A New Turbo-Coded OFDM System Using Orthogonal Code Multiplexing

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Abstract - **In this paper, we propose a new transmission scheme that can improve greatly the performance of turbo-coded orthogonal frequency division multiplexing (OFDM) systems by making all the turbo-coded symbols have the same reliability for OFDM transmission over a frequency selective fading channel. The same reliability, that is, the same fading can be accomplished through multiplexing of turbo-coded symbols using distinct orthogonal codes and spreading over the whole effective subcarriers (hereafter, called as the orthogonal code multiplexing (OCM)). This idea of the same fading for all symbols is the key of the performance improvement using the proposed scheme. As for the orthogonal code selection, a set of Walsh codes could be the best selection in terms of the complexity. However, in the fast Fourier transform (FFT) implementation of OFDM, the number of the whole effective subcarriers may be slightly less than the number of FFT points used. Hence, we choose the set of the discrete Fourier transform (DFT) basis sequences as a good substitute for a set of orthogonal codes, since the code set can hold the orthogonality irrespective of the length. We perform computer simulations using the Log-*maximum-a-posteriori* (Log-MAP) algorithm for iterative decoding in order to assess the performance of the proposed system and to compare it with that of the conventional turbo-coded OFDM system.**

I. INTRODUCTION

Following the invention of so-called "turbo codes" in 1993 [1], a number of turbo-coded systems exploiting the powerful error correction capability have been developed [2-4]. Many factors affect the performance of turbo codes. They include the interleaver size and structure, the generator polynomials and constraint lengths of components codes, the decoding algorithm, the number of iterations, and so on [5]. Using a longer interleaver size can improve greatly the performance of the turbo-coded systems. In practice, however, the maximum interleaver size should be limited due to the Doppler rate and/or the permissible processing delay. In addition, the performance of turbo-coded systems gets improved as the constraint length increases. Following the results in [5], the code with the constraint length K=4 was about 0.25 dB better than that of the code with K=3 at a BER of 10^{-4}, and in the case of K=5, a minor improvement of about 0.1 dB was obtained. However, the decoding complexity also increases exponentially as the constraint length increases.

The turbo codes have been originally proposed for BPSK mapping. For the high data rate transmission, several attempts have been done to incorporate turbo codes into higher order modulations using Gray mapping [6] and two Ungerboeck-type codes in combination with trellis coded modulation (TCM) [2]. However, in contrast with their remarkable performance in an additive white Gaussian noise (AWGN) channel, the performance over a frequency selective fading channel is not satisfactory due to the intersymbol-interference (ISI), especially as the transmission rate gets higher [7].

OFDM seems to be the most suitable multiplexing technique for a high-speed data transmission over a frequency selective fading channel [8]. Hence, it is quite natural to consider the combination of OFDM and turbo-codes as a promising means for the next-generation high-speed wireless communication. In OFDM systems, however, each symbol suffers from a different fading due to the frequency selectivity of the channel. In the turbo-coded OFDM systems [9], the frequency selectivity again is the major factor of the performance degradation of the turbo-coded OFDM systems since each turbo-coded symbol suffers from a different fading, that is, each symbol at the receiver has a different reliability.

In this paper, we propose a new transmission scheme that can improve greatly the performance of turbo-coded OFDM systems without invoking to longer interleaver size. The scheme makes all the turbo-coded symbols have the same reliability in OFDM transmission over a frequency selective fading channel. The same reliability, that is, the same fading for all the symbols can be accomplished through multiplexing using distinct orthogonal codes and spreading over the whole effective subcarriers to be transmitted. This idea of the same fading for all symbols is the key of the performance improvement. As for the orthogonal code selection, we choose the set of the DFT basis sequences as a good set of orthogonal codes, since the code set can hold the orthogonality irrespective of the length. We perform computer simulations using the Log-MAP algorithm for iterative decoding to assess the performance of the proposed system and to compare it with that of the conventional turbo-coded OFDM system.

II. TURBO-CODED OFDM SYSTEM USING OCM

The block diagram of the proposed turbo-coded OFDM system is shown in Fig. 1. A generic turbo encoder first encodes the input data sequence. We use the component code with the constraint length K=3 and the generator polynomials (7,5). The structure of the turbo encoder used is shown in Fig. 2. We also use the pseudorandom interleaver.

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In general, the redundancy bits are punctured before mapping in order to obtain a proper code rate for transmission. The block diagram for the mapping process including puncturing is shown in Fig. 3. In our work, we choose a code rate of 1/2 by puncturing two redundancy bits alternatively. Following the puncturing, the turbo-encoded bit sequence is mapped into the sequence of appropriate modulation symbols such as QPSK and QAM symbols.

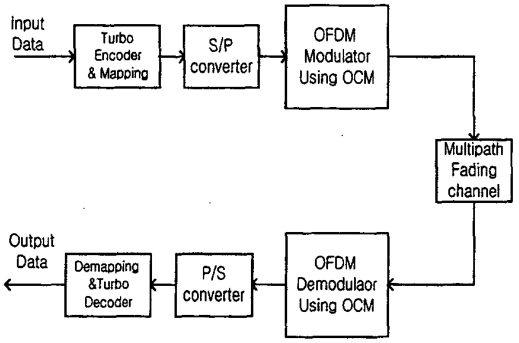

Fig. 1. Block diagram of the turbo-coded OFDM system using OCM.

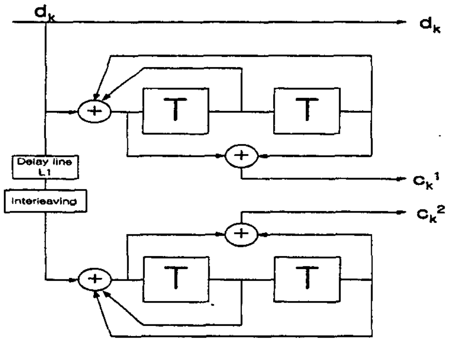

Fig. 2. Structure of a generic turbo encoder with the generator polynomials (7,5).

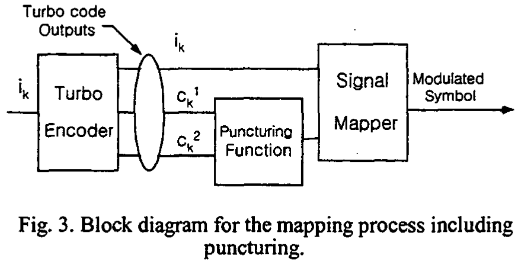

Fig. 3. Block diagram for the mapping process including puncturing.

After serial-to-parallel (S/P) conversion for OFDM symbol stacking, each coded symbol is assigned to a distinct orthogonal code with the same length as the number of effective subcarriers to be transmitted. Hence, M turbo-coded symbols are orthogonally multiplexed using M distinct orthogonal codes for OFDM transmission over the whole effective subcarriers. Fig. 4 shows the structure for OFDM modulator using OCM. In the i-th OFDM symbol, M turbo-coded symbols, $\{d_{i,m}\}, m=1,\cdots,M$, are multiplexed using M distinct orthogonal codes with the length M, the number of the whole effective subcarriers, and then the multiplexed sequence is spread over the whole effective subcarriers before OFDM transmission.

As for the orthogonal code selection, if $M = 2^n$ (n: integer), the set of Walsh codes with the length 2^n is the best selection in terms of the system complexity. In the FFT implementation of OFDM, the transmission using all 2^n subcarriers may not be feasible. In that case, using truncated Walsh codes could not hold the orthogonality any more, thus causing some amount of self-interference. Therefore, we should find a set of orthogonal codes that can hold the orthogonality irrespective of the length. The DFT orthogonal basis sequence with the length M is a good substitute for us and is defined as

$$\mathbf{O}_{m+1}^{(M)} = \left[1, e^{\frac{j2\pi m}{M}}, \ldots, e^{\frac{j2\pi m(M-1)}{M}}\right], \quad m = 0, \ldots, M-1. \quad (1)$$

Note that the sequence can be represented in a closed form and has the equal energy property.

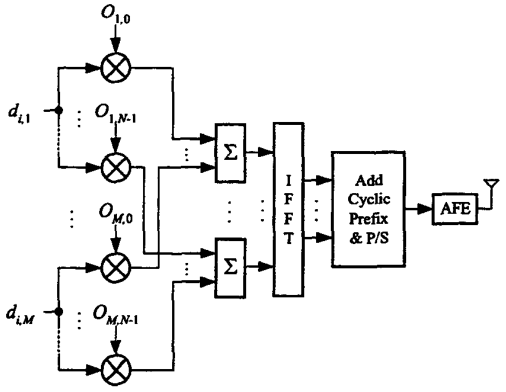

Fig. 4. Structure of OFDM modulator using OCM.

Fig. 5 shows the structure of OFDM demodulator using OCM. The receiver performs the inverse functions performed in the transmitter in the reverse order except for one-tap equalization to retrieve information symbols using OC demultiplexing after frequency-selective fading compensation. In our work, we use the minimum mean-squared error (MMSE) combining method for one-tap equalization because of its excellent performance and robustness.

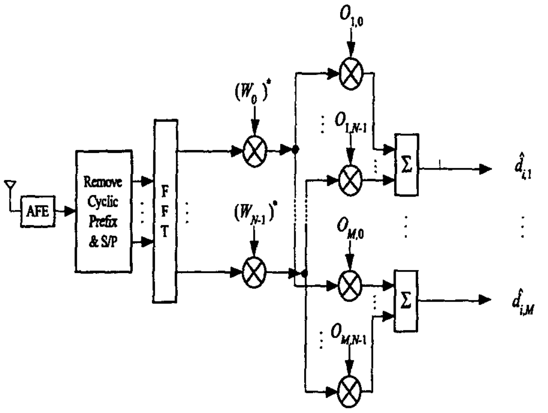

Fig. 5. Structure of OFDM demodulator using OCM.

The demodulated symbols through OC demultiplexing are fed into the log-likelihood ratio (LLR) computation logic following the demapping process. The input of the turbo-decoder is made up of a soft decision value associated to each turbo-coded bit [2]. Fig. 6 shows the block diagram for the LLR computation process and turbo decoding process. The LLR computation logic calculates the bit likelihood ratio from the arbitrary modulated symbols.

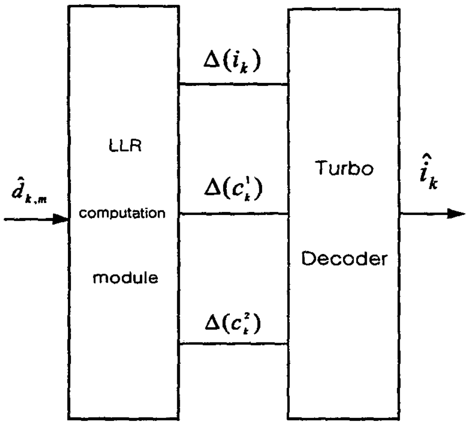

Fig. 6. LLR computation logic and turbo decoder.

So far, there have been several categories for iterative decoding algorithms such as MAP, Log-MAP, Max-Log-MAP, soft-output Viterbi algorithm (SOVA), and so on [10]. The symbol-by-symbol MAP algorithm is optimal, but it has some difficulties in terms of implementation because of the necessity of nonlinear functions and a larger number of computations. The Log-MAP algorithm is equivalent to the MAP algorithm in terms of the performance. Using Log-MAP instead of MAP can reduce the computational complexity by transforming the multiplications into the additions in the logarithm domain. The Max-Log-MAP algorithm is a simplified version of the Log-MAP algorithm using the approximation of the LLR for information bits [10].

In this paper, we use the Log-MAP algorithm for iterative turbo decoding because of its accuracy and simplicity.

III. SIMULATION RESULTS

We performed computer simulations to assess the performance of the proposed turbo-coded OFDM system in frequency selective fading environments. Each OFDM symbol carries 192 turbo-coded symbols using 192 effective subcarriers out of 256 subcarriers (i.e., M=192, N=256). The remaining OFDM parameters are as follows: the bandwidth BW=25 MHz, the effective symbol duration $T_u = 10.24\mu s$ and the cyclic prefix duration $T_{cp} = 2.56\mu s$. We also used the channel impulse response with the root-mean-square (RMS) delay spread of $0.1\mu s$ and the maximum delay spread of $1\mu s$.

Fig. 7 shows the BER performance of both the proposed system and conventional one as a function of SNR. We used the QPSK mapping and the component encoder with code rate of 1/2. We also selected the component codes with the constraint length K=3 for real-time implementation to be possible. Hence, each subcarrier carries one information bit effectively. We use the log-MAP algorithm for the turbo decoding and the iteration number of three. From Fig. 7, in a frequency selective fading channel, the proposed system works quite better that the conventional one. The proposed system can save about 2dB over the conventional one at the BER of 10^{-4}. In addition, note that two graphs have different slopes. Hence, as the required BER gets lower below 10^{-4}, the proposed system would be more effective because, in the conventional system, deep faded subcarriers might be in error even at high SNR values. However, we know that two systems have the same BER performance in an AWGN channel.

Fig. 8 shows simulation results using 8-PSK mapping. We used the same turbo encoder as that in the previous experiment except for the code rate of the component code. In this experiment, we used the turbo encoder with the code rate of 2/3 and 8-PSK mapping. Hence, each subcarrier conveys two information bits effectively. We also used the Log-MAP algorithm for the turbo decoding and the iteration number of three. One point is that as the frequency efficiency increases, the effective interleaver size in turbo encoder is increased because the decoding would be performed at the unit of OFDM symbol block. From Fig. 8, we again can see the proposed system saves about 2dB over the conventional one to achieve the BER of 10^{-4}.

IV. CONCLUSIONS

This paper has investigated the new turbo-coded OFDM system for high-speed data transmission by combining the powerful error correcting capability of turbo codes and the high-rate transmission capability of the OFDM over a frequency-selective fading channel.

One of main factors that affect the turbo code performance is the interleaver size. As the interleaver size increases, the performance of turbo codes gets improved. However, for many applications, such as speech transmission systems, the larger delay inherent in using longer interleaver size may not be acceptable due to the maximum allowable packet size and the processing delay requirement. Therefore, to design a turbo-coded system effective in a shorter frame is one of important research areas. In our work, we proposed the effective turbo-coded OFDM system for the use in the systems with a short frame length. By the computer simulations, we found the OFDM transmission using OCM gives a significant gain as compared with the conventional system over a frequency selective fading channel.

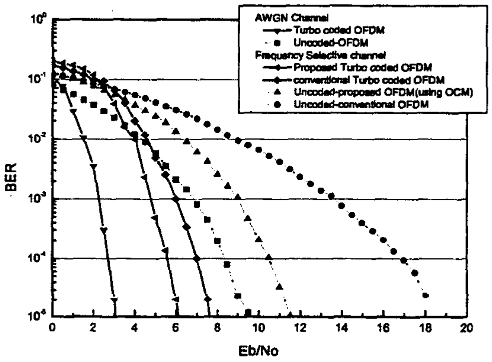

Fig. 7. BER performance of two turbo-coded OFDM systems using QPSK mapping.

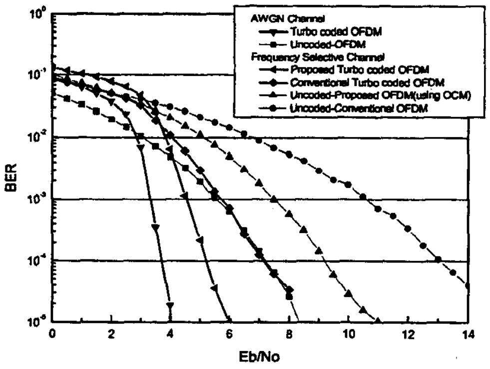

Fig. 8. BER performance of two turbo-coded OFDM systems using 8-PSK mapping.

ACKNOWLEDGMENTS

This work was supported in part by the grant No. R01-1997-00026 from Korea Science & Engineering Foundation, the National Research Lab. Project and IC Design Center in Korea.

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