Performance of PSK/QAM Multi-carrier CDMA Schemes in the Presence of HPA Non-Linearities[†]

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Abstract: In this paper, we investigate the performance of multi-carrier CDMA with higher order PSK/QAM mapping in the presence of HPA non-linearities. We consider two different multi-carrier CDMA schemes and analyse their performance in terms of the BER degradation in the system.

1 Introduction

Multi-carrier CDMA schemes have been proposed as promising candidates for such future generations of wireless systems due to their robustness against multipath fading and implementation advantages over single carrier CDMA systems. However, multi-carrier CDMA, like most multi-carrier systems has one major drawback – high peak-to-average power ratio (PAPR). High PAPR makes the signal more sensitive to the non-linearities of the transmitter HPA. Large peaks in the signal occasionally thrust into the amplifier saturation region and cause signal distortion. This distortion manifests itself as in-band distortion and out-of band distortion. The former causes BER degradation and the latter results in spectral spreading [1].

In this paper we investigate the impact of HPA non-linearities (caused by a solid state power amplifier (SSPA)) on the multi-carrier CDMA systems for different PSK/QAM modulation schemes.

The paper is organised as follows: Section-2 and section-3 describe the system model and the HPA model respectively. Section-4 presents the results obtained and discusses the performance of the two schemes and finally, section-5 provides concluding remarks.

2. System Model

A number of different techniques have been proposed for combining CDMA with MCM. In this study we have further developed the MC-CDMA and MC-DS-CDMA schemes described in [2] to allow for higher order modulation formats. We specifically address the downlink case and hence assume that the transmitter and receiver are synchronised. Complex envelope representation of the signal is used in order to simplify the analytic formulation and reduce simulation time and complexity. User separation is achieved using Walsh Hadamard (WH) codes. The channel is assumed to be AWGN channel (Fig. 1).

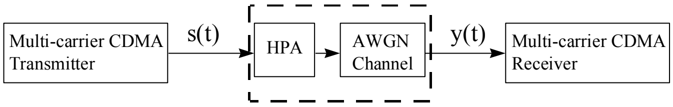

Fig. 1: Transmission Model

MC-CDMA with higher order mapping

Fig. 2a shows the equivalent baseband representation of the MC-CDMA transmitter. At the input of the transmitter, the user data is first mapped onto constellation points by the PSK/QAM mapper. The complex output from the mapper, D_m^u is then copied N times (where N is equal to the length of the spreading code). Each copy of the complex symbol is multiplied by a single chip of the spreading code, c_n^u and multi-carrier modulated using the IFFT. The output of the IFFT is then parallel-to-serial (P/S) converted and a cyclic prefix is inserted. The signal is low pass filtered before transmission.

[†] This work is based on our work in reference [1]

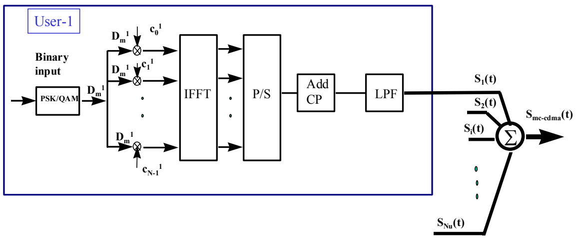

Fig. 2a: MC-CDMA Transmitter

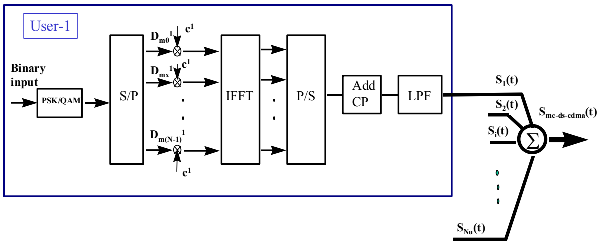

Fig 2b: MC-DS-CDMA Transmitter

The continuous time representation of the equivalent baseband MC-CDMA signal is given by:

$$S_{mc-cdma}(t) = \sum_{u=1}^{N_u} \sum_{m=-\infty}^{\infty} \sum_{n=0}^{N-1} D_m^u c_n^u g_n(t - mT) \tag{1}$$

$$g_n(t) = \begin{cases} e^{\frac{j2\pi n(t-T_{cp})}{T-T_{cp}}} & t \in [0,T] \\ 0 & t \notin [0,T] \end{cases} \tag{2}$$

where $g_n(t\text{-}mT)$ represents the n^{th} subcarrier, T is the duration of the MC-CDMA symbol and T_{cp} is the duration of the cyclic prefix.

MC-DS-CDMA with higher order modulation

The equivalent baseband representation of MC-DS-CDMA transmitter is given in Fig. 2b. In this case, the complex output from the PSK/QAM mapper is first serial-to-parallel (S/P) converted (The length of the S/P converter is equal to the number of subcarriers) and then spread using a user specific spreading code. The parallel streams of spread data are multi-carrier modulated using IFFT. The output of the IFFT is then P/S converted and a cyclic prefix is added to the signal. As in the MC-CDMA case, the signal is low pass filtered before transmission.

The signal at the output of the MC-DS-CDMA transmitter is given by:

$$S_{mc-ds-cdma} = \sum_{u=1}^{N_u} \sum_{m=-\infty}^{\infty} \sum_{n=0}^{N-1} D_{mn}^u c^u(t) g_n(t - mT) \tag{3}$$

where D_{mn}^u is the S/P output for time slot m, subcarrier n and user u , $c^u(t)$ is the WH code for user u and $g_n(t\text{-}mT)$ is the n^{th} subcarrier (as defined in (2)).

3. HPA Model

In this work we have used a memoryless model of the HPA [3]. We specifically consider the case of solid state power amplifiers (SSPA) as they are generally used in mobile communications.

If the complex envelope of the signal at the input of the amplifier (Fig. 1) is given by:

$$s(t) = r(t)e^{j\phi(t)} \tag{4}$$

then the complex envelope of the signal at the output of the amplifier, z(t) is given by:

$$z(t) = R(t)e^{j\phi(t)}e^{j\Phi(t)} \tag{5}$$

where $R(t)=f(r(t))$ represents the AM/AM conversion and $\Phi(t)=w(r(t))$ represents the AM/PM conversion of the non-linear amplifier.

The AM/PM conversion for an SSPA is assumed to be very small and hence can be neglected. The AM/AM conversion can be approximated by [4]:

$$R(t) = \frac{\upsilon r(t)}{\left(1+\left[\left(\frac{\upsilon r(t)}{A_{sat}}\right)^2\right]^p\right)^{\frac{1}{2p}}} \tag{6}$$

where υ is the small signal gain of the amplifier, A_{sat} is the saturation amplitude of the amplifier referred to the output and p is an integer value which controls the smoothness of the transition from the linear region to the limiting region [4].

4. Results and Analysis

In this section, the simulation results for the systems described in section-2 are presented.

MC-CDMA and MC-DS-CDMA systems with 64 users have been considered. In both cases, the symbol duration and the cyclic prefix duration were set to 1 μs and 0.2 μs, respectively (in order to ensure that the signal-to-noise ratio loss due to the cyclic prefix is kept below 1 dB).

The performance of the overall system is evaluated using a computational model developed specifically for this purpose. To account for the non-linear effects of the HPA an oversampling factor of 7 has been used [3].

As stated before, the performance of the two schemes is measured in terms of total degradation, T_D[5]:

$$T_D = \frac{E_b}{N_0} - \frac{E_b}{N_0}_{AWGN} + OBO \tag{7}$$

where E_b/N_0 is the signal-to-noise ratio required to obtain the target BER (10^{-3}) in the presence of the HPA plus AWGN and E_b/N_{0AWGN} is the signal-to-noise ratio required to obtain the target BER in the presence of an AWGN channel.

The performance of both systems was analyzed for BPSK, QPSK, 16PSK and 16QAM with the number of active users set to 16.

Performance of MC-CDMA System

Fig. 3a represents the total degradation of the MC-CDMA signal for different OBO values. From this figure we can observe that the total degradation is high for low OBO and high OBO values achieving a minimum value for intermediate OBOs. For low OBO values the amplifier is power efficient but it operates in its non-linear region. In this case, the major degradation factor is amplifier non-linearities. For high OBO values the amplifier is power inefficient but operates in its linear region. In this case, the major degradation factor is AWGN. This trade off results in the optimum OBO value where the total degradation is minimum. Observation of Fig. 3a also reveals that by changing the modulation format from BPSK to QPSK does not alter the optimum operating point of the HPA but does increase the minimum total degradation by approximately 1 dB. Changing the modulation format to 16PSK and 16QAM increases the minimum total degradation by 4dB and moves the optimum operating point from OBO=5dB to OBO=10dB. This can be justified by the fact that changing the modulation scheme from BPSK to 16PSK and 16QAM results in an increase in the PAPR of the signal [6].

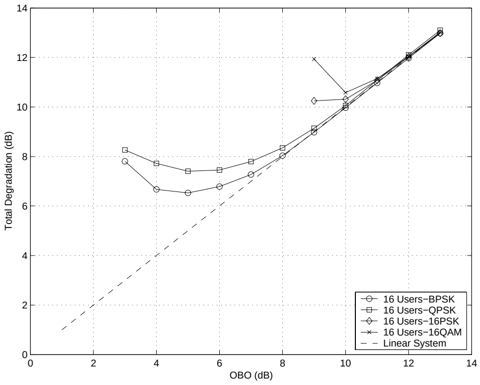

Fig. 3a: Performance of MC-CDMA

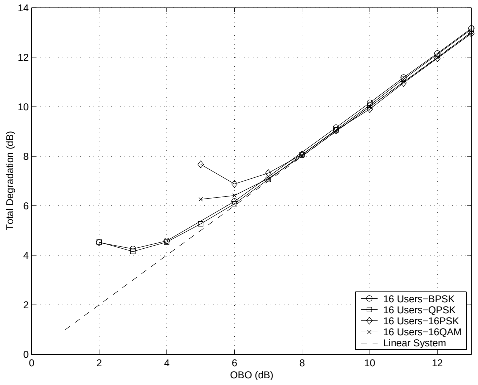

Fig. 3b: Performance of MC-DS-CDMA

Performance of MC-DS-CDMA System

Fig. 3b shows the total degradation of the MC-DS-CDMA signal for different modulation formats. In this case, changing the modulation format from BPSK to QPSK does not alter the optimum operating point of the HPA nor does it increase the minimum total degradation. Changing the modulation to 16PSK and 16QAM increases the minimum total degradation by 3 dB and moves the optimum operating point from OBO=3 dB to OBO=6 dB.

Performance comparison of MC-CDMA and MC-DS-CDMA System

By comparing the total degradation of MC-CDMA and MC-DS-CDMA signals for different PSK and QAM formats, we note that the total degradation of MC-CDMA signals is higher than that of MC-DS-CDMA signals. Hence, we conclude that for the QAM/PSK schemes considered, the overall performance of MC-DS-CDMA signals is better than the overall performance of MC-CDMA signals in the presence of an SSPA.

5. Concluding Remarks

In this paper, we have analysed of the effects of an SSPA on the performance of MC-CDMA and MC-DS-CDMA signals with various different PSK/QAM formats in terms of the total degradation. Results show that for the same level of non-linearity (or OBO), the overall performance of MC-DS-CDMA signals is better than that of MC-CDMA signals for all the modulation formats considered.

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