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Research Article

Performance Evaluation of Multicarrier CDMA System in Rayleigh Faded Channel

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Abstract

Multicarrier CDMA is considered to be the most important technique for future generation mobile systems. It combines orthogonal multicarrier modulation with CDMA and is very robust in multipath fading environment. Despite many potential benefits of MC-CDMA, there are certain implementation issues like choice of proper spreading codes, peak to average power ratio and suitable modulation techniques which require due consideration. Therefore, this paper investigates and evaluates the performance of MC-CDMA system in terms of BER, PAPR and Modulation techniques in Rayleigh faded environment.

Keywords: *Code Division Multiple Access (CDMA), Multicarrier (MC), Bit Error Rate (BER), Peak to Average Power Ratio (PAPR), Spreading Factor (SF), Orthogonal Frequency Division Multiplexing (OFDM).*

Introduction

The demand for progressive services like high speed internet access, live multimedia in wireless communication has significantly increased in the last few years. But the introduction of these new broadband services has posed great challenge in front of researchers (Hui S.Y., *et al.*, 2003). For future applications like 4-G, a hybrid system combining CDMA with multicarrier modulation (Fantacci R., *et al.*, 2005) seems to be very capable in combating multipath fading and simultaneously providing multiple access facility. Recently launched 3-G mobile systems are also based on WCDMA/cdma2000 radio access techniques (Milstein L.B., 2000; Knisely D.N., *et al.*, 1998). Multicarrier CDMA is being offered as a potential candidate for next generation mobile systems which is capable of exploiting frequency diversity and combating frequency selective fading. Besides this, MC-CDMA also offers high spectral efficiency, low complexity equalization and eliminates inter-symbol interference theoretically (Hanzo L., *et al.*, 2006).

Multicarrier CDMA is realized by combining CDMA with orthogonal multicarrier modulation i.e. OFDM. The multicarrier modulation involves division of total bandwidth into parallel, smaller bandwidth sections. A typical multicarrier CDMA modulator (Hanzo L., *et al.*, 2006) is shown in Figure 1.

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The schematic of multicarrier CDMA modulator shown is self-explanatory and need not be elaborated further. The transmitted signal of the ith data symbol of the jth user $S_i^j(t)$ can be written mathematically as (Hanzo L., *et al.*, 2006):

$$S_i^j(t) = \sum_{k=0}^{N-1} d_i^j c_k^j e^{2\Pi(f_0 + k f_d)t} p(t - iT) \qquad (1)$$

Where N denotes number of parallel subcarriers, d_i^j is i^{th} data symbol of j^{th} user, c_k^j denotes the k^{th} chip of unique spreading code, f_0 is the fundamental subcarrier frequency, f_d represents the frequency separation and $p(t)$ denotes the rectangular pulse shifted in time. If frequency separation f_d =1/T, the OFDM signal using orthogonal subcarriers can be generated using Inverse Fast Fourier Transform.

Despite many potential benefits of MC-CDMA, there are certain implementation issues which require due consideration. Some of these issues include choice of proper spreading codes, PAPR and suitable modulation techniques. In order to present a comprehensive picture now, a system level evaluation of performance needs to be carried out with respect to relevant implementation issues. Therefore, in this paper a complete MC-CDMA system is implemented using MATLAB Simulink and the corresponding performance results are reported. An exhaustive investigation and comparative evaluation of performance of MC-CDMA system in terms of BER, PAPR and modulation techniques is being done in Rayleigh faded environment.

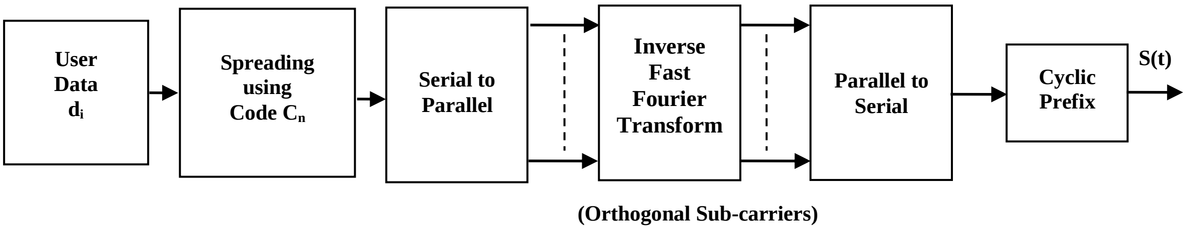

Figure 1: Schematic of Multicarrier CDMA Modulator

Factors affecting performance of MC-CDMA system

There are many important factors which affect the performance of MC-CDMA based next generation wireless communication system. The most important factors related to multicarrier CDMA that have been considered in this paper include choice of spreading codes, peak to average power ratio and suitable modulation techniques, etc.

Spreading Codes

Code Division Multiple Access lies at the heart of multicarrier CDMA based mobile systems. It is well known that the CDMA based systems are mainly reliant on the characteristics of user-unique codes (Dinan E.H., *et al*., 1998). Therefore, in case of a Multicarrier CDMA system also, the choice of spreading sequences is very important and it has significant effect on the performance of the receiver system. In this paper, orthogonal Gold (Ogold) codes (Hanzo L., *et al*., 2006) are being considered for doing the performance analysis of MC-CDMA system using computer simulation. These codes are considered here due to several favorable characteristics like large code family size, simple generation, variable spreading factor capability and tolerable PAPR (Kedia D., *et al*., 2009).

Peak to Average Power Ratio

Apart from many potential advantages of MC-CDMA, multicarrier modulation suffers from high value of PAPR (Han S.H., *et al*., 2005) of the transmitted signal. During the process of multicarrier modulation, the summation of orthogonal sub-carriers may lead to a transmit signal where the peak power is much greater than the average power. The PAPR of the transmitted multicarrier signal $S(t)$ can be defined as (Han S.H., *et al*., 2005):

$$PAPR = \frac{\max\limits_{0 \le t < NT} |S(t)|^2}{\frac{1}{NT}\int_0^{NT} |S(t)|^2 \, dt} \qquad (2)$$

The high value of PAPR produces side-lobes due to non-linearity of the power amplifiers being used. And if linear power amplifiers are used, poor power efficiency is obtained. This PAPR becomes further significant in case of large number of subcarriers. An intense research work is required to handle this issue of high PAPR in multicarrier systems.

Modulation techniques

The choice of proper modulation technique is also very important issue because BER and throughput performance is largely dependent on it (Caldwell R., *et al*., 2005; Smida B., *et al*., 2010). The modulation scheme is chosen keeping in view the channel conditions, SNR threshold and spectral efficiency. One common set of modulation schemes includes BPSK, QPSK and QAM. In case of poor channel conditions either the transmission may be suspended or the robust techniques BPSK / QPSK can be used for satisfactory BER performance. And in case of improved channel conditions 16 QAM or 64 QAM can be used. Further, 16 / 64 - QAM are less robust compared to BPSK / QPSK in terms of BER, but in terms of bandwidth efficiency or throughput these are better than both BPSK and QPSK. Thus, adaptive modulation seems to be a feasible solution to improve BER performance of Multicarrier CDMA system for application to next generation wireless mobile communication.

Performance evaluation of multicarrier CDMA system

It has already been mentioned that MC-CDMA combines the advantages of both OFDM and CDMA. Therefore, to establish the superiority of MC-CDMA over OFDM system, a comparative performance evaluation of the two is desirable. Keeping this objective in mind, both systems are implemented and evaluated using MATLAB Simulink. The MC-CDMA system model implemented in MATLAB is shown in Figure 2.

Firstly, the random data generated by the data source block is XORed with orthogonal Gold code of length 64. The resulting chips are then passed to the modulator block which consists of ½ rate Convolutional encoder and QPSK modulator. The encoded and modulated data is then zero padded and OFDM frame is assembled by adding Training sequence and Pilot bits to it. Zero padding is again done to make the data length suitable for IFFT (multicarrier) operation. After IFFT operation, cyclic prefix (=1/4 IFFT) is appended at the beginning of the frame and parallel to serial conversion is done using Multiplex OFDM block.

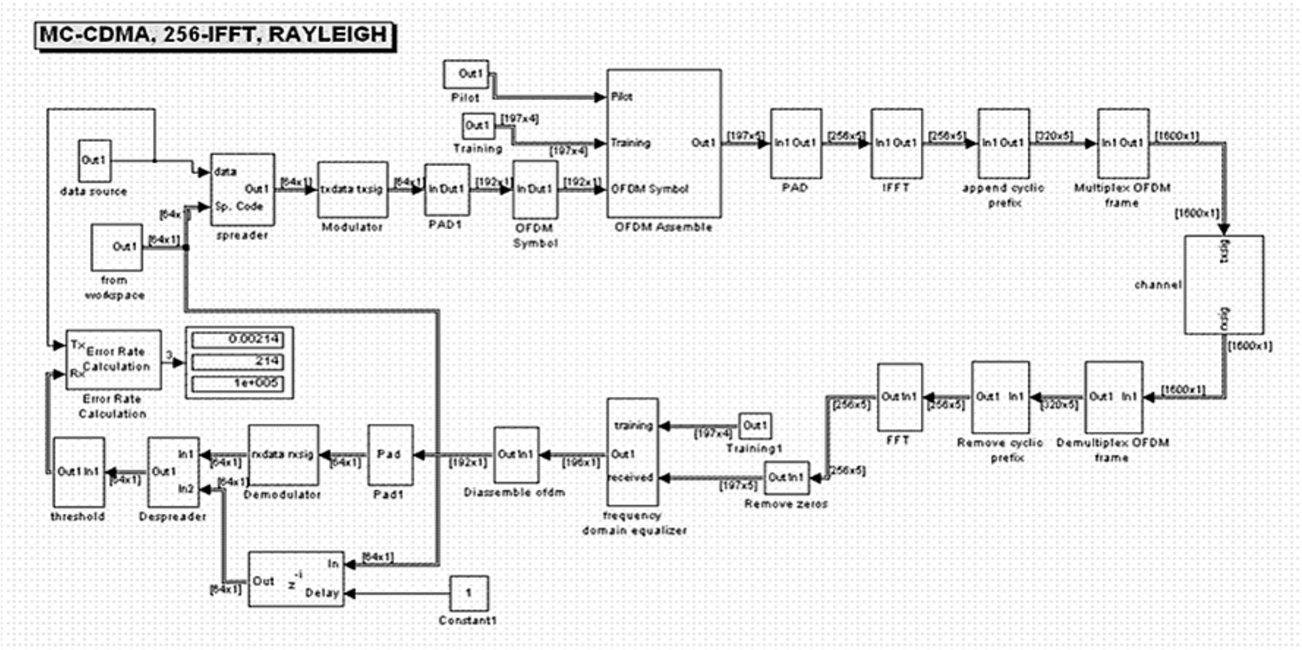

Figure 2: MC-CDMA System Model

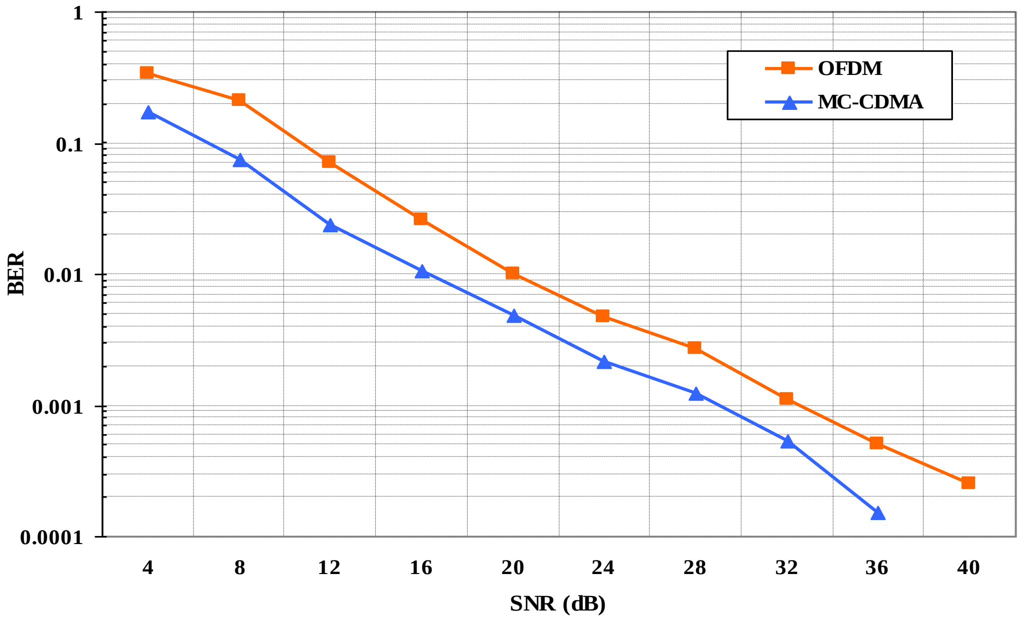

Figure 3: Comparative Performance Evaluation of OFDM and MC-CDMA

The resulting data is then passed to 2-ray multipath Rayleigh faded channel and the received data is serial to parallel converted in demultiplex OFDM block. Next, cyclic prefix is removed and FFT operation is performed for multicarrier demodulation. The resulting signal is then processed in frequency domain equalizer block along with training sequence. The equivalent transmitted signal is therefore restored after removing pilot signals in disassemble block. The data chips are then obtained after QPSK demodulation and Viterbi decoding in the demodulator block. Finally, in the despreader block at receiver side, the received data chips are again XORed with the same spreading code. The data is then obtained after threshold detection. Lastly, the error rate in terms of BER is calculated by comparing the detected data at receiver and the data generated by data source at transmitter side. The MATLAB simulation was run for 0.1 seconds and 01 lakh data bit comparisons were made for each different value of SNR (4 dB to 40 dB) for both OFDM and MC-CDMA systems. And the corresponding BER values for each case are plotted in Figure 3.

It is clear from the Figure 3 that for both OFDM as well as MC-CDMA system, the bit error rate is decreasing with increase in SNR values. But the error performance of MC-CDMA system is clearly better than OFDM system for all values of SNR. It has been observed that number of bit errors in multicarrier

CDMA system is almost 1/3rd to that of OFDM. This is because of the fact that MC-CDMA system combines the advantages of both OFDM and CDMA technique and thus provides better BER performance than OFDM only.

PAPR Performance Evaluation

In this section, the PAPR values for entire family of orthogonal Gold codes have been evaluated. The length of these codes has been varied from 8 to 256. These PAPR values for each code-set of different lengths are tabulated in Table 1.

The simulation results bring out that the PAPR values of Ogold codes are increasing with increase in code length. However, the rate of rise of PAPR value corresponding to length is limited. Therefore, orthogonal Gold codes provide better PAPR performance for MC-CDMA systems.

Now, in the subsequent sections using the MC-CDMA system model of Figure 2, the detailed performance evaluation of Multicarrier CDMA mobile system has been carried out with respect to various digital modulation techniques (BPSK, QPSK and 16-QAM) in Rayleigh fading environment.

Table 1: PAPR Performance of Ogold Codes for various Lengths

Length	Range of PAPR Values (dBs)
8	5.15 to 8.19 dBs
16	5.85 to 9.99 dBs
32	6.54 to 10.73 dBs
64	6.27 to 11.33 dBs
128	7.06 to 11.91 dBs
256	8.49 to 14.097 dBs

BER Evaluation wrt Different Modulation Techniques

In this section, using the system model of Figure 2, BER Vs SNR performance has been evaluated in Rayleigh faded environment. However, the modulator block in this model was modified to incorporate BPSK, QPSK and 16-QAM modulation techniques respectively. For Ogold code of length 64, the results related to the error performance of the system have been obtained with respect to BPSK, QPSK and 16-QAM modulation in Rayleigh fading conditions. The simulation results of MC-CDMA system with regard to different modulation techniques are plotted in Figure 4.

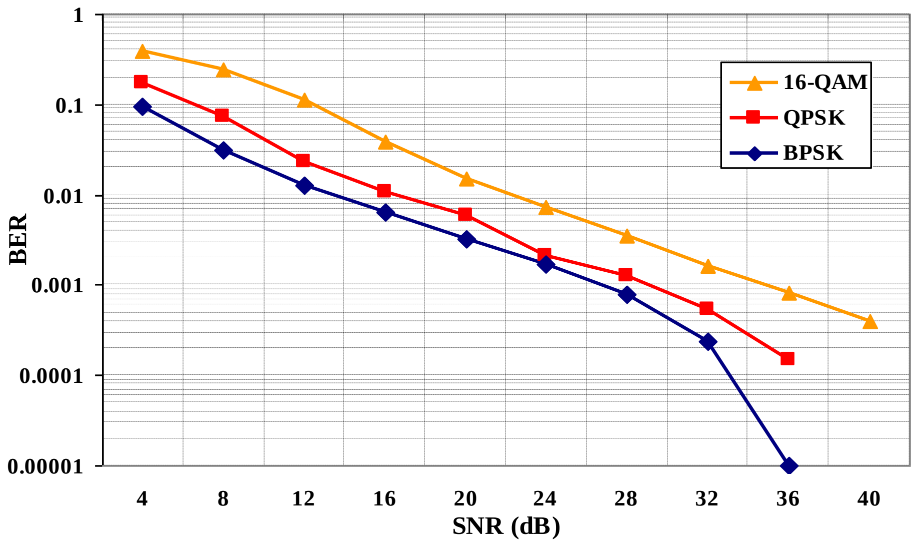

Figure 4: Performance Evaluation of MC-CDMA System in Rayleigh Fading

It is clear from the Figure 4 that BPSK modulation provides the best BER performance followed by QPSK and 16-QAM respectively in Rayleigh fading environment.

Conclusion

Multicarrier CDMA (MC-CDMA) is the most predominant technique for future fourth generation mobile systems. This hybrid system combining CDMA with multicarrier modulation seems to be very capable in combating multipath fading and simultaneously providing multiple access facility. Despite many potential benefits of MC-CDMA, there are certain implementation issues like choice of proper spreading codes, PAPR and suitable modulation techniques which require due consideration.

Therefore, in this paper a complete MC-CDMA system is implemented using MATLAB Simulink and the corresponding performance results are reported. Firstly, in order to establish the superiority of MC-CDMA over OFDM, the two systems were implemented and evaluated. And the error performance of MC-CDMA system is found clearly better than OFDM system for all values of SNR. Next, the PAPR values for entire family of orthogonal Gold codes have been evaluated. It has been observed that the orthogonal Gold codes are also a good candidate providing acceptable PAPR performance for MC-CDMA based mobile systems.

Finally, the detailed performance evaluation of MC-CDMA system has been carried out with respect to various digital modulation techniques (BPSK, QPSK & 16-QAM) in Rayleigh fading environment. The simulation results prove that BPSK modulation provides the best BER performance followed by QPSK and 16-QAM respectively in Rayleigh fading environment. The digital modulation technique 16-QAM proves to be worst in terms of BER however, it provides maximum bandwidth efficiency. Therefore, 16-QAM can also be considered for MC-CDMA, when channel conditions are better.

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