Effect of MAI and Frequency Offset on the Performance of Coded MC-CDMA Synchronous Downlink Systems with MSK Modulation

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Abstract — Effects of Multiple Access Interference (MAI) and frequency offset on bit error rate (BER) performance of synchronous Coded Minimum Shift Keying/Multi-Carrier Code Division Multiple Access (MSK/MC-CDMA) systems were considered using Standard Gaussian Approximation (SGA). Simulations were carried out in AWGN and frequency selective Rayleigh fading channels. Results showed that the un-coded MSK/MC-CDMA system under investigation outperforms the corresponding system with BPSK modulation. Furthermore, coded MSK/MC-CDMA can achieve a better performance than the theoretical performance in AWGN channel for a single user, even in the presence of MAI.

I. INTRODUCTION

Multi-carrier code division multiple access (MC-CDMA) scheme combines high bandwidth efficiency in addition to robustness against distortion caused by multipath frequency selective fading channels. MC-CDMA is an interesting multiple access technique for future mobile communications. Specifically, MC-CDMA allows for low complexity receivers in the downlink, since the use of multi-carriers combats the effect of inter-symbol-interference (ISI) [1], [2]. However, the Performance of this system is sensitive to both Multiple Access Interference (MAI), and to frequency offset [3], [4].

A modulation Scheme that is considered for mobile communication systems is the Minimum shift keying (MSK) modulation scheme, as it is a power efficient modulation scheme with constant envelope and has a self synchronizing capability [5], [6].

The use of random spreading gives an upper bound on the bit error rate (BER) performance, and the exact analysis of BER performance under these conditions seems to be significantly difficult. Hence efficient approximations are desirable. The simplest well known approximation for BER performance is the Standard Gaussian Approximation (SGA), in which the overall effect of MAI in a symbol interval is approximated by a Gaussian random variable. Moreover, it can be generalized for linear modulations and error control coding [7], [8], [9].

Error control coding can be used with MC-CDMA systems with no penalty in bandwidth due to the addition of redundant bits. This makes the application of error control coding very attractive in MC-CDMA systems. The error control coding technique considered in this paper is the cyclic block code.

The organization of this paper is as follows. First, Section II includes a description of the system model and gives an analysis for the BER performance in AWGN channel using SGA. Then, Section III gives numerical results obtained from simulations in AWGN and frequency selective fading channels for both un-coded and coded MSK/MC-CDMA synchronous downlink systems for various values of interferes. Finally, conclusions are provided in Section IV.

II. SYSTEM MODEL AND PERFORMANCE ANALYSIS

The system under investigation has $K$ users with corresponding $K$ sequences of symbols. For the un-coded system, the $K$ sequences are obtained after spreading each with spreading factor ($N$) and MSK modulation. If coding is applied, the sequence is first coded and then MSK modulated after it is being spread. It is assumed that the spreading factor is equivalent to the number of sub-carriers ($M$). The effect of the $K-1$ interferers on the desired user is known as MAI [1]. Employed system applies random spreading codes under the assumption of perfect synchronization. The spreading codes are assumed to be dynamically changing from one bit to the other, and they are independent and identically distributed (i.i.d). All users are assumed to have equal powers $A_k = A$.

The $K$ users with MSK modulated symbols are spread and added. The summation of the $K$ users' $m$-th chip ($m=0,1,\ldots,M-1$) during the $i$-th bit interval is given by:

$$v_i(\theta) = \sum_{k=1}^{K} a_k^i (\theta - \theta_0) d^{i-1} \alpha_k \exp(j\pi f_0)$$

Where, $a_k^i$ represents the data bit of $k$-th user during $i$-th data bit, and $a_k^i$ is the $m$-th chip in the $i$-th bit interval for the $k$-th user. The parameter $\alpha_k$ represents $k$-th user carrier phase and $\theta_0$ is the time offset required for MSK.
The baseband received signal impaired with frequency offset is given as [1]:

\[ r = \frac{1}{\sqrt{M}} \sum_{h=0}^{M-1} y_m \exp(j2\pi(m+\varepsilon)\frac{h}{M}) \quad h = 0, 1, \ldots, M - 1 \]  

(2)

Where, \( \varepsilon \) is the normalized frequency offset.

**A. BER Performance of Un-coded MSK/MC-CDMA System**

The effect of MAI on the BER performance in AWGN channel using SGA for BPSK modulation with the assumption of chip and phase alignment for all users is as given in [5]:

\[ P_b = Q\left( \sqrt{\frac{(2E_b / N_0)N}{K-1}} \right) \]  

(3)

Where, \( E_b/N_0 \) is the bit energy-to-noise ratio. However for the case of MSK modulation, since it is a continuous phase frequency modulation technique, the effect of MAI is equivalent to the case where interfering signals are chip aligned with random phases. Thus, the probability of bit error is influenced by a factor of \( \sqrt{2N} \) instead of \( \sqrt{N} \) for the case of BPSK [5]. Thus, BER is expressed as:

\[ P_b = Q\left( \sqrt{\frac{(2E_b / N_0)2N}{K-1}} \right) \]  

(4)

This means that the BER performance of MSK/MC-CDMA systems outperform BPSK/MC-CDMA systems when the effect of MAI is considered.

Typically, the frequency offset has the same effect on both systems. The probability of bit error with frequency offset assuming MSK modulation is expressed as:

\[ P_b = Q\left( \sqrt{\frac{(\sin(\pi\varepsilon)^2(2E_b / N_0)2N)}{(\pi\varepsilon)^2(K-1)}} \right) \]  

(5)

**B. Performance of MSK/MC-CDMA System with Error Control Coding**

Cyclic codes are linear block codes that have the advantage of being easy to encode, and have very efficient decoding schemes. Furthermore, cyclic codes are easy to implement using modern integrated circuit techniques [10, 11, 12, 13]. The codes considered in this paper are cyclic codes with code rates 7/15, 2/6, and 2/10.

The relation of the code-symbol energy per noise spectral density \( (E_c/N_0) \), to information bit energy per noise spectral density \( (E_b/N_0) \) is given as [14]:

\[ \frac{E_c}{N_0} = \left( \frac{k}{n} \right) \frac{E_b}{N_0} \]  

(6)

Where, \( k \) is the number of message bits, and \( n \) is number of the codeword bits.
The effect of frequency offset on coded MSK/MC-CDMA systems was investigated via simulation for various values of $\epsilon$ and $K$ in AWGN and in frequency selective fading channels. Fig. 10. and Fig. 11 show simulated BER of coded MSK/MC-CDMA using the code (6,2) and the code (10,2) in AWGN channel for various values of $\epsilon$ and $K$, respectively. Moreover, Fig. 12. and Fig. 13. show simulated BER of coded MSK/MC-CDMA in frequency selective fading channel for various values of $\epsilon$ and $K$ using the code (6,2) and (10,2) respectively. Simulated BER performances show the sensitivity of these systems to frequency offset.

IV. CONCLUSIONS

The effect of MAI on BER performance of MC-CDMA systems with MSK modulation is less severe than the corresponding systems with BPSK modulation due to phase continuity. This applies to AWGN and Rayleigh frequency selective fading channels. Nevertheless, the BER performance of these systems is sensitive to carrier frequency offset. Error control coding can be applied to MC-CMDA systems with no extra bandwidth requirements. Some coded-MSK/CDMA systems with MAI can outperform the corresponding un-coded system with a single user.

REFERENCES

Fig. 4. Simulated BER Performance of coded MSK/MC-CDMA, code (15,7), $N=16$ in AWGN channel for various values of $K$.

Fig. 5. Simulated BER Performance of coded MC-CDMA with MSK modulation, code (6,2), $N=16$ in AWGN channel for various values of $K$.

Fig. 6. Simulated BER Performance of coded MSK/MC-CDMA, code (10,2), $N=16$ in AWGN channel for various values of $K$.

Fig. 7. Simulated BER Performance of coded MSK/MC-CDMA, code (15,7), $N=16$ in frequency selective channel for various values of $K$.

Fig. 8. Simulated BER Performance of coded MSK/MC-CDMA, code (6,2), $N=16$ in frequency selective channel for various values of $K$.

Fig. 9. Simulated BER Performance of coded MSK/MC-CDMA, code (6,2), $N=16$ in frequency selective channel for various values of $K$. 