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PAPR ANALYTICAL CHARACTERIZATION AND REDUCED-PAPR CODE ALLOCATION STRATEGY FORMC-CDMA TRANSMISSIONS

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ABSTRACT

In this paper, an approximate analytical expression for the peak-to-average power ratio (PAPR) of a Multi Carrier Code Division Multiple Access (MC-CDMA) signal is derived. Then, it is demonstrated that the PAPR of a MC-CDMA system employing Walsh-Hadamard (WH) codes can be suitably reduced by resorting to a judicious strategy for the allocation of the spreading signature codes. Eventually, a low complexity implementation of the proposed strategy is presented and the relevant benefits, in terms of peak signal occurrence and robustness against nonlinear distortions, is numerically assessed over conventional random allocation strategy.

Key Words*:* MC-CDMA , PAPR ,WH.

1. INTRODUCTION

MULTI-CARRIER (MC) code-division multiple access (CDMA) is a transmission technique offering many appealing properties, such as robustness against multipath fading channels and flexible multiple access capability [1]. However, any MC signal (including MC-CDMA) experiences a high "peak- to-average power ratio" (PAPR), i.e., the peaks of the instantaneous power are much higher than the average power level. Consequently, the signal reveals vulnerable to nonlinear distortions induced by the high power amplifier (HPA) of the transmitter which entail both signal-to-noise ratio (SNR) degradation and out- of-band emission (OBE) [2]. Such a limiting feature spurred a massive research effort aimed at devising efficient techniques for PAPR reduction in MC signals. A comprehensive survey of PAPR reduction techniques for orthogonal frequency-division multiplexing (OFDM) is presented in [3], while the OBE issue is addressed in [4]. Some techniques originally devised for OFDM have been successfully demonstrated to be applicable to MC-CDMA, too, such as the partial transmit sequences (PTS) [5] and theselective mapping (SLM) [6] methods. Both the techniques reveal effective, but require also side information at the receiver and additional processing at the transmitter. In the particular case of MC-CDMA systems, the code-spreading stage, which enables multi-user access, has a twofold importance. i) it makes the analytical characterization of the PAPR more involved; ii) it provides an extra degree of freedom in controlling the PAPR, for instance by carefully selecting the code set among those available from the literature, or by suitably modifying an already existing set, or by designing a completely new code set.

Concerning the former issue, several works focusing on the analytical characterization of the PAPR for MC-CDMA signals in a multi-user context and on its dependence on the spreading signature properties (mainly, code auto- and cross-correlations) have appeared in the literature. However, most of them had to face critical difficulties in the analytical evaluation of signal peak power $P_{\max}$ distribution. To this respect, Choi and Hanzo [7] derived an analytical upper- bound of the crest factor (CF) for a MC-CDMA system using complementary (CP) codes, to be employed as a criterion for the selection of the lowest-PAPR code set. However, such a method is applicable to MC-CDMA systems with binary phase shift keying (BPSK) modulation and 2 or 4 codes, only. Furthermore, in [8] it is demonstrated that an accurate estimate of the PAPR for a MC-CDMA signal cannot be achieved by resorting to simplistic upper-bound approaches. So, a more accurate characterization of the PAPR distribution shall be obtained by means of a statistical approach. For instance, a closed-form approximation forthe PAPR distribution, based on the level-crossing rate analysis, is derived in [9] for OFDM, but, up to date and to the best of authors' knowledge, no simple and reliable analytical tool for the evaluation of the PAPR of a MC-CDMA signal is available in the literature.

In the present work, we focus on the downlink transmission. i.e. from base station (BS), to mobile stations (MSs), of a wireless MC-CDMA network, with a twofold aim. i) to derive a manageable closed-form expression of the PAPR distribution for a generic code set, by resorting to a statistical approach, instead of inaccurate upper-bounds. [8] ii) to derive a judicious and low-complexity, code allocation strategy, applicableto WH codes, which does not require any modification to the transmitter, nor to the receiver, and does not require any additional side information to be sent to the receiver. Based on the analytical PAPR characterization, we derive then a "PAPR metric", as a function of the auto and cross-correlations of the WH codes, and we demonstrate that it is quasi-monotonically related to the PAPR value, so as to play the role of a"cost function" to be minimized [20]. Furthermore, we derive a low complexity allocation strategy for the spreading signatures, based on an incremental-search algorithm, applicable to the Walsh-Hadamard (WH) set [20], which reduces the PAPR metric and yields improved PAPR performance. The complexity of the proposed search method is also numerically evaluated and compared with that of the exhaustive search approach. Eventually, the benefits provided by the proposed allocation strategy are assessed in terms of statistical distribution of PAPR and signal distortion at the output of the transmitter HPA.

2. METHODOLOGY

Let consider the down-link of a MC-CDMA system connecting the BS to N_u MSs. The nth information-bearing symbol $a_n^{(k)}$ of the kth user ($1 \leq k \leq N_u$) runs at rate $1/T_s$, and belongs to a M−QAM constellation with $E\{a_n^{(k)}\} = 0$, $E\{|a_n^{(k)}|\} = \bar{A}_1$, $E\{|a_n^{(k)}|^2\} = \bar{A}_2$, and $E\{|a_n^{(k)}|^4\} = \bar{A}_4$, Any information symbol is copied into N branches (equal to the number of subcarriers), and each of the N replicated symbols isthen multiplied by a different chip of the binary spreading sequence $c_m^{(k)} \in \{\pm 1\}$ $(0 \leq m \leq N-1)$, which acts as the user's channel identification signature[2]. The resulting spreading factor, i.e., the number of replicas of each information symbol transmitted on an OFDM block, is thus coincident with the number of subcarriers N. The spread data $a_n^{(k)} c_m^{(k)}$ of all the N_u active users are then summed together, and subsequently mapped to the N available subcarriers by IFFT (Inverse Fast Fourier Transform) unit. A cyclic prefix of L samples isinserted at the beginning of each IFFT output block to produce a $(N+L)$-sized block containing the samples.

3. MODELING AND ANALYSIS

Numerical results revealed that the metric for the CG, OG, SK, and SR sets does not appreciably depend on the particular selection of the codes that are assigned to the active users (i.e., the array C). This is not the case of WH codes, wherein both the PAPR and the metrics vary with respect to the code selection C. Such a dependence is clearly evidenced by Fig. 1, which plots the 99th percentile of the PAPR distribution ($PAPR_0$ @99%)[4] for N = 64 and N_u = 32. Eight different subsets of N_u codes from the WH set havebeen considered, and for each subset the corresponding metric has been analytically evaluated according to (18), while the relevant $PAPR_0$ @ 99% has been evaluated by simulation. The resulting metric-PAPR pair has been plotted as a circular mark, while the dot-dash line is a 2nd order polynomial fitting in a least squares sense that reveals a (quasi) monotonic trend between metric and PAPR.

Search Methods

All the subsequent numerical results have been derived for the down-link of a MC-CDMA system employing 16-QAM and RRC pulses with α = 0.125 belonging to a code set having size N, taken N_u a time. The number of possible selections of the code vectors composing the array C to be tested with the ESM approach is $P_{ESM} = N!/[N_u!(N-N_u)!]$, which reveals prohibitively large for a practical implementation.

The PAPR can be effectively reduced by resorting to the "Tree-Search Method" (TSM) which will bedemonstrated to bear a much lower complexity with respect to the ESM. The TSM approach, which is pictorially illustrated in Fig. 2, is outlined step by step hereafter, considering N_u active users to be allocated.

4. RESULTS AND DISCUSSION

This Numerical results have been obtained with the same system configuration previously described in sub-section IV-B. Figure 3 compares the analytical approximate expression of the PAPR CCDF (17) (solid line) with computer simulations (dashed line), for CG set (top chart) and OG set (bottom chart), with N = 64 and N_u = 32. Clearly, due to the simplifications used in the analytical characterization of the signal, numerical results differ somehow from simulation data. However, the discrepancy between theory and simulations is about ±1 dB thus demonstrating a rather satisfactory accuracy of the analytical method. Figure 4 compares the simulated CCDFs of the PAPR, for seven RA realizations (dashed lines) and for the RPA method (solid line), with WH set, N= 64 and N_u = 8. As apparent, when

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using the WH set, the RPA provides significant PAPR reductions with respect to the "blind" RA approach. In particular, PAPR reductions vary from 1 to 5 dB, at crossing probability 10−2. Figure 5 compares the simulated values of $PAPRO_0$ @ 99% versus N_u, for various code sets and N_u = 64. For the WH set

5. CONCLUSION

In this paper we have derived an approximate analytical expression for the PAPR of a MC-CDMA signal, and weassessed its accuracy for different code sets. After, we have illustrated the RPA method based on a proper allocation of the users' signatures to minimize the PAPR of the transmitted signal and, accordingly, to improve transmission system performance over nonlinear channels. The proposed RPA strategy is effective on an unmodified WH spreading code set and does not require modifications of the transmitter. In a typical packet-based mobile communication scenario, wherein the users continuously get in and out from the network, by resorting to the TSM implementation of RPA strategy, the admission of a new user involves an additional low-complexity step only. The latter simply consists in the selection of the code signature based upon the evaluation of the branch metric over the not-yet-allocated signatures, without any additional side information to be sent. Simulation results demonstrated that, when using WH codes, the RPA remarkably boosts link performance in terms of PAPR distribution, TD and OBO, over conventional RA strategy. Finally, as an added-value feature, the proposed code allocation strategy can be effectively used with other PAPR-limiting techniques, for boosting system performance.

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