimental setup of MC-CDMA

since the central network unit is capable of synchronously transmitting data to the users in the network. However, using other codes such as m-sequence enables implementation of MC-CDMA for downlink, uplink, and peer to peer communication.

Experimental Setup

The experimental setup is shown in Fig. 2. The input data for all the users is a random sequence of ones and zeros generated in computer. Then QAM mapping, CDMA encoding, IFFT, and adding the cyclic prefix are all done in MATLAB and the output of all these processes is loaded to an arbitrary waveform generator (AWG). The cyclic prefix is necessary for synchronization of the receiver. The waveform generator modulates a CW laser through a single arm Mach-zehnder modulator (MZM) which is biased at the quadrature point. Then the directly modulated signal is amplified by an Erbium doped fiber amplifier (EDFA) and sent through a 70-Km of single mode fiber (SMF). The transmission length ensures the maximum coverage in a PON. At the receiver, a photo-detector converts the optical signal to the electrical signal which is sampled by a real-time oscilloscope. The output of the scope is connected to a computer and FFT, cyclic prefix removing, equalization, CDMA decoding, QAM demapping, and bit error rate (BER) measurements are all implemented in MATLAB.

The signal bandwidth is fixed at ~2.5GHz. This relaxes the bandwidth requirement for the laser and receiver in a PON [6]. Therefore, the frequency spacing of subcarriers is equal to 2.5/N (GHz) and thus the symbol time T_s = N/2.5 (nSec), where N is the number of subcarriers. The bit rate per user depends on the constellation size of the QAM symbols. If QAM size is M, the bit rate will be equal to $R_b = (\text{Log}_2 M)/T_s = (2.5\text{Log}_2 M)/N$ (Gbits/sec). For the QAM mapping we have used Gray coding to minimize the BER. The maximum number of users (the number of code words) that a WH set can support is equal to the code length, L, so the global bit rate of the whole network is equal to $R = LR_b = (2.5L/N)\text{Log}_2 M$ (Gbits/sec).

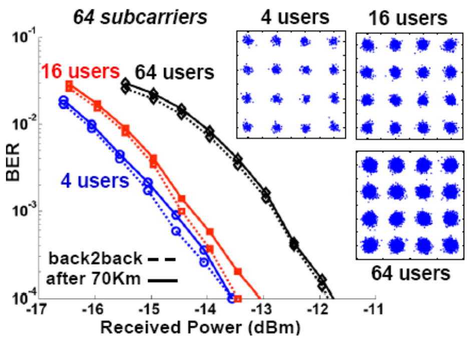

Figure 3: BER curves of different number of active users and corresponding equalized constellations

Results and Discussion

The BER curves are obtained by averaging over the BER of all active users. Figure 3 shows the BER of three different number of active users while N=L=64 and the symbols are 16-QAM. It can be seen there is almost no penalty after 70-Km SMF compared to the back to back case. As the number of users is increased from 4 to 64, less than a 2dB penalty is observed.

In Fig. 4, BER curves for different constellation sizes are presented while the number of subcarriers is N=256 and the code length is L=256. As the constellation size is increased, due to a higher spectral efficiency, the bit rate is also increased, but on the other hand the performance is more degraded. Choosing appropriate values for M, L, and N enables accomplishing the required specifications of different users in the network. For example, based on different required bit rates, different users of the network can employ different QAM mapping. This flexibility is another advantage of MC-CDMA.

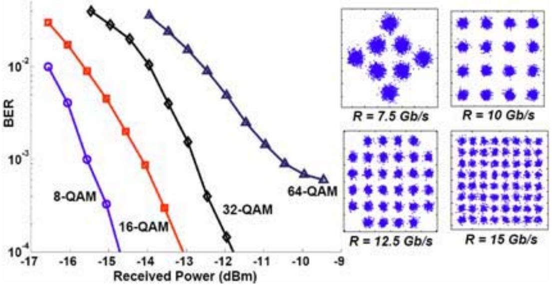

Figure 4: BER curves and equalized constellations for different QAM mappings

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