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Multi-Code and Multi-Carrier CDMA Systems for Next Generation Wireless Systems

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Abstract-This paper proposes a Multi-Code Multi-Carrier Code Division Multiple Access (CDMA) scheme for next generation wireless communication systems. This system retains the advantages of Multi-Carrier CDMA in combating multipath and rejecting interference, and provides variable and adaptive data rates through the use of Multi-Code scheme. The rate adaptation algorithm proposed computes the user data rate as a function of the instantaneous channel condition and application dependent data rates. Exploiting the channel information improves the effective data rate and overall capacity of the system. The performance improvement of the proposed system to the Multi-Code CDMA system is shown through simulations. Walsh-Hadamard, Gold and Kasami codes are explored as possible choices for the multiple codes in the system..

Index Terms— AWGN – Additive White Gaussian Noise, BER – Bit Error Rate, CDMA – Code Division Multiple Access, IFFT – Inverse Fast Fourier Transform, ISSI – Inter Substream Interference, MTC MC-CDMA – Multi Code Multi Carrier-Code Division Multiple Access, OFDM – Orthogonal Frequency Division Multiplexing, PCS – Personal Computer System.

1 Introduction

FUTURE wireless systems like 4th generation (4G) cellular systems aim to integrate a variety of services such as voice, data, image, and video. These services have different requirements on the bandwidth and the rate of transmission on a wireless platform. To this end, future generation systems will have to handle a variety of bit rates. Moreover, wireless channels are characterized by multipath propagation, motion induced temporal variations, and multiple access interference. In recent years, there has been a tremendous amount of research on spread spectrum techniques which have been proved to be attractive choices to combat fading effects of the channel and Multi-Code systems which promise variable data rates. In a CDMA based system that can provide a smooth integration path to Personal Computer System (PCS), either from a digital cellular system or from a wideband CDMA system, to serve both synchronous and asynchronous applications, has been proposed. This approach, dubbed Multi-Code CDMA realizes a unified digital bandwidth-on-demand platform by allocating multiple codes, and hence increased capacity to users. When the user needs M times the basic source rate, the incoming data stream is converted into M parallel substreams and each of the sub streams is spread with a different spreading sequence and added together before transmission. The data rate is proportional to the number of codes assigned to the user.

A variation of multi-code scheme, which supports variable data rates by variation of the set of code sequences assigned to the each user, has been proposed. The users transmit their data by choosing one sequence from their code set and transmitting over the common channel. Thereby, with M codes, a user can transmit $\log_2 M$ bits per sequence period. The data rate is increased by increasing the number of codes used for the transmission. A new multi-carrier DS-CDMA with multi-code in which input data bits are first coded at a low rate (1/R) and every resulting R coded binary bits are then multiplexed with a set of multi-codes to produce code division multiplexing super-bits. After serial-to-parallel conversion, these super-bits are spread using M orthogonal carriers.

Multi-Carrier CDMA is a technique to improve the efficiency of frequency using several sub-bands in the particular frequency band and spreading each subcarrier over the total bandwidth, a combination of Multi-Carrier modulation and DS/SS-CDMA technique. Multi-Code CDMA is a technique for high rate service and multi rate service using orthogonal code sequence. In the Multi-Code CDMA, the high rate data stream is divided into several low rate data sub stream, and then each sub stream is multiplied with an orthogonal code set to discriminate each sub stream and minimize Inter-Sub stream Interference (ISSI) before transmitting data. Multi-Code CDMA and Multi-Carrier CDMA have attracted a lot of attention from researchers, due to their perceived high data rate transmission capability.

The study of multi-rate transmission for Multi carrier-Direct sequence CDMA systems are based on the concepts of multi-code access and variable-spreading gain code access. In the multi-code scheme, the data stream of a user with rate M is first multiplexed into M different streams with basic data rate and each is treated as an individual user with individual spreading codes. Each stream is then serial-to-parallel converted into P parallel sub-streams and then the sub-streams from the same effective user are spread by the same spreading codes with a constant factor. All the corresponding parallel spread signals from other effective users are combined and transmitted by P orthogonal sub-carriers respectively. The rest of the paper is organized as follows. In section two shows the detailed system model section three describes the proposed channel model.

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2 SYSTEM MODEL

2.1 Multi-Code CDMA System

A novel multi-code system has been proposed in to support variable data rates. In this scheme, each user has a set of M codes called the sequence set. The system is an M-ary modulation where a code sequence represents a sequence of $\log_2 M$ bits. The size of the sequence set depends on the required data rate. In the normal case, the set size is 2, i.e., there are two sequences in the set, one to represent a '0' and one to represent a '1'. When the data rate is to be made L times the standard data rate, the sequence set is made of size 2L and each sequence of L bits is mapped to one of the 2L code sequences. Consider a system with K users ($0 \le k < K$). Each user is assigned a sequence set

$$F^{(k)} = \{S_k[m](n)\}\ ;\ 1 \le m \le M$$

of M sequences of length N with constant envelope. With these, M-ary data symbols $b^{(k)}$ are transmitted at rate $1/T$. The sequence set of each user is implemented as a chip wise product ofa user specific sequence $U(n)$ and a set of information sequences $G[m](n)$, $1 \le m \le M$.

$$F^{(k)} = \{S_k[m](n) = G[m](n).U_k(n)\};\ 1 \le m \le M$$

The sequences are modulated with the carrier signal *h(t).* For simplicity, we assume

$$h(t) = \frac{1}{\sqrt{Tc}}\, rect\left(\frac{t}{Tc} - \frac{1}{2}\right),\ where\ T_c = \frac{T}{N}$$

A block diagram of the Multi-Code CDMA system is shown in figure 1.

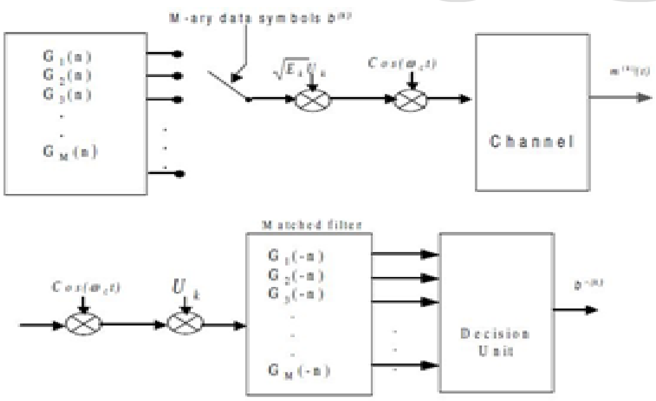

Figure 2.1: Transmitter and Receiver of Multi-Code CDMA System.

As explained above, depending on the required data rate, each user has a set of M codesequences, where M is the ratio of the base data rate and required data rate. The base rate is achieved with set of just two sequences. The M-ary symbol to be transmitted selects one of the code sequences of length N, which is then multiplied chip-wise with the user specific sequence. The user-specific sequence is a PN sequence of the same length N as the code sequences. At the receiver a filter bank is used to detect the transmitted symbol. The received code sequence is first multiplied chip-wise with user sequence and the resultant is correlated with each of the possible M code sequences. The sequence that gives maximum correlation is then mapped back into an M-ary symbol.

2.2 Multi-Carrier CDMA System

There are several equivalent ways of describing Multi-Carrier CDMA (MC-CDMA) system.MC-CDMA can be considered as a form of spread spectrum with spreading in the frequency domain as the code is fixed over time but varies with sub carrier frequency. Another way of describing MC-CDMA is: DS-CDMA followed by an Inverse Fast Fourier Transform (IFFT). MC-CDMA can also be considered as Orthogonal Frequency Division Multiplexing (OFDM) with an orthogonal matrix operation performed on the user bits. As each bit is transmitted simultaneously on many sub carriers, MC-CDMA is a form of frequency diversity. Each sub carrier has a constant phase offset that forms the code to separate users.

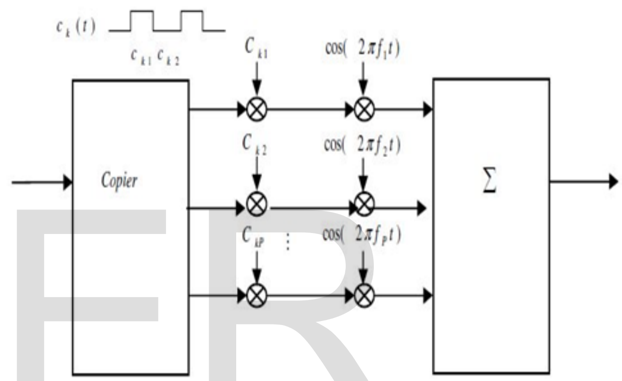

Figure 2.2: Transmitter of Multi-Carrier CDMA System.

In Figure 2.2, the transmitter of a MC-CDMA system is depicted. Each chip is copied onto *P*branches and multiplied by the corresponding chip of the user specific spreading code. Eachbranch then modulates a sub carrier and the modulated sub carriers are summed together andtransmitted. There are several advantages of using MC-CDMA. One of them is multipathmitigation. There is constructive and destructive interference at the receiver due to multipath.Destructive interference causes deep nulls in the received signal power. For a narrowbandtransmission, if the frequency response null occurs at the signal frequency then the entire signalcan be lost. However in wideband signals, dips in the spectrum result in a small loss of signalpower. Also if the transmission bandwidth is divided into many subcarriers, then spectral nulls are unlikely to occur at all of the subcarrier frequencies. Another advantage of MC-CDMA is simplified equalization in the frequency domain.

2.3 Multi-Code Multi-Carrier CDMA System

To improve upon the performance of the Multi-Code CDMA system in a multipath fading channel, we have proposed a Multi-Code Multi-Carrier CDMA system and evaluated its performance. Fig.3 shows the transmitter of a Multi-Code MC-CDMA system.

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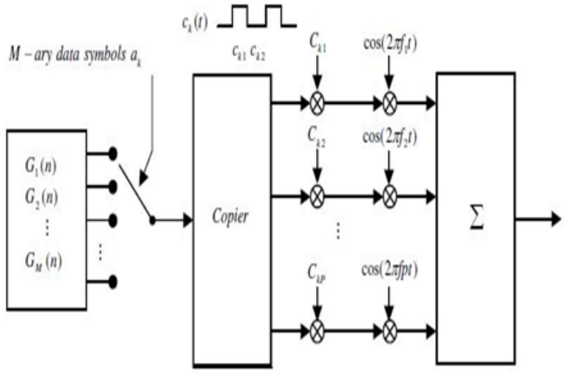

Figure 2.3: Transmitter of Multi-Code Multi-Carrier CDMA System.

As in the Multi-Code CDMA transmitter, an M-ary symbol selects one of M code sequences for transmission. Each chip of the code sequence is copied onto *P* branches. Each chip of the user specific sequence is then multiplied with the corresponding branch i.e. the p^{th}chip of the user specific sequence is multiplied with the p^{th}branch of the copier. Each of these branches then modulates one of the *P* orthogonal subcarriers and the results are summed. This process can be implemented digitally using a size *P* Inverse Fast Fourier Transform (IFFT) to replace the subcarrier multiplication and summation. At the receiver, a size *P* FFT is applied to the input and the output of the FFT is then despread to generate each chip of the received code sequence. Detection then continues using the filter bank described for the Multi-code CDMA system. The use of this multicarrier scheme provides frequency diversity for multipath mitigation.

2.4 Channel Model

We assume multipath Rayleigh fading channel and weused Smith's simulation method. Fig. 4 shows simulated channel gain used in this work.

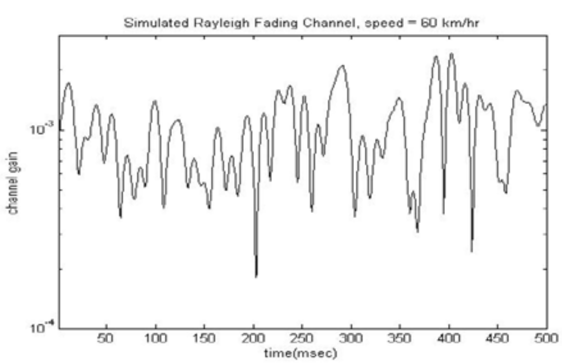

Figure 2.4: Typical Rayleigh fading channel gain.

As shown in Figure 2.5, MTC CDMA system has poor BER performance in multipath fading channel; however, by using multi-carrier system with this multicode system, we can overcome the multipath fading effect. Current CDMA system controls transmission power frame by frame to solve the near-farproblem.

Figure 2.5 shows the average M versus no. of users for MTC-MC CDMA system with adaptation.As the number of users increases, the BER performance can be maintained almost the same by decreasing the average M value. Therefore, for a certain target BER, we can increase the capacity by controlling M, the data rate, depending on the channel environment.

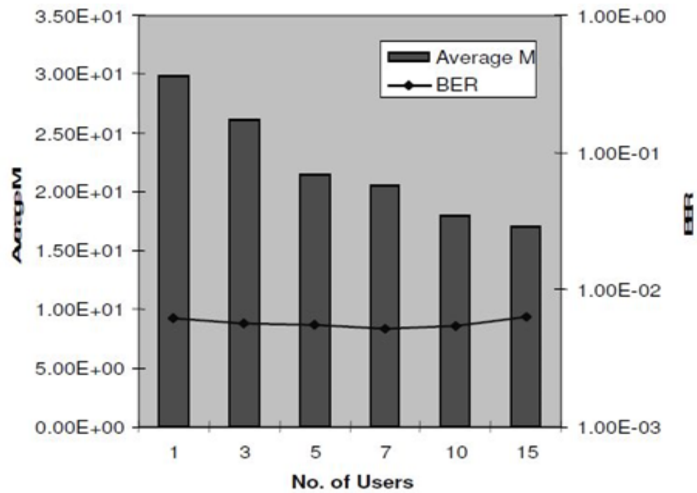

Figure 2.5: Average M versus No. of Users for MTC-MC CDMA with Adaptation in Multipath fading channel.(SNR = 40dB)

3 Conclusion

In this paper, we evaluate the performance of Multi-Code CDMA using different code sets in AWGN and in multipath fading channels. Compared to AWGN channel, the performance of the Multi-Code system degrades drastically in multipath fading channel. We propose a Multi- Code Multi-Carrier CDMA system which retains the variable data rate capability of the Multi- Code system and is robust to multipath fading like Multi-Carrier CDMA. The proposed system has significantly better BER performance to the original Multi-Code CDMA system and hence supports more users for the same BER in a fading channel. The rate adaptation algorithm proposed ensures that the average data rate traces the instantaneous channel condition and thereby improves the overall capacity of the system.

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