World Academy of Science, Engineering and Technology
International Journal of Electronics and Communication Engineering
Vol:9, No:1, 2015

Effect of Iterative Algorithm on the Performance of MC-CDMA System with Nonlinear Models of HPA

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Open Science Index, Electronics and Communication Engineering Vol:9, No:1, 2015 publications.waset.org/10000520/pdf

***Abstract*—**High Peak to Average Power Ratio (PAPR) of the transmitted signal is a serious problem in multicarrier systems (MC), such as Orthogonal Frequency Division Multiplexing (OFDM), or in Multi-Carrier Code Division Multiple Access (MC-CDMA) systems, due to large number of subcarriers. This effect is possible reduce with some PAPR reduction techniques. Spreading sequences at the presence of Saleh and Rapp models of high power amplifier (HPA) have big influence on the behavior of system. In this paper we investigate the bit-error-rate (BER) performance of MC-CDMA systems. Basically we can see from simulations that the MC-CDMA system with Iterative algorithm can be providing significantly better results than the MC-CDMA system. The results of our analyses are verified via simulation.

***Keywords*—**MC-CDMA, Iterative algorithm, PAPR, BER, Saleh, Rapp, Spreading Sequences.

I. Introduction

IN broadband wireless communications is required high bit rate transmission for a high quality communications. The most important objective of fourth generation systems (4G) is to take care of the severe Inter Symbol Interference (ISI) resulting from high data rates. MC-CDMA scheme is the combination of Orthogonal Frequency Division Multiplexing (OFDM) and Code Division Multiple Access (CDMA) and brings the benefits of both the techniques [1], [2]: high spectral efficiency, multiple access capability, robustness in case of frequency selective channels, high flexibility, narrowband interference rejection, simple one-tap equalization, etc. However, OFDM signal has the large peak to average power ratio (PAPR), which severely limits its applications, and as long as the basic operation of MC-CDMA is identical to OFDM system, this undesirable property remains. The high PAPR is a major drawback of MC-CDMA especially when nonlinear elements such as HPA are used in the transmitter. Large peaks in the transmitted signal will occasionally reach the amplifier saturation region and cause nonlinear distortion of multi-carrier signal, which results in a large degradation of performance, i.e. increase of both the bit error rate (BER) and the out-of-band radiation (spectral spreading) [3]-[5].

The data symbols in MC-CDMA consisting of modulated bits are spread by spreading codes such as Walsh-Hadamard codes, Golay codes, Gold and orthogonal Gold codes, polyphase Zadoff-Chu codes, Chaos codes and then mapped into subcarriers of an MC-CDMA modem data symbol which is spread across frequency domain [2], [6], [7]. MC-CDMA is a very attractive technique for a high speed data transmission over the multipath fading channels. The PAPR problem is one of the most important issues for a developing multicarrier transmission system. MC-CDMA is usually used in broadband networks such as Long Term Evaluation (LTE) and mobile broadband communication networks [8]. On the other hand, MC-CDMA systems have the inherent problem of a high PAPR, which causes poor power efficiency or serious performance degradation in the transmitted signal. This brings disadvantages like high Bit Error Rate (BER) and consumption of more power and energy. High power amplifiers are required which results in increased cost component.

Basically in the case of MC-CDMA systems, the BER at the constant number of the active users is affected especially by nonlinear effects due to the HPA of the MC-CDMA transmitter, MAI resulting from cross-correlation properties of the spreading codes assigned to the particular users and by transmission channel complexity. In fact, the analyses of the MC-CDMA signals have shown that due to their multi-carrier nature, the transmitted signal is characterized by large envelope fluctuation [9]. This property of MC-CDMA signals forces the MC-CDMA transmitter HPA to operate with large input back-off (IBO) in order to keep the required BER and the out-of-band radiation below imposed limits. Is necessary to say, the large IBO [10] will result in inefficient exploiting of HPA and consequently decreasing the coverage of the area of interest by acceptable MC-CDMA signals. As a consequence of this fact, it is crucial to minimize the impact of the nonlinear amplification on the transmission system performance at low IBO.

In order to achieve solution, how to solve these problems arising from the use of signals with high PAPR in mobile communication transmitters with nonlinearities, several approaches can be successfully used. Each of them has an advantages and disadvantages. Good way how to find solution is implementation PAPR reduction technique [11]. PAPR reduction techniques vary according needs of the system and dependent on various factors such as PAPR reduction capacity, increase in power in transmit signal, loss in data rate, complexity of computation and increase in the bit-error rate at the receiver end etc. [12].

As we mentioned above, in MC-CDMA we can implemented some several PAPR reduction techniques. One of these methods is the signal distortion technique, which introduces distortion to signals and causes degradation in the performance including clipping, clipping and filtering,

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windowing, peak cancelling, pre-distortion or companding. Signal pre-distortion techniques based on companding to reduce the PAPR have been proposed by several authors using different companding techniques such as μ-Law [13], exponential [14], modified exponential [15] and linear companding [16]. In companding technique, compression in transmitter and expansion in receiver has been proposed by Wang et al. [17]. Clipping is simple and effective and causes IBR and increased BER. The companding transforms' are better than clipping as they reduce distortion significantly. Yuan Jiang [18] proposed an algorithm that uses the special airy function and is able to provide an improved BER and minimized OBI in order to reduce PAPR effectively.

Interesting solution is using different coding techniques, which are proposed for signal scrambling. Of Course, that we can classified into schemes with explicit side information including linear block codes, and multiple signal representations such as Selective Mapping (SLM) and Tone Reservation (TR), Partial Transmit Sequence (PTS), and interleaving schemes [19]. These schemes give an ease of modification, at increased overhead, search complexity, and data loss.

The organization of this paper is a follows. Section II describes the MC-CDMA system model, which is considered consistently throughout the paper. A short review of nonlinear effects due to HPA is outlined in Section III. In Section IV is described MC-CDMA system in which is Iterative algorithm implemented. In Section V (the core part of the paper) the performance properties of MC-CDMA transmission system will be studied and analyzed by using a set of computer simulations. Finally, conclusions and final remarks to this contribution are drawn in Section VI.

II. MC-CDMA System Model

On a block diagram below (Fig. 1) we can see simplified baseband model of MC-CDMA transmitter. As we can see from this figure, the information bits to be transmitted by a particular user. In MC-CDMA transmitter the data bits are firstly baseband modulated into M-QAM modulation symbols and then they are spread by using a specific spread sequence c_m [20]. In the case of MC-CDMA system model, as the spreading codes we can use different spreading codes such as Walsh codes, Golay codes, Gold and orthogonal Gold codes, polyphase Zadoff-Chu codes or Chaos codes. The spreaded symbols are modulated by multi-carrier modulation implemented by inverse fast Fourier transformation operation (IFFT). The IFFT block outputs after parallel-to-serial conversion represents the input signal of a HPA (High Power Amplifier). In fact, the traditional block of cyclic prefix insertion is not included due to AWGN channel assumption [23].

The basic model of receivers is shown on the figure bellow (Fig. 2). From this picture we can see, that the receiver consists of serial-to-parallel converter (S/P), blocks of fast Fourier transformation (FFT), bank of matched filters (BMF), block of linear or nonlinear transformation (labelled as T) and decision device.

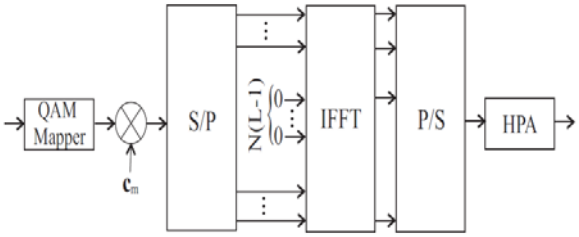


Fig. 1 MC-CDMA transmitter block diagram

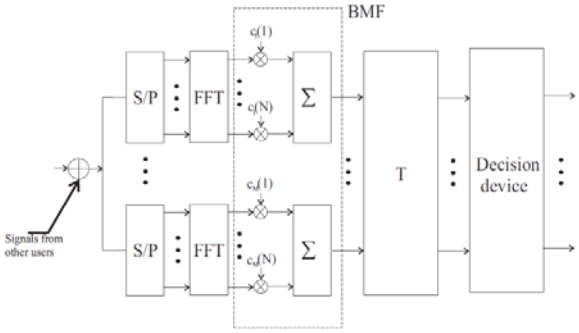


Fig. 2 MC-CDMA receiver block diagram

In order to extend BMF into multi-user receiver, the T-transformation block is included in the receiver structure [21]. The detailed description of MC-CDMA receiver structure we will discuss in the third part of this paper.

III. Nonlinear Effect in MC-CDMA

The high PAPR is a major drawback of MC-CDMA, especially when nonlinear elements such as HPA are used in the transmitter. PAPR is the ratio between instantaneous power and the average power of multicarrier signal, and can be defined as:

$$\mathrm{PAPR}(\mathrm{x}) = \frac{\|\mathrm{x}\|_{\infty}^{2}}{\mathrm{E}\{\|\mathrm{x}\|^{2}\}/\mathrm{N}}, \quad (1)$$

where E[.] is the expectation operator. It can be shown (e.g. [22]), that in the case of MC-CDMA systems, PAPR parameter strongly depends on the applied spreading sequence.

The linearity of a PA response constitutes an important factor that ensures signal integrity and reliable performance of the transmission system. High power amplifier (HPA) suffers from the effects of amplitude modulation to amplitude modulation distortion (AM/AM), and amplitude modulation to phase modulation distortion (AM/PM), during conversions caused by the HPA amplifier. The effects of HPA amplifiers can cause the bit error rate performance of a communication channel to be increased.

Basically, as a common type of power amplifiers typically used in telecommunication systems, is travelling wave tube amplifiers (TWTA). The most popular candidate used as nonlinear model of power amplifier is a Saleh model and AM/AM and AM/PM characteristics are given by:

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$$AM/AM: G(u_x) = \frac{K_G \cdot u_x}{1 + X_G \cdot u_x^2} \quad (2)$$

$$AM/PM: \Phi(u_x) = \frac{K_\Phi \cdot u_x^2}{1 + X_\Phi \cdot u_x^2} \quad (3)$$

On the other site, Rapp model of HPA is described by the following AM/AM and AM/PM characteristics:

$$AM/AM: G(u_x) = \frac{K_G \cdot u_x}{\left(1 + \left(\frac{u_x}{O_{sat}}\right)^{2p}\right)^{\frac{1}{2p}}} \quad (4)$$

$$AM/PM: \Phi(u_x) = 0 \quad (5)$$

where p is the smoothness factor and O_{sat} is the output saturation level.

The analysis of MC-CDMA transmission system for the different spreading sequences, IBO parameters, nonlinear models of HPA and receiver types is presented in the next part of this paper.

IV. Iterative Receiver

The following article describes a simple iterative algorithm based on hard decoding method of the received vector, but other alternatives are even possible [24]. If we get inspired by Tellado's idea of Iterative maximum-likelihood (ML) receiver, is possible modify this simple iterative algorithm based on hard decoding method of the received vector. The main idea of this solution is very simple. For example, if the transceiver includes some error correction, the estimate of X will be more accurate. Performing hard decoding on the received vector Y_g will result in a simple estimate of the transmitted symbol X:

$$X^{(1)} = \left[\left\langle\frac{Y_0^g}{H_0}\right\rangle \dots \left\langle\frac{Y_{N-1}^g}{H_{N-1}}\right\rangle\right]^T = \left\langle\frac{Y^g}{H}\right\rangle \quad (6)$$

from this estimate, we can compute with following formula $X^{(1)}$ = IDFT ($X^{(1)}$). With this main idea, we can easily modify the structure and result is presented by model of iterative receiver (IR).

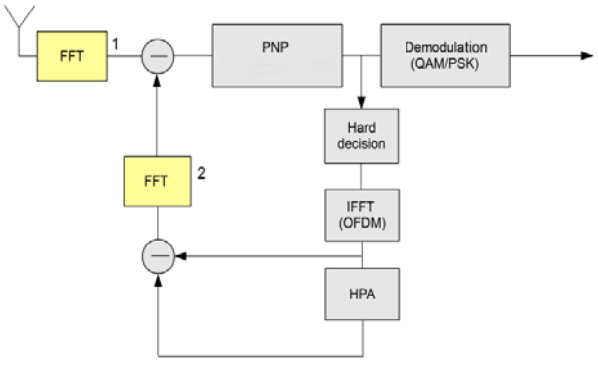


Fig. 3 MC-CDMA receiver with Iterative algorithm

From block diagram we can see the model of receiver in which is Iterative algorithm implemented. The transmitted signal is modulated in FFT and PNP block. After modulations, signal is modified by hard decision condition on value 1 or 0. Important step comes after IFFT, where the signal is divided between two threads. One of them is changed in HPA and subtract of both treads is input for a FFT block. The loop of first iteration is finished if value of FFT1 is subtracted from FFT2 and signal continues again into the PNP block. After iteration are applied QAM or PSK modulations.

This theoretical knowledge is the basis for further simulations. The performance analysis of MC-CDMA system with Iterative algorithm for the different number of users, IBO parameters, models of HPA and spreading sequences is presented in the next section.

V. Numerical Results

Performance analysis of MC-CDMA transmission system presented in this part is based on computer simulations, which were developing in environment Matlab and .Net.

From Figs. 4 and 5 we can see, that iterative algorithm achieved better performance after the first iteration. Saleh model as the nonlinear amplifier was employed. For a 16QAM and 64QAM with different value of IBO we can see, that our model of transmission system achieved improved performance.

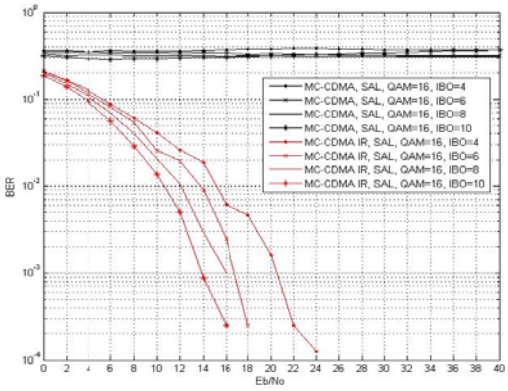


Fig. 4 BER vs. Eb/N0 for MC-CDMA system and MC-CDMA with Iterative algorithm. HPA model: Saleh. 16QAM and IBO = 4-10dB

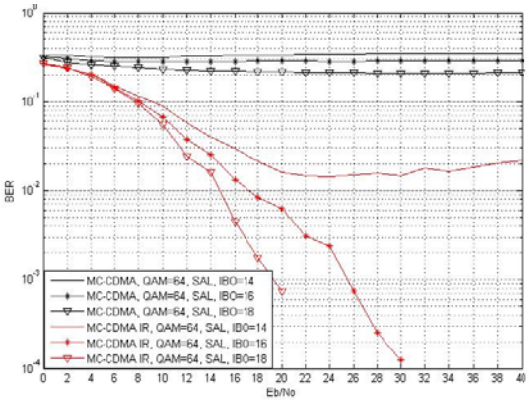


Fig. 5 BER vs. Eb/N0 for MC-CDMA transmission system and MC-CDMA with Iterative algorithm. HPA model: Saleh. 64QAM and IBO = 14-18dB

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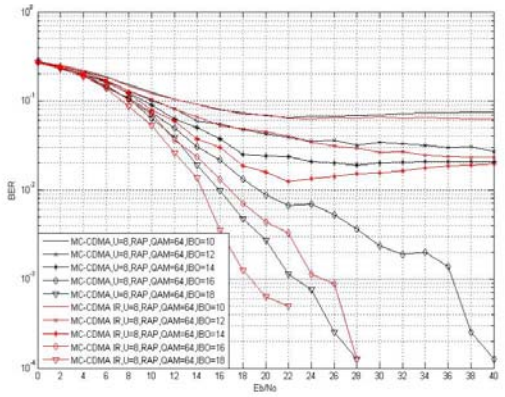


Fig. 6 BER vs. Eb/N0 for MC-CDMA transmission system and MC-CDMA with Iterative algorithm. Number of User=8. HPA model: Rapp. 64QAM and IBO = 10-18dB

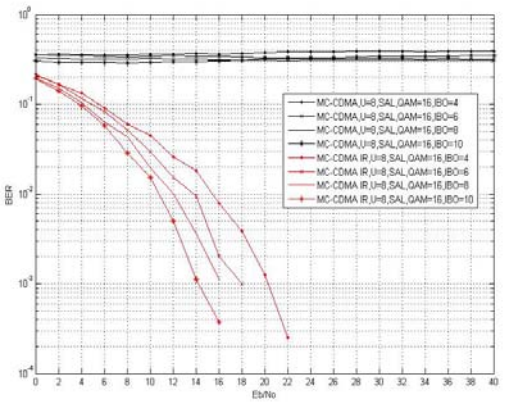


Fig. 7 BER vs. Eb/N0 for MC-CDMA transmission system and MC-CDMA with Iterative algorithm. Number of User=8. HPA model: Saleh. 16QAM and IBO = 4-10dB

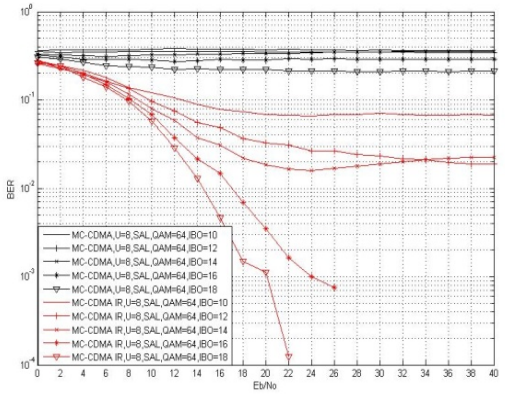


Fig. 8 BER vs. Eb/N0 for MC-CDMA transmission system and MC-CDMA with Iterative algorithm. Number of User=8. HPA model: Saleh. 64QAM and IBO = 10-18dB

For a following scenario we tested 8 users for a different value of IBO, 16 and 64 QAM, in combination with Saleh and Rapp as nonlinear amplifier.

From Fig. 6 we can see, that the both systems in combination with Rapp with lower value of IBO has almost the same performance. If the value of IBO is higher, our system again brings benefits like a lower value of BER.

Figs. 7 and 8 demonstrate important results of simulations. In following scenarios were 8 users employee. As we can see from simulations results, number of user doesn't have effect on behavior of the transmission system. Our presented model with implemented iterative algorithm in combination with Saleh nonlinear amplifier and different value of IBO has improved result again.

It follows from above mentioned facts that the MC-CDMA performance expressed by BER depends strongly on spreading sequences, HPA models and the applied receiver. Fig. 9 has shown that spreading codes have a significant effect on the system behavior. In this case was implemented different kind of spreading sequences such as Walsh codes, Golay codes, Gold and orthogonal Gold codes, polyphase Zadoff-Chu codes and Chaos codes. These simulation results confirm the previous conclusions i.e. good bit error performance can be obtained by using Golay and Walsh codes in combination with receiver, in which is implemented iterative algorithm.

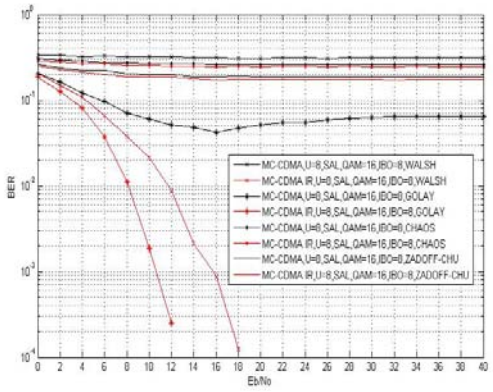


Fig. 9 BER vs. Eb/N0 for MC-CDMA transmission system and MC-CDMA with Iterative algorithm for different spreading sequences. Number of User=8. HPA model: Saleh. 16QAM and IBO = 8dB

VI. Conclusion

In this paper, we have compared performance of conventional MC-CDMA transmission system and system model with implemented iterative algorithm for a two different models of HPA (Saleh and Rapp model), the different spreading sequences (Walsh, Golay, Chaos and Zadoff-Chu) and different IBO parameter values. It has been found that iterative algorithm in combination with Saleh model of HPA has better performance BER as with Rapp model. From this results we can see, that the model with iterative algorithm brings improved performance after the first iteration.

The goal of this topic was presentation functionality of Iterative algorithm in MC-CDMA transmission system. This model brings improved performance, but the other alternatives are possible.

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