A Numerically efficient power optimization scheme for coded OFDM systems in achieving minimum frame error rate

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Abstract- Coded OFDM is a transmission technique that is used in many practical communication systems. In a coded OFDM system, source data are coded, interleaved and multiplexed for transmission over many frequency sub-channels. In a conventional coded OFDM system, the transmission power of each subcarrier is the same regardless of the channel condition. However, some subcarrier can suffer deep fading with multi-paths and the power allocated to the faded subcarrier is likely to be wasted. In this paper, we compute the FER and BER bounds of a coded OFDM system given as convex functions for a given channel coder, inter-leaver and channel response. The power optimization is shown to be a convex optimization problem that can be solved numerically with great efficiency. With the proposed power optimization scheme, near-optimum power allocation for a given coded OFDM system and channel response to minimize FER or BER under a constant transmission power constraint is obtained.
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Index Terms- FER, BER, OFDM, Convex Optimization, Near-Optimum power allocation

I. INTRODUCTION

In recent years, the demand for high data rate transmission has increased in wireless communications. High data rate transmission may require a very complex equalizer which is not desirable in wireless communications. Orthogonal Frequency Division Multiplexing (OFDM) is a transmission scheme for which a receiver can be implemented that is easily implemented without an equalizer. Therefore, the OFDM technique has attracted attention for many wireless applications. OFDM is a transmission technique that divides the data into several frequency sub-channels whose bandwidth is less than the total data rate. The uncoded performance of an OFDM system can be different in different frequency selective channels. To solve this problem, some solutions that are used include discrete multi-tone (DMT) and coded OFDM. In the case of DMT, the bits and power are allocated to each sub-channel with a water-filling optimization. However, a DMT system does not provide frequency diversity, since each sub-channel is coded independently. In this paper, equation for the bit error rate (BER) and frame error rate(FER) bounds of a coded OFDM systems. The upper bounds can be expressed as sums of exponential functions or sums of Q-functions that are convex functions. Therefore, the power allocation to minimize the target BER or FER for a total transmission power constraint is shown to be a convex function. Optimization problem by solving the present convex power optimization problem, we can improve the performance of a coded OFDM system compared with that of conventional constant power allocation. This paper shows the performance improvements with the proposed power allocation. The paper is structured as follows. Section II describes the system model used in this paper. The proposed power optimization is shown to be convex optimization in Section III.

II SYSTEM MODEL

In this section, the system model of the proposed coded OFDM system used in the proposed power allocation scheme. The system model is based on bit-interleaved coded modulation [2] [3]. However, it is also possible to use trellis-coded modulation [4] with some modification of the model for the power allocation of the coded OFDM system. Figure 1 shows the block diagram of the proposed coded OFDM system. Information bits are coded with the channel encoder. After channel encoding, the number of coded bits is larger than that of the uncoded information bits. The coded bits are interleaved at the inter-leaver to achieve frequency diversity.

The interleaved bits are demultiplexed into several sub-channels. The number of interleaved bits for each sub-channel islog2M, where M is the constellation size of the modulation. The demultiplexed bits are mapped to a constellation point for the given modulation scheme. For bit-interleaved coded modulation, a Gray mapping is usually used. After mapping, the transmitter sends the modulated symbols to the channel.

The channel is wireless channel is assumed to be $|H_i|^2$ and quasi-static within the sub-channel for the transmission period of a frame. After experiencing the Channel, AWGN noise is added to the signal at the receiver. At the receiver, the received signal is demodulated. Usually a DFT is used to convert the time-domain signal to a frequency-domain signal. After the DFT, the received signal .The soft metric is de-interleaved at the de-interleaver and sent to the decoder. The receiver also estimates the gain and phase components of the channel response for coherent detection. Channel gain plays an important role and power allocated depends upon channel gain

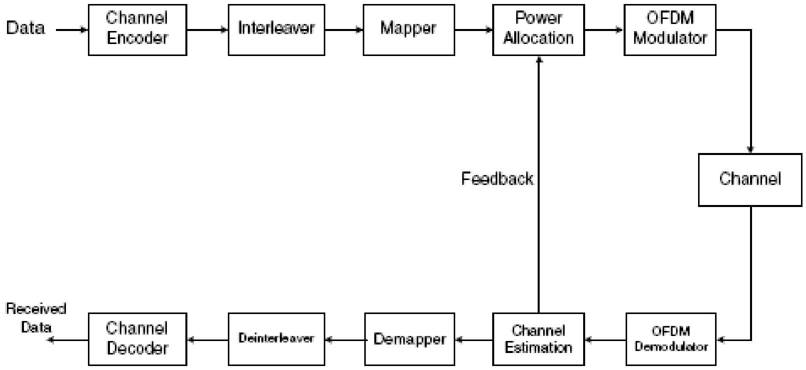


Fig 1.Block diagram of the a coded OFDM system

In the proposed power allocation scheme, a feedback link from the receiver to the transmitter is assumed. The receiver sends the channel response information to the transmitter and the transmitter computes the power level of each sub-channel. The transmission power of each sub-channel is adjusted based on the computed power levels.

III POWER OPTIMIZATION

A. Performance Bounds:

With the system model presented described in the last section, the performance of a coded OFDM system can be represented by upper bounds. For simple analysis, assume that the channel code is linear and the modulation is BPSK or QPSK. With these linear conditions, can fix a codeword c0 as the transmitted codeword. For a general non-linear case, an average over C0 may be required. There is no closed form for the BER or FER of coded systems except for some trivial cases that include uncoded systems and orthogonal coding. Upper bounds are the conventional method for the performance analysis of coded systems. The upper bounds of coded systems are obtained with the union bound technique. Using the union bound technique, the upper bounds of BER and FER are given by

$$P_{FER} \leq \sum_i Z_i \quad (1)$$

Where Z_i is the pair-wise error probability (PEP) that a codeword

$$P_{FER} \leq \frac{1}{N_b} \sum_i Z_i \, . \, b_i \quad (2)$$

Where N_b the total number of information is bits in a frame and b_i is the Hamming distance of the source data.

The pair-wise error probability Z_i is given by the following equation

$$Z_i = Q\left(\sqrt{\frac{2D_i^2}{N_0}}\right) \quad (3)$$

Where D_i is the is the distance between the all-zero codeword and the i-th codeword at the receiver.

$$D_i^2 = \sum_k |H_k|^2 . P_k . E_{i,k}^2 \quad (4)$$

Where P_k is the allocated power at the k-th sub-channel and $E_{i,k}^2$ is the sum of the squared Euclidian distance of coded symbols located at the k-th carrier of the i-th codeword, when unit power is allocated to each sub channel .From (1), (2) and (3), BER and FER of a coded OFDM system. The present system is upper bounded by sums of Q functions or sums of exponential functions. The FER and BER bounds are given as

$$P_{FER} \le \sum_i Q\left(\sqrt{\frac{2D_i^2}{N_0}}\right) \le \sum_i \frac{1}{2} exp\left(\frac{-D_i^2}{N_O}\right) \quad (5)$$

$$P_{BER} \le \sum_i \frac{b_i}{N_b} Q\left(\sqrt{\frac{2D_i^2}{N_0}}\right) \le \sum_i \frac{b_i}{2N_b} exp\left(\frac{-D_i^2}{N_O}\right) \quad (6)$$

The BER and FER upper bounds in (6) or (7) are expressed as sums of exponential functions or Q-function. These upper bounds can be shown to be convex functions. The target of the proposed power allocation is to minimize the FER bound in (5) or the BER bound in of a coded OFDM system under this constraint

$$\sum_k P_k \le P_T \quad (7)$$

$P_K \ge 0$ For k=1……..N_c (8)

Where P_K is the transmission power of the k-th sub-channel, P_T is the total transmission power and is N_c is the number of Sub-channels in a coded OFDM system. The upper bounds on FER and BER for QAM modulation are convex functions, since FER and BER are linear sums of conditional FER's and BER's which are convex functions [6]. Therefore, the FER or BER bound of a coded system can be given as a sum of Q functions or a sum of exponential functions which are convex functions. The constraints for the power optimization of (7) and (8) are also linear inequalities. Therefore, power optimization to minimize the FER or BER bound under the constant power constraint is a convex optimization problem. Generally, there is no analytical solution for a convex optimization problem. However, there are many numerical methods which can solve the problem efficiently [5]. Most of the numerical methods are based on iteration. The number of iterations to obtain an optimized solution depends on the cost function and choice of a numerical method. The upper bounds to be log-convex functions [5]. For most systems, it requires less number of iterations to solve the problem using the cost functions .It has so many advantages. Since the proposed power optimization uses upper bounds as the cost functions, it cannot be said that the proposed power optimization is optimal. However, the upper bound approach is the best method to analyze the performance of the coded system, since it is impossible to obtain a closed form formula for the performance of a coded system except some trivial cases. Furthermore, the upper bound is very close to the actual performance for the most Eb/N0 range of interest. Therefore, it can be said that proposed power optimization provides a near optimum power allocation for the given channel encoder, modulation scheme and inter-leaver.

IV RESULTS

A. Simulation Environments

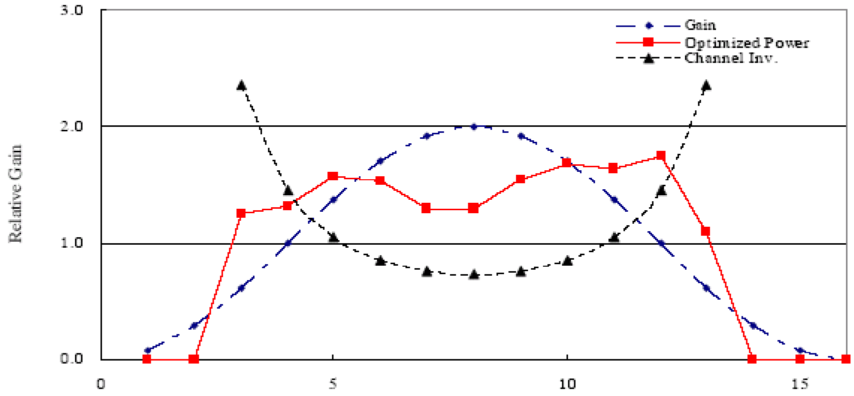
In this section, simulation environments are presented for the coded OFDM system used for performance evaluation. For the performance simulation, a simple coded OFDM system with 16 sub-channels is used. The basic coding and modulation scheme for the coded OFDM system is bit-interleaved coded modulation. For channel coding, a convolutional code with rate rc = 1/2 and constraint length k = 9 is used. A simple block inter-leaver and estimation and an ideal Viterbi decoder are assumed. It is also assumed that there is no error in the feedback information from the receiver to the transmitter. For simple comparison, the average channel gain is normalized so that

$$\frac{1}{N_c}\sum_{i=1}^{N_c} |H_i|^2 = 1 \quad (9)$$

Where Nc is the number of sub-channels of the OFDM system. The most computationally demanding part for the proposed power optimization is computing the cost function. The cost function is the FER or BER upper bound of the coded OFDM system. In this letter, upper bounds are computed using the Nev significant error events of the convolutional code. The Nev significant error events are computed and all possible time shifts of the error events are considered in computing the coefficients of the upper bounds. The complexity to compute the upper bound is that of decoding 10 - 1000 frames, depending on the number of terms and input variables used for the bounds. Nev = 1000 is used to compute the upper bound of the example system. Ten iterations are used for the optimization with the interior point method [4].

B. Performance Results

The performance results are obtained for the coded OFDM system described in IV-A with the previous conventional constant power and the proposed power allocations is the power allocations and the channel gain for a channel response h1(t). The channel gain has a peak at the center of the sub-channels and nulls at the both ends of the sub-channels. The solid line shows the power allocation with the proposed power optimization method. The dotted line shows the power allocation obtained from channel Inversion with some low gain channels dropped. The power allocated to a sub-channel is the proportional to the inverse of the channel gain in the case of channel inversion technique The channel inversion would require infinite power for the null bands. Therefore, the performance of channel inversion improves if some sub-channels with lower gains are not used. The figure shows the best performance power allocation for channel inversion with bad channel dropped. Fig. 2(b) shows the performance results for the coded OFDM system with the channel response h1(t). The conventional coded OFDM with constant power allocation shows the worst performance. Using the channel inversion technique with bad channels dropped improves the performance of the coded OFDM system by 0.5 - 0.6 dB. However, with the proposed power optimization, the performance gain is about 1.2 dB compared with the conventional constant power allocation. An OFDM system with 7 sub-channels and a data frame composed of four information bits. For the channel coding, Consider a simple (7,4) Hamming code which has a minimum Hamming distance 3. The Hamming code is designed to correct one bit error in the codeword with hard decision decoding. Another widely used transmission scheme is coded OFDM. In a coded OFDM system, data are encoded by a channel coder, interleaved and divided into several frequency sub-channels. Due to the channel coding and interleaving, frequency diversity can be archived. This coded OFDM is used in practical communication systems including Wireless LAN. However, the power allocated to the nulls of the frequency response is likely to be wasted in a coded OFDM system. Therefore, if the power is allocated to the best sub-channels, the performance of a coded OFDM can be improved .The FER and BER of a coded OFDM system are bounded by sums of exponential functions or by sums of Q-functions. In this paper, these bounds are shown to be convex functions. Therefore, power allocation to minimize the target BER or FER is shown to be a convex optimization problem with a total transmission power constraint. With the power allocation obtained from the optimization, the performance of a coded OFDM system is improved. The proposed scheme provides a near-optimum power allocation for a given channel coding, interleaver and modulation The performance of the proposed allocation schemes is simulated with a simple OFDM system in static and dynamic channel environments. From the simulation and analytical results, we show that the proposed allocation schemes provide performance gain over conventional coded OFDM systems. In static channel environments, DMT shows the best performance. The performance of coded OFDM with constant power allocation is worse than that of DMT. The proposed power allocation improves the performance of coded OFDM systems. For the channel models of this dissertation, the proposed schemes can achieve 1-2 dB performance gain over the conventional coded OFDM systems.



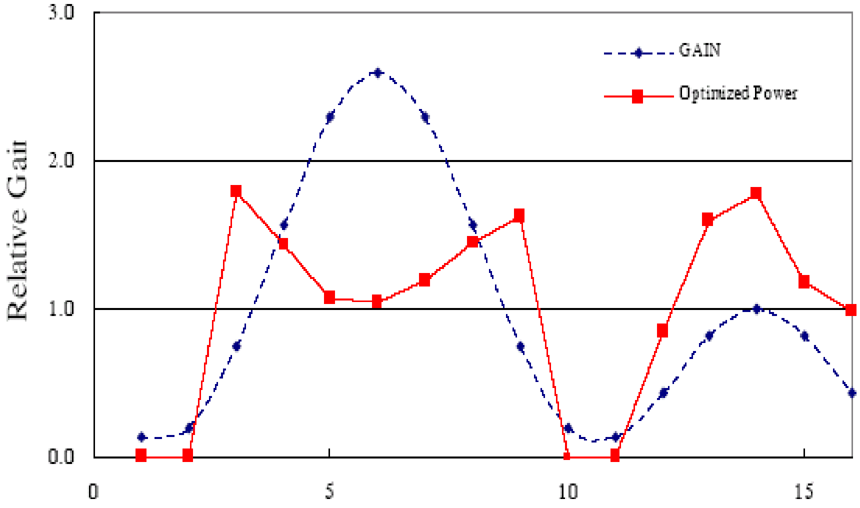
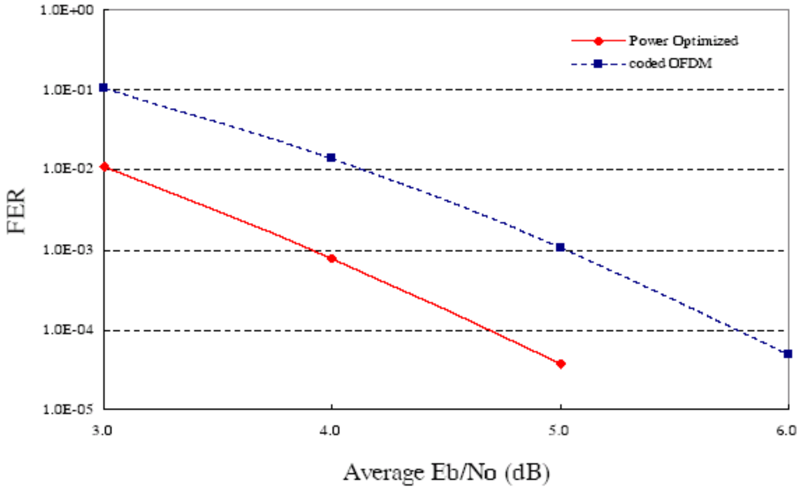


Fig 2 Performance of channel response $h_1(t)$

The power allocations and the channel gain for another channel response h2(t). The channel gain in the frequency domain shows two peaks near sub-channel six and fourteen. The power allocation from the proposed optimization is shown as a solid line. The power allocation near sub-channel six is similar to channel inversion. However, for the power allocation near sub-channel fourteen, the higher The channel gain, the higher the allocated power level. The performance results for the coded OFDM system with the channel response and the power allocations given in above figure. With the power allocation obtained from the proposed optimization, the performance gain is about 1.2 dB.

V CONCLUSION

In conventional coded OFDM systems, the power of each Sub-channel is the same regardless of the channel and response. With a feedback link from the receiver to the transmitter, the transmitter can optimize the power of each sub-channel to minimize the FER or BER under constant total transmission power constraint. In this paper, it is shown that the present power optimization problem can be solved with convex optimization. Simulation results shows that the proposed power optimization can improve the performance of coded OFDM systems.



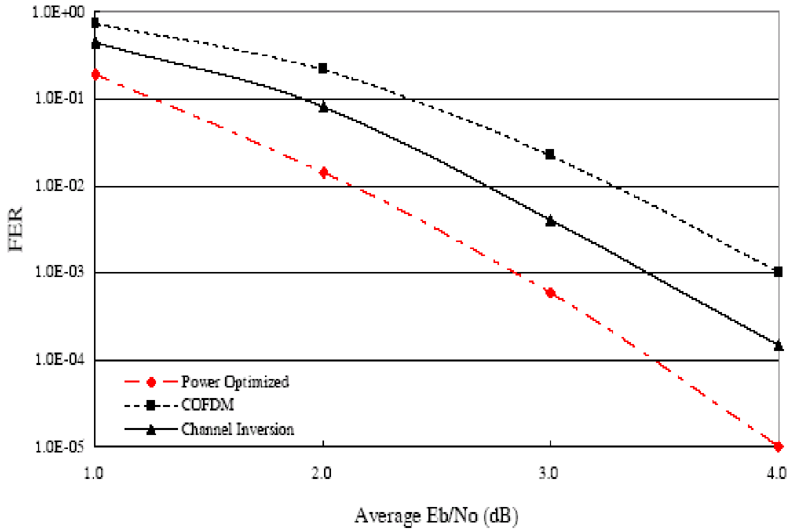


Fig 3 Performance of channel response $h_2(t)$

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