Subband Spreading Technique Using Orthogonal Code Multiplexing in OFDM Systems

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Abstract

We propose a subband spreading technique to average a frequency selective fading channel which produces different signal-to-noise ratios (SNR) per subcarrier in orthogonal frequency division multiplexing (OFDM) systems. Data symbols are spread over a subband using orthogonal codes and transmitted. Each subband is composed of a group of subcarriers. Received symbols in a subband have the same reliability even in a frequency selective fading channel due to the subband spreading at the transmitter. As the number of subcarriers per subband increases, the averaging effect increases even though the complexity to multiplex the symbols increases. We compare the bit error rate (BER) performance of the proposed scheme with that of the conventional OFDM systems including the pre-equalization scheme. Furthermore, we propose an adaptive modulation scheme using the subband spreading technique in order to reduce signaling overhead and complexity. The proposed scheme can outperform the conventional subcarrier-by-subcarrier adaptation scheme in terms of throughput when the channel varies quickly.

1. Introduction

OFDM is the most promising technique for high-speed data transmission over frequency selective fading channels. In OFDM systems, a high-rate data stream is split into lower-rate data streams and these data are transmitted simultaneously [1]. Since the parallel transmission over a frequency selective fading channel yields longer effective symbol duration than delay spread, each subcarrier experiences rather flat fading channels. However, each subcarrier is affected by different fading channels, that is, each subcarrier generates different reliability at a receiver. In this situation, the overall BER performance is limited by deep-faded subcarriers [2].

To compensate for the frequency selectivity of a channel, various techniques can be used. In pre-equalization schemes, OFDM symbols are pre-distorted with the inverse of an estimated channel transfer function at a transmitter [3-4]. If the transmitter can predict channel information exactly, the system performance can be improved up to that in an AWGN channel. However, in real systems, wireless channel is time-varying and channel mismatches cause severe performance degradation in the pre-equalization system. Moreover, to compensate for deep-faded subcarriers, the transmitter may require high power and it results in a high peak-to-average power ratio (PAPR).

Another approach for overcoming the frequency selective characteristics is to take an adaptive modulation algorithm [5-6]. The basic idea of the adaptive modulation is to adaptively change modulation schemes according to channel transfer functions. Since bit errors of OFDM systems tend to concentrate on deep-faded subcarriers, the overall system performance can be improved if we use more robust modulation schemes on subcarriers with relatively low SNRs. However, a large amount of signaling information is transmitted to inform the modulation mode required for a specific subcarrier. Hardware complexity also increases at a transmitter to select an appropriate modulation mode per subcarrier. If a channel varies quickly, compared with feedback delay of channel information from the receiver, the adaptive modulation scheme yields no performance enhancement.

The techniques to combine OFDM with code division multiplexing (CDM) offer frequency diversity as a solution for the deep-faded subcarrier problem since modulated symbols are spread over multiple subcarriers [7-9]. At a transmitter, modulated symbols are spread over multiple subcarriers by distinct orthogonal codewords. However, system cost increases at the transmitter and receiver due to the spreading and dispreading process, respectively.

Forward error correction codes are needed in OFDM systems to recover the bits corrupted by deep fading channels. As noted before, the overall performance of OFDM systems may be signigicantly affected by a few subcarriers with low SNRs. We can reduce the effects of these faded subcarriers by using error correction codes [10-11].

In this paper, a subband spreading technique is proposed in order to average frequency selectivity in OFDM systems and the performance of the proposed OFDM system is compared with that of the conventional systems. Furthermore, the subband spreading technique can be applied to an adaptive modulation scheme, which gives a better performance when the channel varies quickly. This paper is organized as follows: Section 2 introduces our proposed subband spreading technique and the adaptive modulation system based on the proposed technique. The performance of the proposed system is evaluated in terms of throughput through computer simulations in Section 3. Finally, conclusions are addressed in Section 4.

2. Proposed Subband Spreading Technique

Fig. 1 shows an overall block diagram of the proposed OFDM system using the subband spreading technique. Generic error correcting codes, such as convolutional codes or turbo codes can be used to encode the input data sequence. After channel encoding, the coded bit sequence is mapped into a sequence of appropriate modulation symbols such as QPSK and QAM symbols. These symbols are converted into a parallel form through a serial-to-parallel (S/P) converter for OFDM symbol stacking and are interleaved to compensate for burst errors due to frequency selective fading. Since each modulated symbol is mapped into a specific subcarrier directly in conventional systems, if subcarriers that convey specific symbols are attenuated severely by deep fading, the corresponding symbols may not be correctly recovered due to low SNR values.

The subband spreading processing using the orthogonal code multiplexing (OCM) is shown in fig. 2. In the proposed system, each interleaved symbol (***S***) is spread over the subband according to a subcarrier grouping policy. Through the spreading process the performance of the system is improved. When the whole frequency band is divided into several subbands, the number of subbands (N_{sub}) can be selected flexibly according to applications ($1 \le N_{sub} \le N$, *N* is the number of total data subcarriers). A distinct orthogonal codeword with the same length as the number of subcarriers in a subband is assigned to each symbol. In other words, *M* ($M = N / N_{sub}$) symbols are multiplexed (***u***) using *M* distinct orthogonal codewords (***O***) for OFDM transmission over subcarriers in a subband. To maximize the diversity effect interleaver is used before the OFDM modulation. The orthogonal codes are used for multiplexing symbols of one user in OFDM systems and they are different from the spreading codes multiplexing symbols of different users used in [6]. In this paper, we assume that one user uses the whole frequency band at a specific time.

Adaptive modulation is an effective method to mitigate the effect of frequency selective fading. We also improve the performance of the conventional adaptation system by using the proposed subband spreading technique. The whole frequency band is divided into subbands and the spreading technique is applied to each subband for averaging frequency selective fading characteristics. However, in this application, the interleaver between the subband spreader and OFDM modulator cannot be used because the correlation of the channel transfer function is used for the determination of modulation modes. As explained before, if the subband spreading is applied to an OFDM system, symbols in a subband have the same reliability (approximate a harmonic mean of SNR values of subcarriers) at a receiver because each symbol suffers from averaged fading effect. Therefore, each subband has a constant SNR which is different each other. The harmonic mean among the SNRs of subcarriers in each subband is computed and the corresponding modulation mode for each subband is determined from a pre-computed table.

3. Simulation Results and Discussion

We consider a multipath fading channel with an exponential delay profile where each delay component is independently Rayleigh-distributed. The root-mean-square (RMS) value of delay spread is 5 μs and the maximum delay spread is 25 μs . OFDM parameters are set as follows: the center frequency is 1.9 GHz; the bandwidth (BW) is 5 MHz; the number of subcarriers is 1024; the effective symbol duration is 204.8 μs , and the guard interval is 25.6 μs . Theses parameters are based on a wide-area cellular-like system with target data rates of 10 to 20 Mbps [12].

Fig. 3 compares the BER performance among the proposed system with a subband spreading technique and the conventional systems in a frequency selective fading environment. A QPSK or 16QAM modulation for a mapping process and turbo codes (a code rate of 1/2) are applied. We assume that all subcarriers (1024) are used for transmitting data and all subcarriers are multiplexed by the orthogonal codes for the best performance in this simulation. The proposed system can reduce the required Eb/No in frequency selective fading channels by approximately 13 dB and 11 dB, compared with the conventional OFDM systems for QPSK and 16QAM, respectively, at a BER of 10^{-3} in uncoded systems. Furthermore, we can save power by 2 dB and 5 dB, compared with the conventional OFDM systems for QPSK and 16QAM, respectively, at a BER of 10^{-4} in turbo coded systems. Note that the BER performance of the uncoded proposed system with QPSK mapping is nearly identical to that of the turbo coded conventional system with 16QAM (a system with the same spectral efficiency - 2048 bits per OFDM symbol) at a BER of 10^{-3} . The proposed system has a strong merit in frequency selective fading channels if we consider hardware complexity, the required memories, and delay due to the turbo decoder. Fig. 4 shows the averaging effect according to the number of subcarriers per subbands, i.e., the subband size, in the uncoded QPSK system. As the subband size increases, the average effect increases, and it results in performance improvement.

Fig. 5 shows the performance comparison between the proposed system and the pre-equalization scheme. The full inversion scheme in the pre-equalization technique yields the worst performance among the pre-equalization schemes because most of the available power at the transmitter is consumed to compensate for deep-faded subcarriers. The performance of the pre-equalization can be improved by setting a limit power to consume for a specific subcarrier. We assume that the channel information is exactly known to the transmitter and the channel is invariant in the pre-equalization schemes. The proposed system has power gains of 5, 10, and 13 dB over the three pre-equalization methods at a BER of 10^{-3}. Note that the proposed system needs no channel information at the transmitter. Therefore, if the channel information is not correct or channel varies during the feedback delay, the performance degradation becomes more serious in the pre-equalization schemes.

Fig. 6 compares the effective throughput (bit per symbol, BPS) of the proposed adaptation scheme with that of the conventional subcarrier-by-subcarrier adaptation scheme with/without taking into account signaling overhead. The effective throughput is defined as the throughput of real data except the signaling overhead in an OFDM symbol. A target BER of the system is 10^{-2} and the subband size is 32, and thus, the whole frequency band consists of 32 groups. The channel condition is assumed to be known to the transmitter from the reliable feedback information and to be time-invariant during a channel estimation delay feedback time. The transmitter changes only the modulation mode. The modulation modes used in simulation are no transmission, BPSK, QPSK, and 16QAM, and then, the maximum BPS is 4. The subcarrier-by-subcarrier adaptation scheme exhibits the best performance in terms of throughput, without signaling consideration, as expected. In this model, we assume that the channel varies slowly and the signaling overhead is negligible.

However, if the channel varies fast, 1024 QPSK symbols should be sent for signaling information in the subcarrier-by-subcarrier adaptation scheme since the number of modulation modes is 4 and the number of subcarriers is 1024. 32 QPSK symbols for signaling are transmitted in the proposed system because the 32 subcarriers are grouped into a subband which is applied to one modulation mode. In this model, we assume the situation that we should send signaling information about the transmission parameters in each transmission since the channel varies very quickly. We assume the signaling information is sent according to the adaptive transmission policy for computing the throughput as an upper bound though the signaling information is sent in a reliable manner in general. The proposed scheme yields a better throughput than the subcarrier-by-subcarrier scheme in this model. Actually, the performance shows the upper and lower bounds according to the channel variation of both systems. The proposed system is robust in both situations and simple since the adaptive technique is applied to the several subbands not to the whole subcarriers.

4. Conclusions

A subband spreading technique is proposed to compensate for frequency selective fading channel. Simulation results show that the proposed scheme yields a significant performance improvement in both uncoded and coded OFDM systems. Furthermore, the proposed scheme outperforms the pre-equalization scheme even in the channel whose information is correctly known to the transmitter. The proposed subband spreading technique can be applied to adaptive modulation systems to reduce the hardware complexity and signaling overhead. The proposed adaptive modulation algorithm yields a better throughput performance in a fast channel environment.

5.Acknowledgement

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6. References

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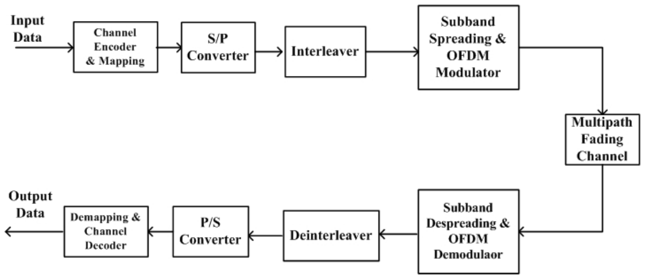

Fig.1. Overall block diagram of the proposed systems

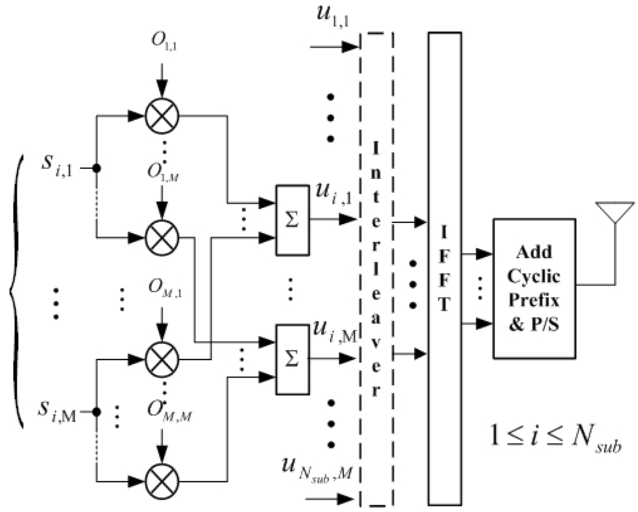

Fig.2. Subband spreading and OFDM modulation of the proposed systems

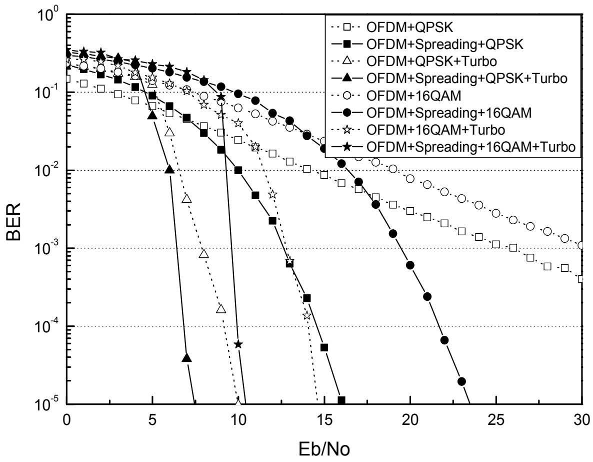

Fig.3. BER performance comparison between the proposed and conventional systems.

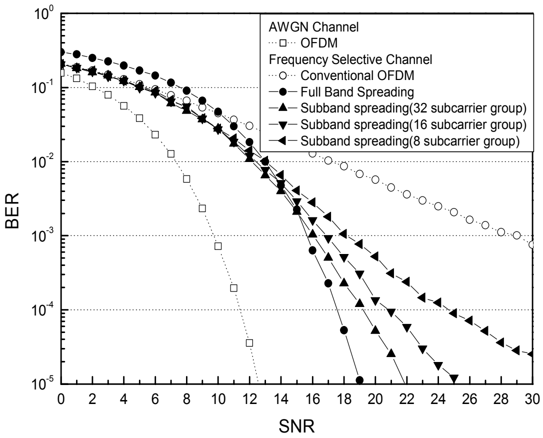

Fig.4. BER performance according to the number of subcarriers per subband in uncoded system.

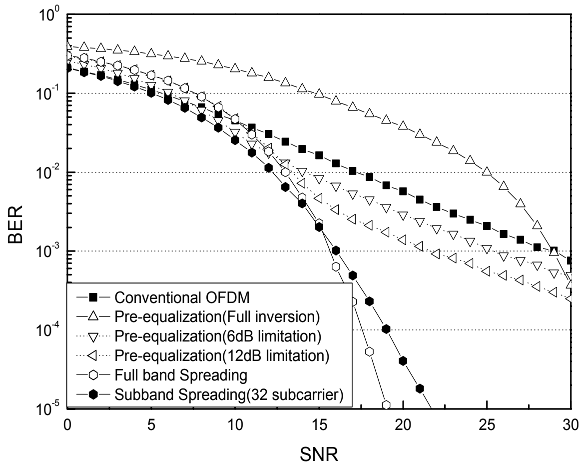

Fig.5. Performance comparison between the proposed system and the pre-equalization system

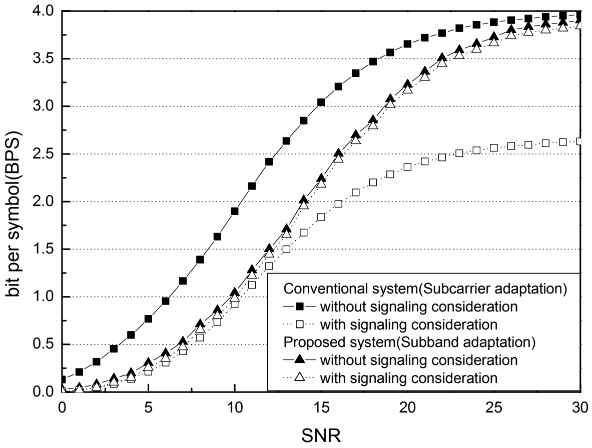

Fig.6. Effective BPS of the proposed adaptive modulation scheme