Analysis of Extended OFDM-CDMA System

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Abstract— **This paper proposes a hybrid extended OFDM-CDMA modulation technique which can be used principally in mobile communication. It supports the advantages of both of the OFDM and the CDMA systems. The detailed specification is set down. The examination is partitioned into two divisions that are the transmitter and the receiver. The channel which has been used by the simulation is set to linear time-varying filter channel. The performance of these system has been tested by extensive simulations and compared with the OFDM and the CDMA. In very noisy multipath channel the proposed hybrid scheme works efficiently and gives good Bit Error Rate value.**

I. Introduction

Orthogonal Frequency Division Multiplexing (OFDM) is a special form of multi-carrier modulation. It was designed in the 1960's and 1970's in which multiple user symbols are transmitted in parallel using different subcarriers [1]. These subcarriers have overlapping spectra, but their signal waveforms are specifically chosen to be orthogonal [2]. An OFDM system transmits symbols, which have longer time duration with the help of a cyclic prefix than the length of the impulse response of the channel [3]. In this case we avoid Intersymbol Interference (ISI) which is the most important effect of multipath delay spread. Another disadvantage is the loss of the subchannel orthogonality when the channel impulse response changes during one OFDM block [3]. The OFDM modulation technique is very efficient in indoor wireless communication.

Most third generation mobile phone systems are proposing to use Code Division Multiple Access (CDMA) as their modulation technique [2]. It is a spread spectrum technique for outdoor environment communication that uses neither frequency channels nor time slots. In CDMA, the narrow band message is multiplied by a large bandwidth signal which is a pseudo random noise code (PN code). All subscribers in a CDMA system use the same frequency band and transmit simultaneosly. It has three kinds: DS-SS (Direct-Sequence Spread Spectrum), SFH (Slow Frequency-Hopped spread spectrum) and FFH (Fast Frequency-Hopped spread spectrum) [4].

Several proposals have been made to combine the use of OFDM and CDMA for wireless multiple access with the desirable properties of them and without the disadvantages of them [5], [6]. With OFDM-CDMA, the data symbols are transmitted over many modulated subcarriers. OFDM-CDMA systems employ the OFDM technique resolve the frequency selectivity in multipath fading channels and have good spectral properties [1]. The Multi-Carrier Code Division Multiple Access (MC-CDMA) is a hybrid OFDM-CDMA modulation technique which uses orthogonal spreading code sequences (Walsh-Hadamard) in the frequency domain [5]. Thus we get a form of frequency diversity. This codes differentiate the users from one another. In this case the MC-CDMA can handle N simultaneous users with good BER. The signals can also be detected with fairly simple receiver structures, using an FFT and a variable gain diversity combiner, in which the gain of each branch is controlled only by the channel attenuation at that subcarrier. The receiver may "Rake" together energy dispersed in the frequency domain [6].

Although MC-CDMA resembles the signal structure for OFDM when the subcarriers are spaced as close as theoretically possible, the manner in which the subcarriers are utilized is very different. The same data bit is transmitted over all subcarriers [1].

Another form of combined OFDM-CDMA involves feeding different spread input symbols to the subcarriers [6]. The spreading codes for a given user may be the same as in our work, or could be different. No integral relationship between the processing gain and the number of subcarriers is required. It keeps all of the advantages of the MC-CDMA system, but it drew in subcarriers. It would not be transmitted each bit on every subcarriers, but on some channels, which are chosen after the channel assignment. Thus in cases of flat fading we do not lose all of the same bits, only some of them. Each subcarrier is applied by more user. These users are separated by orthogonal codes (Walsh-Hadamard or Gold codes). In this case one spreading code is employed on all subcarriers of each user, where chips are long in time duration, but narrow in bandwidth. We apply the spreading in the time domain [6].

The outline of this paper is as follows. In the Section II we describe the transmitter, the channel and the receiver model detailed. Then we submit in section III the simulation results we made. The disassembly of the channels section gives a possible solution to increase the baud rate. At all we draw a conclusion about the efficiency of these extended OFDM-CDMA system in Section IV.

II. OFDM-CDMA system model

Our suggested modulation technique is a hybrid combination of CDMA spread spectrum and OFDM modulation techniques. The detailed model is described in the following sections.

A. The transmitter model

The basic equivalent complex-valued extended OFDM-CDMA transmitter model is shown in Figure 1. A digital data source emits vectors $\underline{\mathbf{x}}[k]$, where k indicates the discrete time. The source and channel coding are included in $\underline{\mathbf{x}}[k]$, but not considered here. The serial data stream is mapped into data symbols with a symbol rate of $1/T$, employing a general phase and amplitude modulation scheme, and the resulting symbol stream is demultiplexed into a vector of N data symbols x_1 to x_N. Each of the resulting bit is multiplied with a spreading code sequence, which is Walsh-Hadamard code ($\underline{\mathbf{C}}_b$), where index b refers to the b^{th} column vector of with size of $N \times 1$. These bits are modulated onto N subcarriers by an inverse discrete Fourier transformation (IDFT), which can be described as

$$F_{vp}^{-1} = \frac{1}{\sqrt{N}} e^{j\frac{2\pi}{N}(v-1)(p-1)}, \quad (1)$$

where $j = \sqrt{-1}$, $v = 1, \ldots, N$ and $p = 1, \ldots, N \cdot N$. The parallel data symbol rate is $1/(N \cdot PG) \cdot T$, i.e., the parallel symbol duration is $N \cdot PG$ times longer than the serial symbol duration T [7]. Thus the effects of the dispersive channel become less damaging,

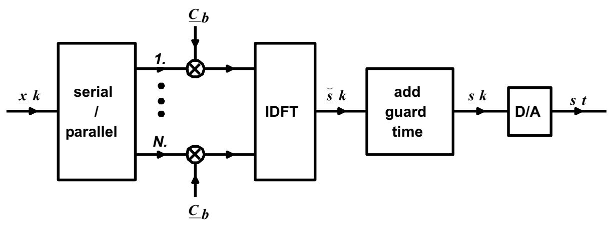

Fig. 1. The proposed transmitter model

affecting only only a fraction of the extended signaling pulse duration.

$$\underline{\check{\mathbf{s}}}[k] = \underline{\underline{\mathbf{F}}}_b^{-1} \left(\underline{\mathbf{C}}_b \otimes \underline{\mathbf{x}}[k] \right), \quad (2)$$

where the symbol $\otimes$ denotes elementwise multiplication. The last l elements of the vector $\underline{\check{\mathbf{s}}}[k]$ are copied and put as a cyclic prefix (CP) onto the begin of the information block. The cyclic prefix takes place as a guard time, which avoids the Inter Symbol Interference. The cyclic extension in the time-dispersive environments reduces the efficiency of the system by a factor of $N/(N+l)$. The duration l depends on the duration of the channel impulse response [7]. The output signal is

$$\underline{\mathbf{s}}[k] = \underline{\underline{\mathbf{G}}}_{pp}[k] \cdot \underline{\check{\mathbf{s}}}[k] \quad (3)$$

with

$$\underline{\underline{\mathbf{G}}}_{pp} = \begin{pmatrix} \underline{\underline{\mathbf{0}}}_{l\times(N\cdot N-l)} & \underline{\underline{\mathbf{1}}}_{l\times l} \\ \underline{\underline{\mathbf{1}}}_{N\times N} & \underline{\underline{\mathbf{1}}}_{N\times N} \end{pmatrix}, \quad (4)$$

where $\underline{\underline{\mathbf{0}}}$ indicates a matrix with the size of $l \times (N \cdot N - l)$ and all zeros bits and $\underline{\underline{\mathbf{1}}}$ is the unit matrix as well as the index pp after the matrix $\underline{\underline{\mathbf{G}}}$ denotes the cyclic extension. After a digital-to-analog conversion the information is emitted through the mobile radio channel.

B. The channel model

The channel model assumed is that of a finite impulse response (FIR) filter with time-varying tap values. Every propagation path i is characterized by a fixed delay τ_i according to one symbol duration and a time-varying amplitude $A_i(t) = a_i \cdot g_i(t)$, which is a product of a complex amplitude a_i and a Rayleigh-fading process $g_i(t)$. The Rayleigh-process $g_i(t)$ are independent from each other. The time-variant impulse response is given as

$$h_k(\tau, t) = \sum_{i=1}^{z} A_i(t) \cdot \delta(\tau - \tau_i) = \sum_{i=1}^{z} a_i \cdot g_i(t) \cdot \delta(\tau - \tau_i), \quad (5)$$

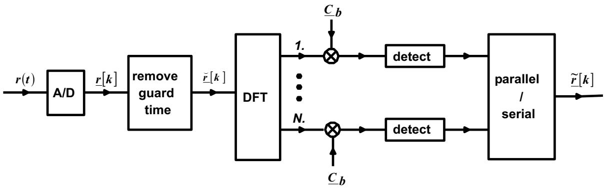

Fig. 2. Receiver model

where z refers to the number of paths [7]. The function $\delta(\tau - \tau_i)$ is the Kroenecker-delta, its value is one if $\tau = \tau_i$, otherwise zero. The time-variant impulse response $h_k(\tau, t)$ is convolved with the transmitted signal $s(t)$, or its Fourier transformation $H_k(f, t)$ is multiplied with the transfer function of the transmitted signal $S(f) = \mathrm{F}\{s(t)\}$ [7]. The channel gives white additive Gaussian noise $n(t)$ to the signal, too.

C. The receiver model

The resulting received signal $r(t)$ is denoted by

$$r(t) = \mathrm{F}^{-1}\left\{\mathrm{S(f)} \cdot \mathrm{H_k(f,t)}\right\} + \mathrm{n(t)}. \qquad (6)$$

The receiver model is shown in Figure 3. After an analog-to-digital conversion $r(t) \rightarrow \underline{\mathbf{r}}[k]$ the cyclic prefix is discarded from the signal vector is denoted by

$$\check{\underline{\mathbf{r}}}[k] = \underline{\underline{\mathbf{G}}}_{nn} \cdot \underline{\mathbf{r}}[k], \qquad (7)$$

where $\underline{\underline{\mathbf{G}}}_{nn} = \begin{pmatrix} \underline{\underline{\mathbf{0}}}_{N\times l} & \underline{\underline{\mathbf{1}}}_{N\times N} & \underline{\underline{\mathbf{1}}}_{N\times N} \end{pmatrix}$ is a matrix with the elements of zeros and ones and the index nn of the matrix $\underline{\underline{\mathbf{G}}}$ denotes the taking away of the guard time. The receiver performs the demodulation by the discrete Fourier transformation (DFT), which can be described as $F_{vp} = \frac{1}{N} e^{-j\frac{2\pi}{N}(v-1)(p-1)}$ [3]. Every bit is multiplied with the Walsh-Hadamard code sequences ($\underline{\mathbf{C}}_k$) then detected and converted to serial data stream $\tilde{\underline{\mathbf{r}}}[k] = \underline{\mathbf{C}}_k \cdot \underline{\underline{\mathbf{F}}}_k \cdot \check{\underline{\mathbf{r}}}[k]$ for further signal processing. By the detection we used the method of the DS-CDMA (Direct Sequence Code Division Multiple Access).

III. Simulation results

We confirmed the validity of our proposed scheme by computer simulation. The BER (Bit Error Rate) performances in the AWGN (Additive White Gaussian Noise) channel and in the linear time-varying channel (plus AWGN) are presented. The IDFT size were chosen to 2048 and the number of carriers is 32. The length of the guard time is a quarter or an eighth of the IDFT size, which is set to 512 (25%) or 256 (12.5%) or there is no guard time set. The number of

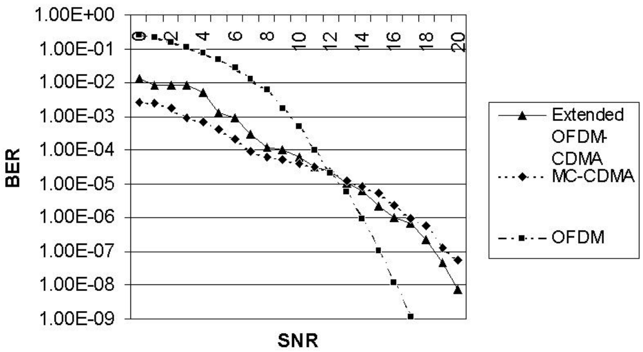

Fig. 3. The extended ODFDM-CDMA model in AWGN channel

total simulated words is set to 24000. The wordsizes are chosen to 1, 2, or 4 bit/Hz by DPSK (Differential Pulse Shift Keying). We simulated the pursuit of the system by a few hundred times whereby we got statistical results.

A. The simulation events

We performed two kinds of simulation. Within the first one we analyzed the performance of the proposed scheme, while the second one serves as a comparison with other well known systems.

1. The channel is a multipath fading channel with AWGN or we assumed that the channel gives only AWGN to the useful signal. The length of the guard time changes between 1/4 and 0 length of the IDFT size. It has not really importance of the Bit Error Rate (BER) by this model. These technique functions very efficiently in AWGN channel that can be seen at the Figure 3. The length of the delay spread is varying between 1/10 and 1/3 length of the IDFT size. We can see that in this case it is not necessary to put a cyclic prefix in front of each symbol because this guard time has not really importance of the Bit Error Rate (BER) by this model. Therefore the baud rate would not be decreased. If the delay spread is considerably big, the hybrid OFDM-CDMA becomes more responsive and gives even worse BER values.

2. Comparison with the simulation results of an OFDM system and with the simulation results of an MC-CDMA system. The Figure 5. shows the Bit Error Rate by some modulation techniques. By lower Signal to Noise Ratio (SNR) the extended OFDM-CDMA system gives better performance issues than the OFDM system. The MC-CDMA can handle the effects of the multipath fading channel a little bit better than the elaborated hybrid system, but the MC-

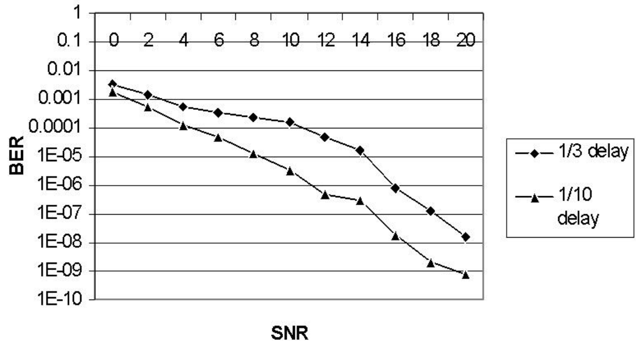

Fig. 4. The extended OFDM-CDMA model in noisy time-varying multipath channel

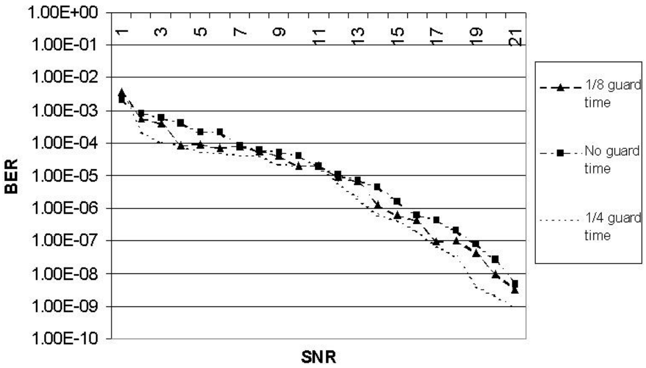

Fig. 5. Comparison of BER by different modulation techniques

CDMA works by much lower baud rate. Thus in very noisy channel it is submitted to use these extended OFDM-CDMA method. By the value 12dB of the SNR the three system operates nearly at the same BER. By a less noisy channel the OFDM can reduce the best the undesirable effects of the time-varying multipath channel. The OFDM is slower than the extended OFDM-CDMA because of the guard time. By the OFDM the cyclic extension plays an important part, but the hybrid system does not need definitely the guard time that show the simulation results.

B. The disassembly of the channels

We divide the users into two traffic classes (speech and data). Since data communication requires the whole available frequency band, speech only needs a group of them. Thus we get a faster communication transmission. CDMA codes are appropriate for the control of the channel selection, however, channel assignment is solvable either with control of the Base Station or the subset can monitor the channel. This system can operate in a highly time dispersive channel with satisfactory bit error rate.

IV. Conclusion

In this paper we have studied an extended OFDM-CDMA system which compounds the advantages of two other transmission manners such as OFDM and CDMA. We described the system detailed and then presented a simulation with its circumstances and with results. We compared its performance with the systems of OFDM and CDMA. Although it works N times slower than the conventional OFDM but it has approximately 100 times better BER proportion by very noisy multipath channels. The analytically study has shown that it is a simple realizable technique and has good performance properties. In the future we will analyze how this scheme works with whole source coding and interleaving and how can we employ it by Power Line Telecommunication (PLC).

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