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PAPR Minimization in MCCDMA Systems

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Abstract: The multi-carrier code division multiple access (MCCDMA) combines the strong points of CDMA and orthogonal frequency division multiplexing (OFDM) which has the advantages of high frequency efficiency and excellent capacity to resist frequency selective fading. The MCCDMA has broader usage in cellular mobile, wireless LAN and Ultra Wide-Band (UWB) communications. And now, people have considered MCCDMA as the effective solution scheme in the 4G communication systems. The key technologies such as the resistance of high Peak to Average Power Ratio (PAPR), channel estimation and system synchronization are deeply researched in this paper. The transmitter model and the receiver modes were detailed. This article investigates the PAPR minimization. Based on the model of high power amplifier (HPA), the distortions caused by HPA nonlinearity and the impact of PAPR minimization on performance were analyzed.

Keywords: peak to average power ratio, OFDM, MCCDMA, distortion, clipping.

I. INTRODUCTION

The multicarrier systems are resilient to the multipath, but also disadvantages [1]. One of such drawback of multicarrier systems is high value of ratio between the peak and the mean signal power. The signal distortion degrades the system when the If the power amplifier takes signal with high peak to average power ratio (PAPR)[2].

Hence, it should work in linear region for its saturation and its optimal efficiency. The modulations are designed with non-constant envelope for the multicarrier systems.

Recent wireless systems based on multicarrier principle (WiMax, IEEE 802.11a, DAB, etc.) is easily feasible using Inverse Fast Fourier Transform (IFFT) and latest Digital Signal Processors (DSP) versions [3 and 4].

A. Need for PAPR Reduction

The PAPR of OFDM signal is maximum limit by the value N. This result is quite pessimistic and most of the time the instantaneous value of PAPR is much smaller. Using cumulative distribution function (CDF), PAPR can be described for the case of higher values. The following expression for the PAPR CDF holds

$$\Pr(\mathrm{PAPR} > \gamma) = 1 - (1 - \exp(-\gamma))^N \qquad (1)$$

For practical purposes, it is possible to distinguish between the PAPR of pass band and band pass signal. As derived in the PAPR of real pass band signal is twice the PAPR of corresponding complex envelope. For realistic PAPR CCDF results, the oversampling (usually by zero-padding in the frequency domain) of multicarrier modulation signal is necessary [5]. The oversampling has been used thorough all the experiments described below. The influence of oversampling on CDF and CCDF plots for the case of OFDM system with 64 subcarriers. OFDM signal are Gaussian distributed, while the amplitude and phase have Rayleigh and uniform distribution, respectively [6 and 7].

II. PAPR MINIMIZATION IN MCCDMA SYSTEMS

Several combinations of multicarrier and Spread-Spectrum principle have been proposed in the literature. For the MCCDMA systems, user data symbols are copied on all subcarriers and spread by the user-specific code of length N across the frequency domain [8]. After spreading, the IFFT is performed to obtain the time domain signal s(t). Note, that there is a strong correlation between data sent on IFFT inputs. M, Q and M& Q modifications of MC-CDMA have been proposed for better system flexibility. MC-DS-CDMA uses serial to parallel conversion of input symbols, similarly to OFDM. Each bit on the individual subcarrier is the spread in time domain by user spreading code frequency diversity is exploited by sending the same information on several subcarriers.

In order to minimize the problems arising from the use of signals with high PAPR in communication transmitters with nonlinearities, several approaches can be successfully used [9 and 10]. Each of them has its advantages and disadvantages [11 and 12]. The PAPR reduction is at this paper's main center of interests and will be described in more details in the next chapter. The linearization techniques can be applied for enhancing the efficiency [13].

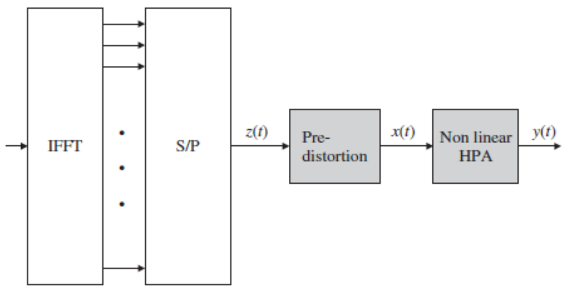

Fig1. Block diagram

Probably the simplest alternative is to back-off the PA that unfortunately results in its poor efficiency. The linearization techniques can provide almost linear PA

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characteristics in expense of either complex analog circuitry (feed-forward or feedback techniques) or complex digital signal processing (digital pre-distortion).

As shown in figure 1, the pre-distortion is usually adaptive in order to track the changes in analog circuitry. The pre-distorter's characteristic is adaptively calculated from the amplifier input and output signals. The effective method for digital predistortion algorithm has been presented in our previous research paper with the results recapitulated. It shows the output power spectra for the case of no predistortion and two selected predistortion algorithms. The digital pre-distorts suffer from analog circuitry imperfections, as has been shown in supposing the GSM-EDGE input signal with high PAPR. For example, the adjacent channel emissions of power amplifier output depend on the IQ modulator phase imbalance.

A. Signal Distortion

The clipping is simple method to reduce PAPR values. This method simply clips the signal s(t) for the level of A.

$$S^{clip}(t)=l^{s(t)} \quad \text{for } s(t)<A$$
$$A\exp(j\arg\{s(t)\}), \quad \text{for } s(t)>A \qquad (2)$$

As the clipping represents the nonlinear function, there is tradeoff between PAPR signal and signal distortion and BER. Thus the EVM and ACPR will increase as well. The clipping as presented above is thus suitable only for slight PAPR reduction and relaxed EVM/ACPR requirements.

B. Active Constellation Extension

The sophisticated variant of clipping - Active Constellation Extension (ACE) has been proposed and analyzed. The ACE method is based on the time domain clipping of the OFDM signal, with some allowable constellation distortion defined by the sets of constraints. In the conventional ACE approach, only the outer points of the constellation (usually M-QAM) are allowed to be spread in the outward direction. Thus, this method results in no BER increase. In small pre-defined distortion of inner points is also allowed (distortion bound). This result in reduced PAPR but increased BER.

C. Distortion less methods for PAPR reduction

The instantaneous PAPR depends on data symbol sent on the subcarriers. Some symbol vectors results in higher PAPR than the others. The worst case is represented by the same symbol sent on all subcarriers.

For arbitrary OFMD symbol index. In block coding approach has been used to avoid such vectors from transmission. Another approach is the search for optimal codes with low PAPR. Popover has shown the application of Golay complementary sequences to PAPR reduction. Note that any form of coding reduces the useful data rate. The idea of integration of the PAPR reduction and error protection coding has been presented in several papers..

III. EVALUATION OF SYSTEM PERFORMANCE

The performance and impact of nonlinearities are obtained based on various parameters. In order to quantify the effects of nonlinearity on digital (but not limited to) communication signal, it is possible to use the parameters Error Vector Magnitude (EVM) and Adjacent Channel Protection Ratio (ACPR).

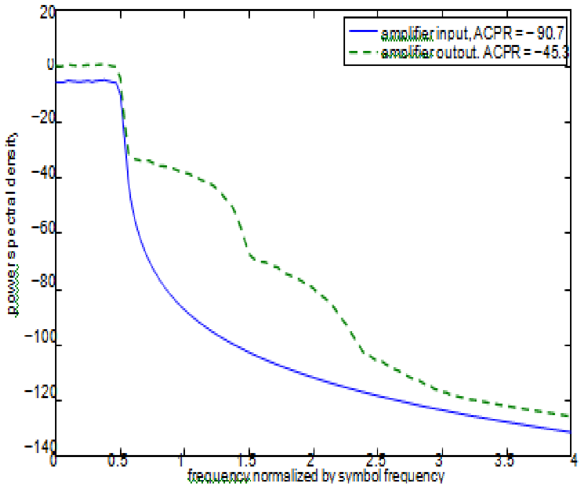

Fig. 2. Spectrum of signal with and without distortion and corresponding values of ACPR

As shown in figure 2, the performance evaluation using ACPR for find the effects of imperfections in communication systems on the constellation diagram. The effects of nonlinearity on the constellation diagram in single carrier system include constellation attenuation, offset, rotation, warping and cloud-like shape of constellation points. In OFDM based systems, the nonlinearity results only in attenuation, rotation and cloud-like shaping of constellation points. The maximal authorized values of EVM differ for each communication standard. The nonlinear distortion of constellation points is closely related to the symbol error rate (SER).

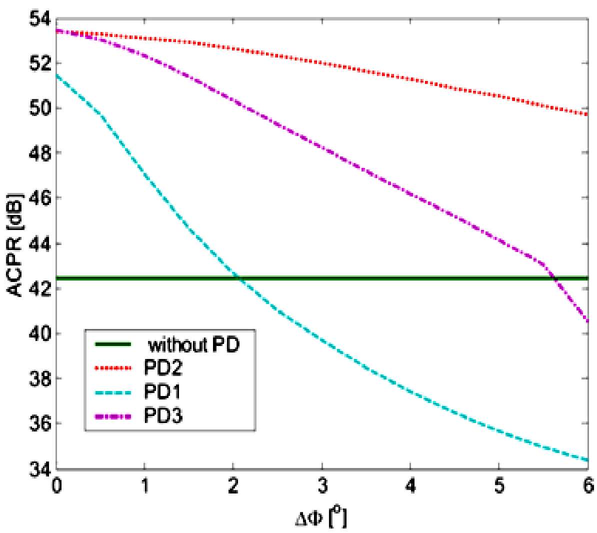

Fig. 3. Impact of ACPR on the phase imbalance for three types of pre-distorters.

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The several approaches to bound the constellation distortion have been compared and evaluated using simulations. As shown in figure 3, results confirmed their similar performance considering the imperfections due to as ACPR parameters while the methods differ in their complexity. Although the main principle of the method used in the presented paper is very close to the one in, its starting point was the method presented in with the repeated clipping and filtering replaced by the simplified clipping and filtering. The described method shows the improvement of 3 dB for PAPR CCDF probability 10^{-4} compared to the original OFDM without PAPR reduction. The PAPR degradation caused by the distortion bound is around 2dB compared to simple clipping with unbounded constellation distortion.

IV. CONCLUSIONS

This habilitation summarizes the work in the multicarrier communications with high signal envelope variations. The research has been oriented mainly into the PAPR reduction of multicarrier signals - OFDM and its combination with spread spectrum. The following most important results have been achieved,

- The distortion less method for OFDM PAPR reduction based on the concatenation of multiple signal representation and simplified clipping and filtering method has been proposed and evaluated
- Several approaches for distortion bounding in the method of simplified (repeated) clipping and filtering with bounded distortion for OFDM PAPR reduction have been compared
- The improvement of power amplifier efficiency due to the PAPR reduction has analyzed using computer simulations. The results confirm the ability of efficiency improvement, especially in the case of MC-CDMA.

Moreover, the alternatives to PAPR reduction have been considered thorough the research work. A part of the research has been devoted to their performance and to the evaluation of the influence of nonlinearities on communication signals with high envelope variation. As the continuation, the further research can be directed for example into the PAPR reduction methods with no necessary side information and further reduced complexity. It is also possible to concentrate on the two dimensional spread spectrum multicarrier system PAPR reduction, PAPR reduction for MIMO and cooperative systems. Another axe of the future development can be the effective implementations of PAPR reduction methods in modern programmable devices. The implementations have been started in the framework.

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