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BER Analysis in Multi-Carrier CDMA Systems over Rayleigh Fading

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ABSTRACT

Multicarrier Code Division Multiple Access (MC-CDMA) is a predictable technique for future high data rate and high capacity wireless communication systems. From this point, this research paper presents two MC-CDMA systems synchronous and asynchronous simulated using Walsh code and using Pseudo Noise code respectively. The differences between these two systems are analyzed to show which is better to use and when. These two MC-CDMA systems are broadcasted over Rayleigh Fading and AWGN channel.

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1. MULTI-CARRIER CDMA SYSTEMS

The basic idea for a CDMA system to overcome the multipath problem is built on the fact that a spread spectrum signal has a much wider bandwidth occupancy than its original baseband signal, such that the spread spectrum signal will offer a unique property that multipath diversity can be made possible due to its excellent time resolution derived from its very wide bandwidth signaling.

A RAKE receiver can then be used to resolve different multipath returns individually and combine them again in a coherent or non-coherent way, to achieve the multipath diversity capability, which has become one of the most important technical features that make CDMA a very attractive multiple access technology for 2G and 3G wireless communications [1].

In this system instead of applying spreading sequences in the time domain, they are applied in the frequency domain, mapping a different chip of a spreading sequence to an individual OFDM subcarrier [2]. In the frequency domain, the capability of a CDMA system to overcome the multipath interference problem can be explained using the following text. Also, due to the very wide spectral width of CDMA signaling, the loss of energy owing to the nulls of a frequency-selective fading channel will not cause too much damage to the total energy of the CDMA signal due to its relatively wide spectral occupancy in the frequency domain. Therefore, it can be shown that the resilience of a CDMA system against frequency-selective fading is much stronger than any of the other traditional multiple access technologies, such as FDMA and TDMA, which are also called narrowband technologies [1].

The loss of energy in the CDMA signaling due to the nulls of a frequency-selective fading channel will still have some negative impact on the signal detection efficiency at a CDMA receiver.

Therefore, some methods were proposed to recover or minimize the energy loss of CDMA signaling due to frequency-selective fading. Multi-carrier CDMA is one of them.

One possible implementation of a multi-carrier CDMA system can be described as follows. The input bit stream should first go through a serial to parallel conversion to form N sub-channels and then the N different parallel data streams will be spreading modulated by N different spreading codes, followed by carrier modulation by N distinct carrier frequencies. Of course, another possible scheme to implement multi-carrier CDMA is that after the serial to parallel conversion the N different sub-channels will be spreading modulated by using one spreading code. In this case, the N modulated multi-carrier signals are not separable in the CDMA code space, but only separated by different carrier frequencies.

Nevertheless, for both cases the serial to parallel conversion has converted the wideband single data stream into N narrowband sub-streams, making the signal more resilient against frequency selective fading in the channel. It is noted that the capability of a multi-carrier CDMA system to mitigate frequency-selective fading is acquired through a very different approach compared to the way that normal wideband CDMA overcomes the same problem. The multi-carrier CDMA system splits up a wideband signal into many narrowband sub-streams, and thus if a few sub-streams unfortunately fall into the nulls of a frequency-selective fading channel, the rest will not be seriously affected.

Those sub-streams that fall into the nulls can be recovered by using some kind of interleaving and error correction coding schemes.

In addition, multi-carrier CDMA can overlap the spectra for different sub-streams to forma so called orthogonal multi-carrier CDMA system to further improve its bandwidth efficiency. The spectra shapes for traditional wideband direct sequence CDMA, multi-carrier CDMA, and orthogonal multicarrier CDMA are shown in Figure 1. It is seen from the figure that inter-symbol interference will be a problem if an orthogonal multi-carrier CDMA system cannot maintain the orthogonality among all sub-channels, whereas the normal multi-carrier CDMA system will not have such a problem as long as a sufficient guide band is used to separate neighboring sub-channels. Another salient feature for the orthogonal multi-carrier CDMA system is that it can be implemented by inverse fast Fourier transform (IFFT) and fast Fourier transform (FFT) in the transmitter and receiver, respectively, to greatly reduce the implementation complexity of the radio transceiver[1].

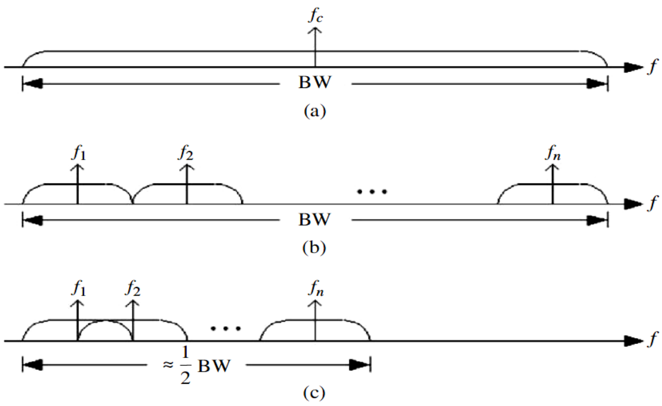

Figure 1. The spectra shapes for (a) traditional wideband direct sequence CDMA, (b) multi-carrier CDMA, and (c) orthogonal multi-carrier CDMA signals.

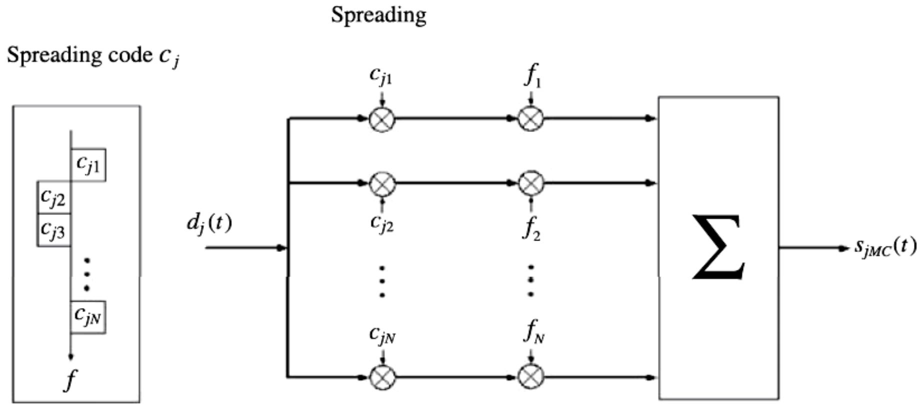

Figure 2. A multi-carrier CDMA transmitter with frequency domain spreading.

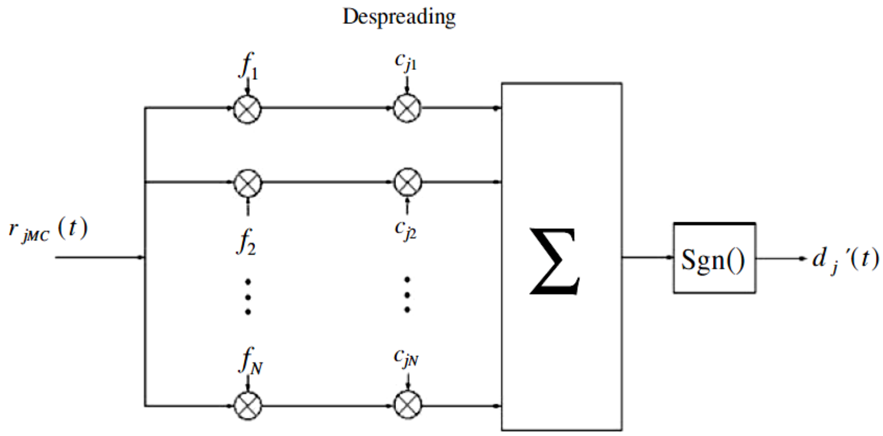

Figure 3. A multi-carrier CDMA receiver with frequency domain spreading.

It is clear that a multi-carrier CDMA system can also use both time domain spreading and frequency domain spreading at the same transmitter to meet particular application and implementation requirements. Obviously, time domain spreading can offer an extra separation among different subcarriers and thus it is in particular well suited for a non-orthogonal multi-carrier CDMA system. On the other hand, the frequency domain spreading provides no division among sub-carriers and thus it can only be used in an orthogonal multi-carrier CDMA system.

2. SPREADING CODES

A spread spectrum communication system spreads the original information signal using user specific signature sequences. When multiple users are accessing the system for services, each code sequence assigned to a user must be distinguishable from every other user code sequence in the set and ideally should generate little or no interference to other users sharing the channel. The receiver then correlates the synchronized replica of the signature sequences with the received signal, in order to recover the original information. Due to the noise-like properties of the spreading sequences, “eavesdropping” is not straightforward. DS-CDMA exploits the code’s autocorrelation properties in order to optimally combine the multipath signals of a particular user. In contrast, the different users’ codes exhibit a low cross-correlation, which can be exploited for separating each user’s signal. MC-CDMA also relies on this cross-correlation property in supporting multi-user communications. The characteristics of the spreading sequences play an important role in terms of the achievable system performance [3] [4].

2.1. Walsh codes

Walsh code sequences are obtained from the Hadamard matrix which is a square matrix where each row in the matrix is orthogonal to all other rows, and each column in the matrix is orthogonal to all other columns [5]. These codes are formed by binary codewords with values {1, -1} and length $N = 2^n$. Codewords are N in number. For $N = 2^0 = 1$ the codeword is the unique vector $C_0 = [1]$. For $N = 2^1 = 2$ the two Walsh codewords are the rows of matrix

$$C_1 = \begin{bmatrix} 1 & 1 \\ 1 & -1 \end{bmatrix} \quad (1)$$

For higher values of N, the $N = 2^n$ codewords are the rows of matrix $\boldsymbol{C}_n$ that is derived from $\boldsymbol{C}_{n-1}$ by the recursion

$$\boldsymbol{C}_n = \begin{bmatrix} \boldsymbol{C}_{n-1} & \boldsymbol{C}_{n-1} \\ \boldsymbol{C}_{n-1} & -\boldsymbol{C}_{n-1} \end{bmatrix} \quad (2)$$

so that

$$C_2 = \begin{bmatrix} 1 & 1 & 1 & 1 \\ 1 & -1 & 1 & -1 \\ 1 & 1 & -1 & -1 \\ 1 & -1 & -1 & 1 \end{bmatrix} \quad (3)$$

and

$$C_3 = \begin{bmatrix} 1 & 1 & 1 & 1 & 1 & 1 & 1 & 1 \\ 1 & -1 & 1 & -1 & 1 & -1 & 1 & -1 \\ 1 & 1 & -1 & -1 & 1 & 1 & -1 & -1 \\ 1 & -1 & -1 & 1 & 1 & -1 & -1 & 1 \\ 1 & 1 & 1 & 1 & -1 & -1 & -1 & -1 \\ 1 & -1 & 1 & -1 & -1 & 1 & -1 & 1 \\ 1 & 1 & -1 & -1 & -1 & -1 & 1 & 1 \\ 1 & -1 & -1 & 1 & -1 & 1 & 1 & -1 \end{bmatrix} \quad (4)$$

Walsh codes are closely related to the so-called Hadamard matrices, which are matrices C_n where each -1 is replaced throughout by a 0. Moreover, Walsh codes have the characteristic property that the codewords are pairwise orthogonal, as the reader can verify by induction [6].

2.2. Pseudo Noise Sequences

In practice, Pseudo Noise (PN) sequences or linearly frequency modulated signals (chirp signals) have become the prevalent sounding sequences. Maximum-length PN sequences (m-sequences), which can be created by means of a shift register with feedback, are especially popular. Such sequences are well known from Code Division Multiple Access (CDMA) systems [7].

The property of a PN sequence is that the sequence appears to be noise-like if the construction is not known at the receiver. They are typically generated by using shift registers. Often used PN sequences are maximum-length shift register sequences, known as m-sequences. A sequence has a length of $n = 2^{m-1}$ bits and is generated by a shift register of length m with linear feedback. The sequence has a period length of n and each period contains 2^{m-1} ones and $2^{m-1} - 1$ zeros; i.e. it is a balanced sequence [8].

3. RESULTS AND ANALYSIS

The MC-CDMA is simulated using Matlab environment. The system was simulated over Rayleigh fading and Additive White Gaussian Noise (AWGN) channel model to show the effect of it on the bit error rate relating to signal to noise ratio.The simulation is executed through the steps of the following algorithm:

```
Start
Generating of Code (Walsh or PN code)
Generating data for 64 Users
Spreading data of 64 Users
Apply OFDM (IFFT)
Add CP
```

```
Broadcast over Rayleigh fading and AWGN channel
Remove CP
Apply OFDM Inverse (FFT)
De-spreading data of 64 Users
Calculate BER
Sketch the results of users' examples
End
```

Rayleigh fading is a statistical model for the effect of a propagation environment on a radio signal, such as that used by wireless devices. It models a multipath transmission environment, which lacks the presence of line of sight and hence the significant multipath. It assumes that the magnitude of a signal that has passed through the channel will vary randomly, or fade, according to a Rayleigh distribution, the radial component of the sum of two uncorrelated Gaussian random variables. The Rayleigh distribution is frequently used to model multipath fading with no direct line-of-sight (LOS) path [9] [10] .This paper demonstrates the outcome for MC-CDMA system which has 64 users, where each user has 10000 bits and the data was modulated using binary phase shift keying. Figure 4 shows the relationship between the bit error rate and signal to noise ratio for MC-CDMA system. The data were spread using Walsh code. These codes are set be orthogonal due to poor cross correlation (is zero), the orthogonality is required to have no interference between physical channels and they are also used because of their good autocorrelation properties.

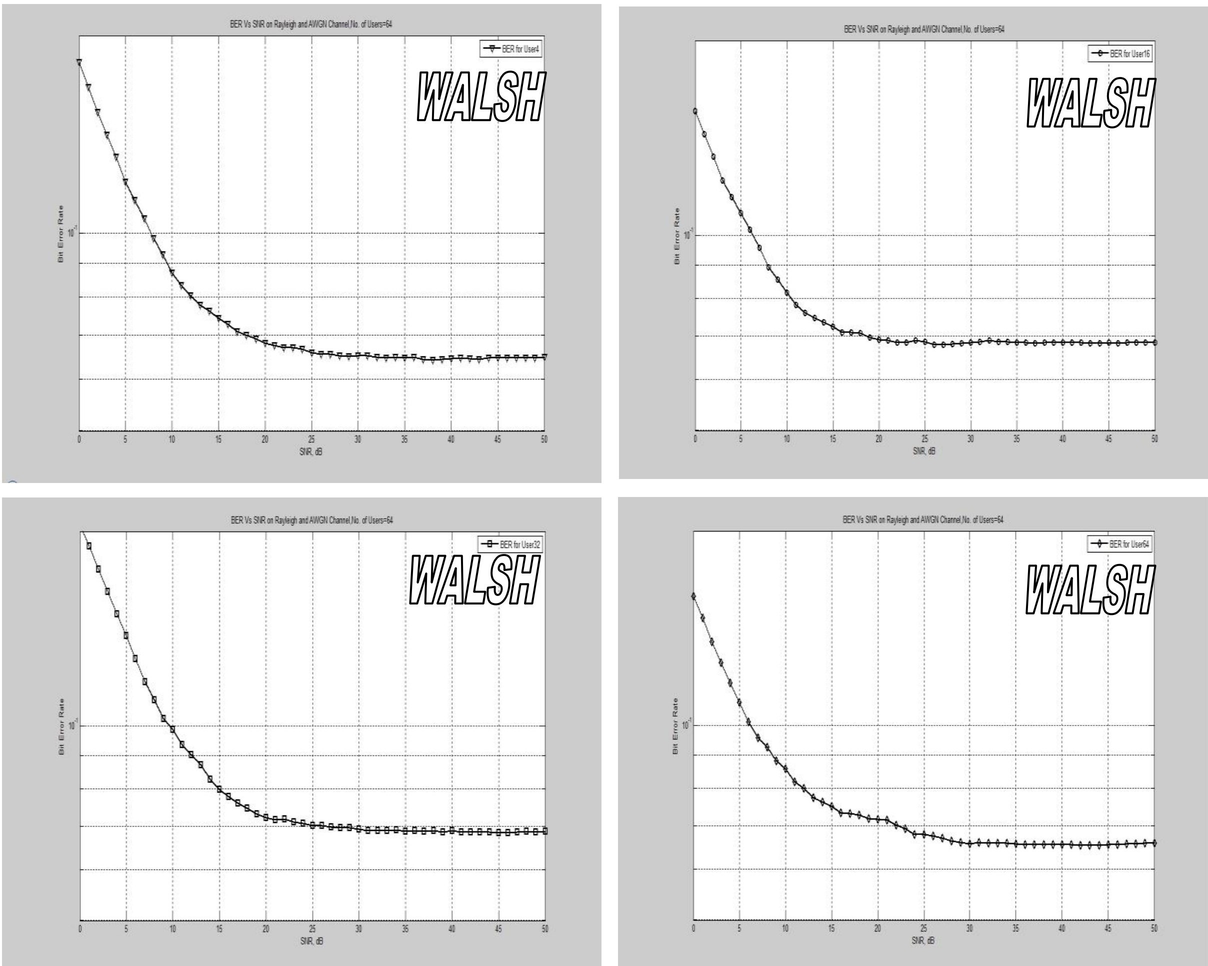

Figure 4. MC-CDMA system using Walsh code broadcasting over AWGN channel

While Figure 5 shows the relationship between the bit error rate and signal to noise ratio for MC-CDMA system has 64 users. The data were spread using Pseudo Noise (PN) code and modulated using binary phase shift keying.

PN Codes exhibit Randomness properties and can be suitably used as spreading and scrambling sequences. As shown in the two figures ,the BER is plotted with SNR for user 4,16, 32, 64.

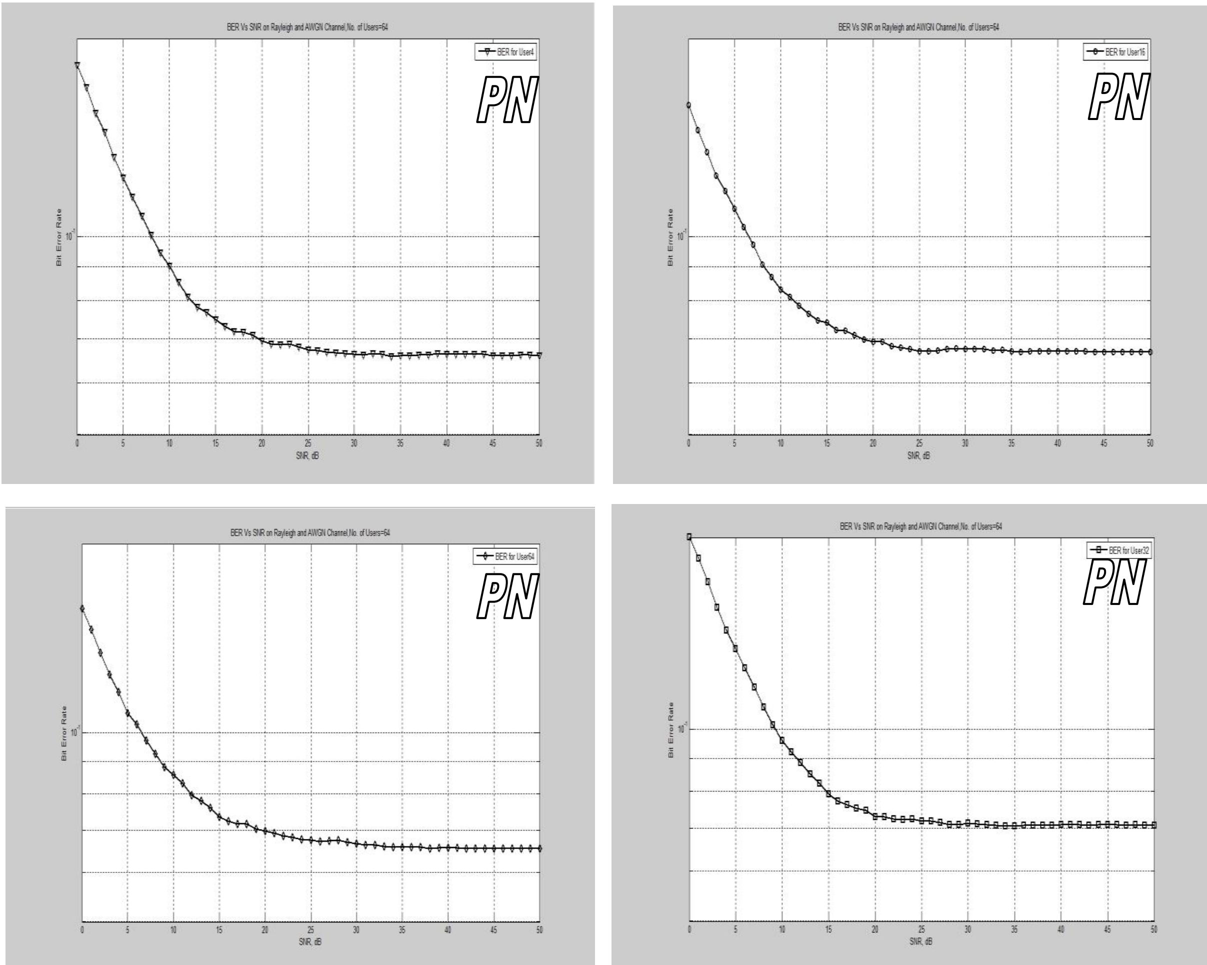

Figure 5. MC-CDMA system using Pseudo Noise code broadcasting over AWGN channel

4. CONCLUSION

In this paper, MC-CDMA system is simulated using Walsh code and Pseudo Noise code to show the effects of the spreading codes on the system. The results show that in synchronous MC-CDMA it is better to use Walsh code as a spreading code. Walsh code has the advantage to be orthogonal and the rid of any multi-access interference is certainly obtained. While in asynchronous MC-CDMA it is better to use PN code because it exhibits Randomness properties and can be suitably used as spreading and scrambling sequence and because even the fact that it appears random but it can be reproduced in a deterministic manner by intended receivers.

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Mayada Faris Ghanim has experiences in computer engineering, CDMA, MC-CDMA, SC-FDMA and other related technologies. Her educational attainments are BSc and MSc from Computer Engineering Department, College of Engineering at University of Mosul, Mosul, Iraq, her PhD. from Faculty of Electrical and Electronic Engineering at University Tun Hussein Onn Malaysia, Malaysia. Since 2006 she is working in Computer Engineering Departement, College of Engineering, University of the Mosul, Iraq. She has published many refereed journal and conference papers. She is a member of IEEE, IAENG, SIE, SDIWC, IACSIT and SCIEI.

Mohammad Faiz Liew Abdullah received BSc (Hons) in Electrical Engineering (Communication) in 1997, Dip Education in 1999 and MEng by research in Optical Fiber Communication in 2000 from University of Technology Malaysia (UTM). He completed his PhD in August 2007 from The University of Warwick, United Kingdom in Wireless Optical Communication Engineering. He started his career as a lecturer at Polytechnic Seberang Prai (PSP) in 1999 and was transferred to UTHM in 2000 (formerly known as PLSP).
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