A New OFDM Transmission Scheme Using Orthogonal Code Multiplexing

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Abstract: We propose an effective orthogonal frequency division multiplexing (OFDM) transmission scheme using orthogonal code multiplexing (OCM). This scheme makes all modulation symbols have the same reliability even in a frequency selective fading channel. The same reliability is accomplished through a distributed transmission of each symbol over the whole effective subcarriers using a distinct orthogonal code. As an appropriate set of orthogonal multiplexing codes, we use the set of discrete Fourier transform (DFT) basis sequences that hold the orthogonality irrespective of the length. Using this set, we also can greatly reduce the peak-to-average-power ratio (PAR) of the resulting OFDM signal. Simulation results show that the proposed scheme can significantly reduce the required SNR at a given bit error rate (BER) over the existing schemes. The scheme can maintain the PAR within a reasonable range of about 6 dB even up to 512 subcarriers and works well even with PAR clipping of 1.5 dB.

Key Words: OFDM, orthogonal code multiplexing, distributed transmission, PAR

1. Introduction

OFDM allows high-speed transmission over frequency selective fading channels by dividing a data stream into multiple substreams and then transmitting them simultaneously using overlapping orthogonal subcarriers [1]. However, the resulting OFDM signal displays a very high PAR value, which tends to reduce the amplifier power efficiency [2]. In the conventional OFDM transmission scheme in which the same modulation format for all the subcarriers is used, each symbol suffers from a different degree of fading due to the frequency selectivity, thus resulting in a different reliability for each symbol. In such a circumstance, the overall BER is dominated by deep-faded symbols [3].

In the discrete multi-tone (DMT) systems, the adaptive bit-loading (ABL) scheme [4] has been adopted to make all information bits have the same reliability by allocating the different number of bits per subcarrier. However, the scheme cannot use fractional bit energy for each subcarrier and requires the exact knowledge of the channel state information at the transmitter. Recently, the OFDM transmission scheme using Walsh code multiplexing (WCM) (hereafter, called as the WCM scheme), which compensates effectively the frequency selectivity through a distributed transmission of each symbol over a large number of subcarriers using a distinct Walsh code sequence has been proposed [5]. However, the Walsh code sequences do not hold the orthogonality any longer when the number of effective subcarriers is not an integer power of two. In that case, interlacing of several WCM sequences using lower-order Walsh sequences has been adopted. However, it is sub-optimum since only a subset of modulation symbols over a limited frequency region suffers from the same degree of fading. In addition, using the Walsh codes as orthogonal multiplexing codes may display still a relatively high PAR value.

In this paper, we propose an effective OFDM transmission scheme that makes all modulation symbols have the same reliability even in a frequency selective channel, thus maximizing the resource utilization. The same reliability in the frequency selective fading channel is accomplished through a distributed transmission of each modulation symbol over the whole effective subcarriers. The scheme multiplexes the modulation symbols using distinct orthogonal codes and then spreads the multiplexed sequence over the whole effective subcarriers prior to

OFDM transmission. We use the DFT orthogonal basis sequences. Computer simulations are performed to demonstrate the performance of the proposed scheme in terms of the BER and PAR.

2. The OFDM-OCM System

Fig. 1 shows the transmitter structure of the OFDM-OCM system. Assuming M effective subcarriers in the system, M modulation symbols are multiplexed using M distinct orthogonal codes with the length M, and then the multiplexed sequence is spread over M effective subcarriers before OFDM transmission including the inverse fast Fourier transform (IFFT) and the cyclic prefix insertion. In Fig. 1, note that the m-th modulation symbol of the i-th OFDM symbol, $d_{i,m}$, is transmitted using the m-th orthogonal code $\mathbf{O}_m$.

Fig. 2 shows the receiver structure of the OFDM-OCM system. The receiver performs the corresponding inverse operations in the reverse order except for one-tap equalization in order to retrieve the original modulation symbols through orthogonal code demultiplexing from the distorted signal over the frequency selective fading channel. For equalization and combining, we consider the minimum mean squared error combining.

3. The Set of Orthogonal Multiplexing Codes

In this section, we deal with the selection of an appropriate set of orthogonal multiplexing codes. We review some desirable conditions for the code set. First, the codes should hold the orthogonality irrespective of the code length in order to fully exploit frequency diversity under all the possible subcarrier configurations. Second, they should have equal chip energy to evenly distribute the symbol energy over the whole effective subcarriers. Third, they should not make the PAR become large. Fourth, the easy representation is strongly required for complexity reduction.

If $M = 2^n$ (n: an integer), the set of Walsh codes with the length 2^n could be the best selection in terms of both the system complexity and equal chip energy property. In the FFT implementation of OFDM, however, transmission using all the 2^n subcarriers may not be feasible due to interference from/to adjacent bands. In addition, some of subcarriers may be prohibited from transmitting the signal. In these cases, truncated Walsh codes could not hold the orthogonality. The interlacing scheme mentioned above may become one solution to the orthogonality problem only at the expense of performance loss.

In this paper, we introduce the set of the DFT basis sequences with an arbitrary length M. The set would be better in terms of the three major conditions except for the fourth one. The DFT orthogonal basis sequences with the length M can be expressed as

$$\begin{aligned}\mathbf{O}_m &= \left[O_{m,1}, O_{m,2}, \cdots, O_{m,M}\right]^T,\ m = 1, \cdots, M, \qquad (1)\\ &= \frac{1}{\sqrt{M}}\left[1, e^{-\frac{j2\pi(m-1)}{M}}, \cdots, e^{-\frac{j2\pi(m-1)(M-1)}{M}}\right].\end{aligned}$$

4. Simulation Results

We performed computer simulations to evaluate the BER performance of the proposed DFT-basis OCM scheme and to compare it with those of the ABL scheme, the WCM scheme, and the conventional OFDM transmission scheme. We used the quadrature phase shift keying (QPSK) modulation. Each OFDM symbol carries 192 modulation symbols using only 192 effective subcarriers among 256 subcarriers (i.e., M =192, N =256). For the WCM scheme, three independent multiplexed sequences each using 64-Walsh code sequences were interlaced [5]. The remaining OFDM parameters are as follows: the bandwidth BW=25 MHz, the effective symbol duration T_u =10.24μs and the cyclic prefix duration T_{cp} =2.56μs. We also used a frequency selective fading channel with the root-mean-square delay spread of 0.1μs and the maximum delay spread of 1μs. Finally, we assumed perfect frame synchronization and channel estimation, and no frequency offset.

Fig. 3 shows the BER performances of the proposed scheme and the three existing schemes such as the ABL scheme, the WCM scheme, and the conventional scheme. In the additive white Gaussian noise (AWGN) channel, all the four schemes have the same BER performance. In the frequency selective fading channel, however, the proposed scheme and the ABL scheme perform much better than the other two schemes. At this point, it should be noted that the ABL scheme requires the exact knowledge of the channel state information at the transmitter. The proposed scheme can save about 4dB and 1.7 dB at BER=10^{-5} over the conventional scheme and the WCM scheme, respectively. The performance degradation of the WCM scheme is due to interlacing of lower-order WCM sequences instead of using full-length orthogonal code sequences. Note that when all the 256 subcarriers are engaged in data transmission, the two schemes have the same BER performance.

In this work, computer simulations also have been done to measure the PAR values of the three OFDM schemes such as the proposed scheme, the WCM scheme, and the conventional scheme. The peak power for these has been collected over 10^6 independent OFDM symbols. Table 1 shows the PAR values when all the 2^n subcarriers are used for effective transmission. From Table 1, the proposed scheme shows always the PAR of 0 dB irrespective of the number of subcarriers, because the DFT orthogonal basis sequences are combined with IFFT processing. However, the PAR values for the conventional scheme and the WCM scheme become higher as the number of subcarriers increases. Table 2 shows the PAR values according to the number of effective subcarriers when $N = 256$. From the table, the proposed scheme has the PAR value of about 6dB irrespective of subcarrier loading conditions, but the conventional scheme has much higher values. Table 3 shows the PAR values of the three schemes according to the number of subcarriers under a fixed condition of $M / N = 0.75$. From Table 3, we see that the proposed scheme has much lower PAR values of about 6 dB up to 512 subcarriers.

Fig. 4 shows the BER performances under the same environment as in Fig. 3, except for clipping of the resulting OFDM signal at the PAR level of 1.5 dB. From the figure, the proposed scheme works well even with PAR clipping of 1.5 dB.

5. Conclusions

In this paper, we proposed the OFDM-OCM scheme that makes all the modulation symbols have the same reliability even in frequency selective channels, thus maximizing the resource utilization. The scheme distributes each symbol evenly over the whole effective subcarriers using a distinct DFT orthogonal basis sequence in order to fully utilize frequency diversity. The DFT-OCM scheme also greatly reduce the PAR of the resulting OFDM signal, especially of 0 dB when all the subcarriers are engaged in the effective transmission. The simulation results show that the proposed scheme can save about 4dB and 1.7 dB at BER=10^{-5} over the conventional scheme and the WCM scheme, respectively, under the simulation condition. In addition, the proposed scheme maintains the PAR at a reasonable range of about 6 dB even up to 512 subcarriers and works well even with PAR clipping of 1.5 dB.

Acknowledgements

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Table 1. PAR values according to N when all the subcarriers are used for effective transmission.

N	PAR (dB)		
	Proposed scheme	WCM scheme	Conventional scheme
16	0	6.56	12.78
32	0	8.66	15.32
64	0	9.43	16.99
128	0	11.72	17.68

256	0	12.93	19.85

Table 2. PAR values according to the number of effective subcarriers when N =256.

M (N=256)	PAR (dB)	
	Proposed scheme	Conventional scheme
224	5.90	19.44
208	6.68	18.89
192	6.69	18.34
176	5.99	17.38
160	6.20	15.61
144	6.49	14.54

Table 3. PAR values according to the number of subcarriers under a fixed condition of M / N = 0.75.

M (N)	PAR (dB)		
	Proposed scheme	WCM scheme	Conventional scheme
12 (16)	4.93	10.24	11.97
24 (32)	5.39	11.85	15.09
48 (64)	5.78	13.21	16.59
96 (128)	6.47	15.36	17.44
192 (256)	6.69	16.84	18.34
384 (512)	6.70	18.03	21.98

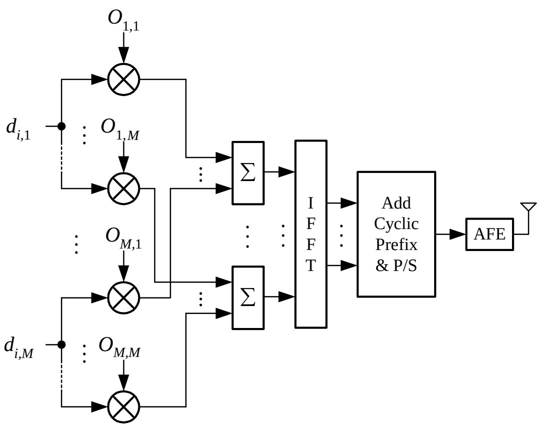

Fig. 1. Transmitter structure of the proposed OFDM-OCM system.

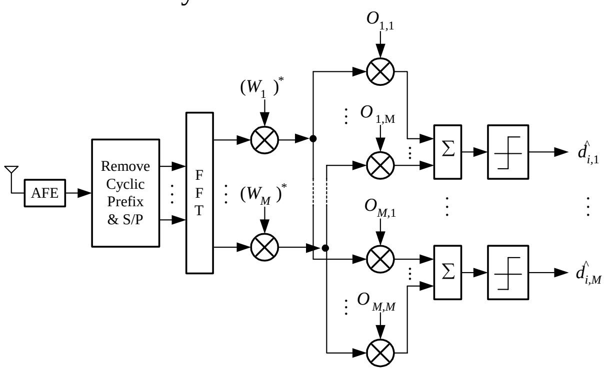

Fig. 2. Receiver structure of the proposed OFDM-OCM system.

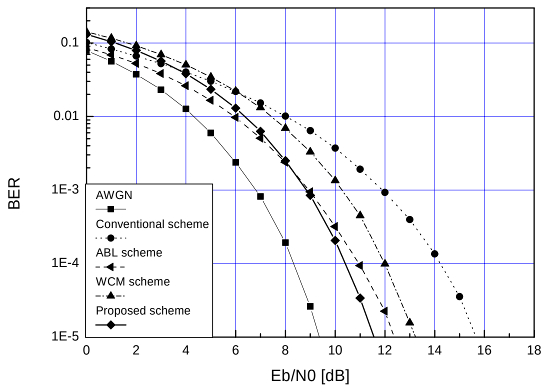

Fig. 3. BER performances of the four OFDM transmission schemes considered in the AWGN and frequency selective channels. (M =192, N =256).

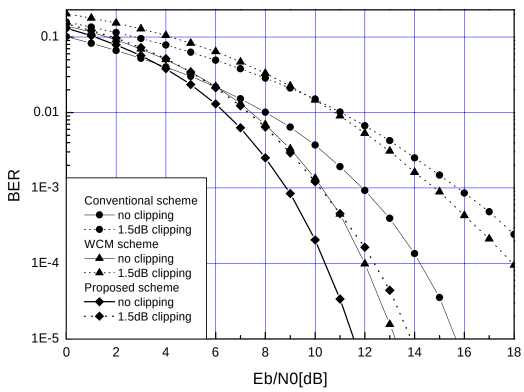

Fig. 4. BER performances under the same environment as in Fig. 3, except for clipping of the

resulting OFDM signal at the PAR level of 1.5 dB.