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**First UK-India International Workshop
on Cognitive Wireless Systems
(UKIWCWS 2009)**
(December 11-12, 2009) IIT Delhi, India
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A Novel Multiple Access Scheme using MSE-OFDM for Uplink

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Abstract— This paper presents a novel multiple access scheme for uplink of future mobile communications using Multi-Symbol Encapsulated Orthogonal Frequency Division Multiplexing (MSE-OFDM). MSE-OFDM is a bandwidth efficient OFDM scheme, where a number of OFDM symbols are grouped together as a frame and protected by one single cyclic prefix (CP). This reduces the extent of redundancy caused by the CP and increases the bandwidth efficiency of the system. In the proposed scheme, a number of OFDM symbols from one user are grouped and one cyclic prefix is used for a group of symbols. Thus, we can get better spectral efficiency as compared to conventional OFDMA. The FFT size is also reduced, which improves the robustness to synchronization errors and reduces the PAPR.

I. INTRODUCTION

In MSE-OFDM, a number of OFDM symbols are grouped together as a frame and protected by one single cyclic prefix (CP) [1-5]. This reduces the extent of redundancy caused by the CP and increases the bandwidth efficiency of the system. There are two different implementations of the MSE-OFDM scheme, the CP-reduced MSE-OFDM, which is designed to improve the bandwidth efficiency for static channels and FFT-size-reduced MSE-OFDM, which improves the PAPR and robustness to frequency offset for mobile channels. Motivated by the advantages of MSE-OFDM, we decided to explore using it for multiple access schemes. In this chapter, we propose a new multiple access scheme MSE-OFDMA to improve bandwidth efficiency in uplink. A number of OFDM symbols from one user are grouped together and one cyclic prefix is used for a group of symbols. A number of such groups from different users are combined to form a frame. Thus, we can get better spectral efficiency as compared to conventional OFDMA. The bandwidth efficiency improvement of this scheme over the conventional OFDMA increases with the length of cyclic prefix.

MSE-OFDMA is similar to OFDMA, where each transmitted frame conveys simultaneous information from multiple subscribers. The available subcarriers are grouped into a number of subchannels, each consisting of same or different number of subcarriers depending on the scheme of grouping. We assume the situation where equal number of subchannels is assigned to distinct users, even though more subchannels may be allocated to the same user depending on its requested data rate. Similar to OFDMA, the subcarrier assignment in MSE-OFDM can also be contiguous, interleaved or distributed. Dynamic subcarrier assignment (DSA) and adaptive power

allocation (APA) to multiple users can be employed to improve the system data rate [6-7].

In the downlink the signal conveys information to all active users, while in the uplink each terminal only transmits its own data. Transmission occurs in blocks, where each block of information symbols is mapped over subcarriers assigned to the considered user. In the uplink, each transmitted signal propagates through a different multipath channel and is received at the base station with distinct timing and frequency offsets. This makes uplink synchronization a rather difficult task. To solve this problem, a synchronization policy is used where timing and frequency estimates computed by each terminal during the downlink phase are used not only to detect the downlink data stream, but also as synchronization references for uplink transmission. Even with this approach, however, residual timing and frequency errors may still be present on the uplink signals arriving at the base station. If the Doppler shift is sufficiently smaller than the subcarrier spacing, frequency synchronization is not necessary since the resulting ICI is negligible in this case. Similarly, if the CP is designed to be sufficiently larger than the CIR duration, timing synchronization may be unnecessary since the timing errors can be compensated for by the channel equalizer in this case.

This paper is organized as follows. Section II gives a general description of the proposed multiple access scheme in uplink and the system model for implementation of this scheme. The performance analysis for this scheme is given in Section III. Simulation results are discussed in Section IV to show the effectiveness of the proposed method. Some concluding remarks are made in Section V.

II. THE PROPOSED MULTIPLE ACCESS SCHEME

In conventional OFDMA, data for all the users are used to generate one OFDM symbol and protected by one CP [7]. In MSE-OFDMA, a number of OFDM symbols are taken in one group and one cyclic prefix is used in one group [8]. In downlink OFDM symbols of different users can be grouped together and transmitted. However, in the uplink, it is difficult to collect all users' data and group them. So a number of OFDM symbols of one user are grouped together and one CP is used in each group. Thus better spectral efficiency is obtained in MSE-OFDMA as compared to conventional OFDMA. Groups of data of different users are transmitted

on orthogonal subcarriers similar to OFDMA [7]. In MSE-OFDMA, each OFDMA block is divided into smaller FFT blocks reducing the number of subcarriers for each block, thus reducing the FFT size. The number of subcarriers is reduced, keeping the bandwidth constant. This reduces the relative frequency offset. Therefore the system becomes more robust to synchronization errors. The PAPR is also reduced due to the usage of a smaller number of subcarriers. Following this approach, we get both the advantages, i.e., improvement in the bandwidth efficiency, the robustness to synchronization errors and reduction in PAPR.

A. Transmitter

A typical block diagram of the transmitter for the proposed MSE-OFDMA scheme in the uplink is shown in Fig.1. The MSE-OFDMA signal consists of data from K users. B complex OFDM symbols from one user are grouped together and one CP is used. The number of subcarriers is N in each OFDM symbol. The subcarriers include all available subcarriers and virtual subcarriers in the guard band. In each group, B OFDM symbols are time division multiplexed and N_{cp} samples from the last OFDM symbol are used as cyclic prefix. $N_{cp} = f.N$, where f is a fraction and may be $1/4$, $1/8$ or $1/16$ depending on the delay spread of the channel. Thus each group consists of $NB + N_{cp}$ samples and one frame consists of $K(NB + N_{cp})$ samples. The total overhead due to CP in each group is $(B-1)$ times less than in conventional OFDM, where each OFDM symbol uses one CP. Thus the bandwidth efficiency is improved. The data of K different users are shifted to K different orthogonal frequencies f_0 to f_K and transmitted. This scheme can be used to increase the bandwidth efficiency for static or slow fading channels, where the channel remains constant over a number of OFDM symbols.

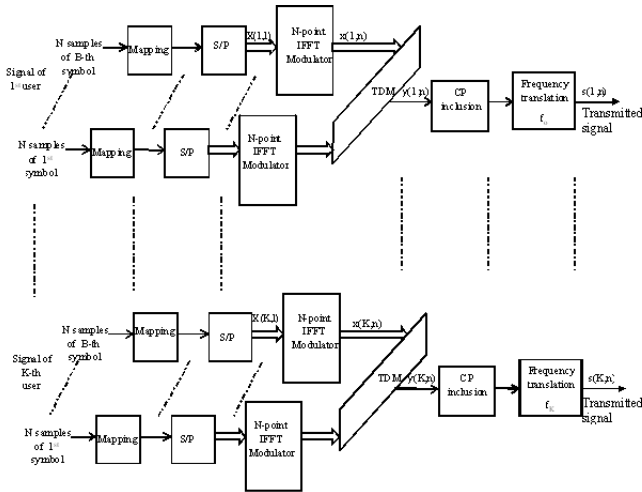


Fig. 1. The Proposed MSE-OFDMA Transmitter

In MSE-OFDMA, N -point FFT blocks are used which are smaller as compared to OFDMA, reducing the number of subcarriers for each block, thus reducing the FFT size. In OFDMA, NB -point FFT size will be required for BK

users. When the number of subcarriers is reduced, keeping the bandwidth constant, the relative frequency offset becomes smaller, so the system becomes more robust to synchronization errors. The PAPR also reduces due to smaller number of subcarriers. Thus, we get all the advantages i.e. improvement in the bandwidth efficiency, the robustness to synchronization errors and reduction in PAPR.

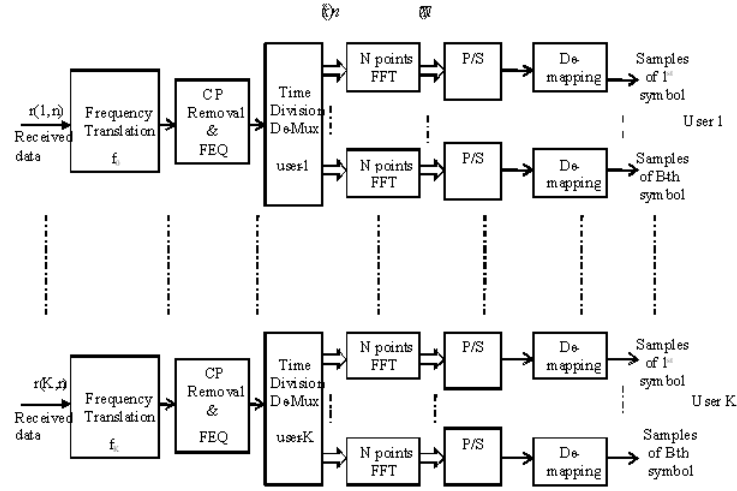


Fig. 2. The Proposed Receiver

B. Receiver

A block diagram of the receiver for the proposed MSE-OFDMA scheme in uplink for K users is shown in Fig.2. In the receiver, the signals of the users are demodulated using synchronous orthogonal subcarriers from the received composite signal. Then for each user, the CP is removed and frequency domain equalization is performed. As long as the length of CP interval is larger than maximum expected delay spread, all reflections of previous symbols are removed and orthogonality is restored. After taking inverse OFDM the whole frame is equalized to remove any ISI among the signals of different users as explained in [1-2]. After channel estimation, the output of each subcarrier is equalized. To demodulate each OFDM symbol separately, the whole frame is converted back to time domain. Then the samples for each OFDM symbol are selected and demodulated using N point FFT. The samples for each user are selected based on the information from the transmitter. The demodulation and decoding used at the receiver should be corresponding to modulation and coding used at the transmitter. All these information are passed to receiver in the beginning of every frame in form of a preamble.

C. Channel Model

A mobile radio propagation channel is characterized by frequency selective multipath channel consisting of many propagation paths with different time delays. The simulation is first carried out under ideal channel conditions where the noise is considered only due to AWGN. Then the ITU-R defined

TABLE I
ITU-R DEFINED VEHICULAR A PROPAGATION CHANNEL MODEL

Tap	Relative delay (ns)	Average gain (dB)
0	0	0
1	710	-1
2	1110	-9
3	2090	-10
4	3730	-15
-5	4510	-20

Vehicular A propagation channel model having six Rayleigh faded discrete paths is considered. As per this model, a channel is modeled as an FIR filter whose impulse response can be expressed as

$$h_i(n) = \sum_{i=0}^{P-1} a_i(n)\delta(n - \tau_i) \quad (1)$$

with $a_i(n)$ and τ_i being the complex path gain and time delay of the i th propagation path in a P path model.

The channel parameters are summarized in Table I.

D. Channel Estimation

When coherent detection is used in receivers, information about the channel state is required and has to be estimated by the receiver. The basic principle of pilot symbol aided channel estimation is to multiplex reference symbols, known as pilot symbols, into the data stream. The receiver estimates the channel state information based on the received, known pilot symbols. The pilot symbols can be scattered in time and/or frequency direction in OFDM frames. Here we have used frequency domain equalizer, so pilot symbols are multiplexed with data symbols in frequency direction. At the receiver, the guard intervals of the received signals are removed and the resultant symbol sequence is converted to a modulated signal of each subcarrier using FFT. For channel estimation, the channel impulse response at each subcarrier is found by averaging the impulse response measured for each of the dedicated pilot symbols. Using the obtained channel impulse response, the output of each subcarrier is equalized. Finally, the regenerated symbol sequences are parallel to serial converted to recover the transmitted binary data.

With the help of cyclic prefix, frequency domain equalizer can be realized for the MSE-OFDMA system using NB point FFT and IFFT. The ISI among the subcarriers is minimized by using frequency domain equalizer for the whole group. This increases the computational complexity in the receiver. This complexity can be reduced to a great extent by using time domain equalizer proposed in [9].

III. PERFORMANCE ANALYSIS

The following assumptions are taken for analysis:

- i. Carrier frequency offset is uniformly distributed between 0 and 2π radians
- ii. Timing offset is uniformly distributed between 0 and T_b (one bit duration)

- iii. Input bits are random, independent and equiprobable
- iv. The signals for different users are synchronous
- v. The channel is an ITU-R vehicular-A fading channel.

The binary input bit stream $d(l)$ at a data rate of R_b from each user is first grouped into blocks of size N_b ($N_b = \log_2 M$) and then mapped into one of M complex symbols $X_b(k, l)$ drawn from the M-QAM constellation. $X_b(k, l)$ is the complex sample to be modulated onto the l -th subcarrier of b -th symbol of k -th user at a data rate R_s , where $R_s = R_b/N_b$.

The sequence of N complex samples $X_b(k, l)$, is then serial-to-parallel converted and modulated by the N -point IFFT onto N orthogonal subcarriers to get one OFDM symbol of the baseband modulated signal.

The b -th OFDM symbol of k -th user is given by the N -point complex modulation sequence through IFFT.

$$x_b(k, n) = \sum_{l=0}^{N-1} X_b(k, l) \exp(j2\pi nl/N) \quad n = 0, 1, \dots, N-1 \quad (2)$$

One group of MSE-OFDMA signal for k -th user is generated by grouping B OFDM symbols (time division multiplexed) and adding a CP of N_{cp} samples

$$x(k, n) = \sum_{l=0}^{N-1} X_{B-1}(k, l) \exp(j2\pi l(N - N_{cp} + n_1)/N) + \sum_{b=0}^{B-1} \sum_{l=0}^{N-1} X_b(k, l) \exp(j2\pi l(n_2 - N_{cp} - bN)/N) \quad (3)$$

where $0 \leq n_1 < N_{cp}$ and $N_{cp} \leq n_2 < NP + N_{cp}$

The 1st term represents the CP and second term represents the actual data to be transmitted.

Thus one group of the transmitted signal $s(n)$ consists of $NB + N_{cp}$ data samples from one user and one frame consists of $K(NB + N_{cp})$ data samples from K users.

The modulated data symbols $x(k, n)$ of each user are frequency shifted i.e. mapped onto orthogonal subcarriers assigned to the user and transmitted. The transmitted signal of the k -th user can be written as

$$s(k, n) = x(k, n) \exp(jw_k t) \quad (4)$$

where w_k , $k = 0, 1, 2, \dots, K$ are the orthogonal frequencies allotted to K users related by

$$w_k = 2\pi f_k = 2\pi k/T_s \quad (5)$$

The received signal of k -th user can be written as

$$r(k, n) = \sum_{b=0}^{B-1} \sum_{l=0}^{N-1} X(b, l) H_k(l) e^{j2\pi(n-bN+\Delta n)(l+\Delta l)/N} + w(k, n) \quad (6)$$

where $H(l)$ is the channel transfer function at the l -th subcarrier frequency, $w(k, n)$ is the zero-mean additive white

TABLE II
SIMULATION PARAMETERS

Parameters	values
Number of subcarriers in one OFDM symbol	64
Total number of subcarriers	2048
Number of users	8
Number of OFDM symbols/user	4
Cyclic prefix per user	16
Modulation	QPSK
Relative frequency offset	0.05
Relative timing offset	0.05

Gaussian noise (AWGN) with power spectral density of N_o , Δn is the relative timing offset (ratio of the timing offset to the sampling interval), and Δl is the relative frequency offset (ratio between frequency offset to the subcarrier spacing).

Using QPSK modulation, we get the probability of bit error of the MSE-OFDMA system as

$$P_e = \int Q\left(\sqrt{\frac{\gamma_{k,i} E_b}{N_o + \sigma_{ICI}^2 + \sigma_{ISI}^2}}\right) f(\gamma) d\gamma \quad (7)$$

where γ_i is the fading amplitude in i -th subcarrier, E_b is the bit energy, σ_{ICI}^2 is the variance of ICI, σ_{ISI}^2 is the variance of ISI and N_o is the additive noise variance.

The variances of ICI and ISI have been derived as

$$\sigma_{ICI}^2 = X^2 \sum_{i=0, i \neq l}^{N-1} H_k^2(l) \left\{ \frac{\sin^2(\pi \Delta l)}{N^2 \sin^2(\pi(i-l+\Delta l)/N)} \right\} \quad (8)$$

$$\sigma_{ISI}^2 = X^2 H_k^2 \left[\frac{\pi \Delta l (N-1) + 2\pi(l+\Delta l)\Delta n + 2\pi K N \Delta l}{N} \right]^2 \quad (9)$$

These variances increase with increase in frequency or timing offsets, thereby increasing the probability of error. The MAI may be due to this ICI and ISI among different users' signals and can be minimized by using synchronization algorithms proposed for OFDMA systems. Simulations have also been carried out to evaluate the bit error rate (BER) of the multiple access scheme using MSE-OFDM system under different channel conditions.

IV. SIMULATION RESULTS

Table II summarizes the simulation parameters assumed in this paper. Fig. 3 shows the BER performance of the proposed multiple access system in multipath fading channel without any frequency offset. Symbols of 8 users are transmitted on orthogonal subcarriers. The modulation used is QPSK and total number of subcarriers is 2048. Number of subcarriers in each OFDM symbol is 64. Four OFDM symbols from each user are grouped together and one CP is used for these 4 symbols. The performance of MSE-OFDMA system is compared with conventional OFDMA system and both were found to be almost identical for AWGN and fading channels. It is observed that

the MSE-OFDMA signal gives better spectral efficiency than OFDMA without degrading the BER performance.

Fig. 4 shows the effects of frequency offset on a conventional OFDMA and MSE-OFDMA for 8 users. The effect of frequency offset is found to be less on MSE-OFDMA system as compared to conventional OFDMA due to reduction in FFT size. An improvement of 2-3 dB in SNR is observed in MSE-OFDMA over OFDMA due to a relative frequency offset of 0.05.

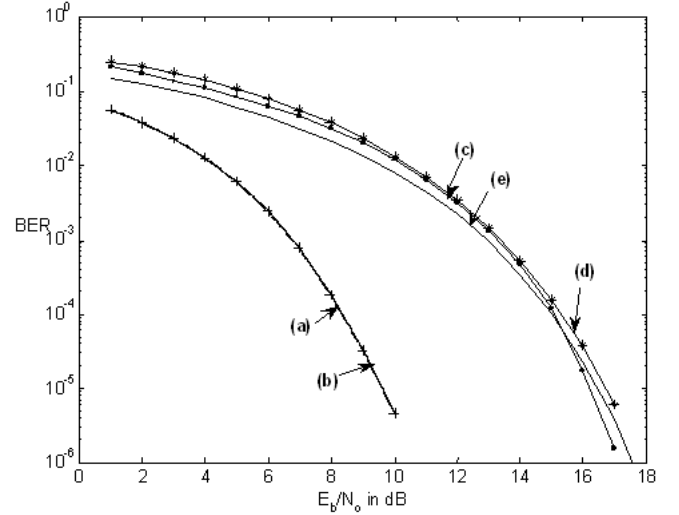


Fig. 3. BER performance of OFDMA and MSE-OFDMA systems for 8 users in uplink (a) OFDMA in AWGN channel (b) MSE-OFDMA in AWGN channel (c) OFDMA in fading channel (d) MSE-OFDMA signal in fading channel and (e) analytical result for MSE-OFDMA system in fading channel.

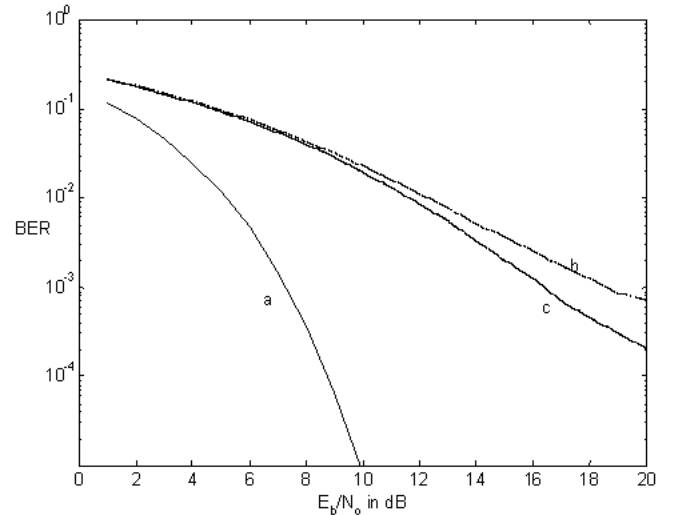


Fig. 4. BER of OFDMA and MSE-OFDMA in uplink channel (a) in AWGN channel (b) OFDMA in fading channel with a relative frequency offset of 0.05 (c) MSE-OFDMA with same frequency offset.

V. CONCLUSIONS

In this paper, we have explored the possibility of using MSE-OFDM for multiple access in the uplink. In MSE-OFDMA, a number of OFDM symbols from each user are grouped together and protected by one cyclic prefix. This reduces the redundancy due to cyclic prefix and better spectral efficiency is obtained as compared to conventional OFDMA, where each OFDM symbol uses one cyclic prefix. With this scheme, we get improvement in the bandwidth efficiency, the robustness to synchronization errors and reduction in PAPR. The analysis has been carried out for the proposed scheme and expressions for probability of error for multi-user MSE-OFDM in presence of inter-channel interference (ICI) and inter-symbol interference (ISI) have been derived.

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