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***Index Terms*—OFDM, Peak-to-Average Power Ratio, Power Control, DVB-T2, Tone Reservation, kernel phase optimization, latency.**

I. Introduction

During the last three decades, multicarrier modulation (MCM) schemes have attracted a lot of attention among the scientific community in the field of telecommunications and terrestrial broadcasting. Till date, orthogonal frequency division multiplexing (OFDM) is the most widespread MCM scheme. OFDM has been extensively deployed in wireless communication systems such as DVB, WiFi, WiMAX and LTE, primarily for its advantages in frequency selective channels. However, OFDM like any other MCM signal exhibits a high peak-to-average power ratio (PAPR), which is one of its main drawbacks.

The high power amplifier (HPA) is one of the key component in the modern communication systems. Unfortunately, it is an analog component and is inherently non-linear (NL). Signals with high amplitude fluctuations, as in the case of MCM systems, pose a serious challenge to the RF design of HPAs. In order to get rid of the amplified signal distortion, the HPA is made to operate in its linear region, which has very poor energy efficiency. The presence of high peaks cause in-band (IB) and out-of-band (OOB) interference when the MCM signals are amplified in the non-linear region of the HPA. IB distortions cause inter-carrier interference while OOB distortions lead to interference with adjacent channels and the breaking of the spectral mask.

The HPA linearity and energy efficiency are two vital parameters for any multicarrier wireless transmitter and especially for high power ones as used for TV broadcasting or macro base stations of 4G cellular networks. This has motivated many works in literature aiming at reducing on one hand the PAPR of the transmitted multicarrier signals and on the other hand the nonlinearity introduced by the HPA itself.

In recent years, tone reservation (TR) techniques [1], one among many PAPR reduction techniques, has been selected in various standards such as Digital Video Broadcasting - second generation DVB-T2 [2] and the American Digital Video broadcasting standard ATSC3.0 [3], for PAPR reduction. Unfortunately, the TR algorithm adopted by the DVB-T2 standard and described in [2] does not offer a sufficient performance-complexity trade-off to be implemented in todays DVB-T2 modulators. That is why, to the best of our knowledge, the TR adoption in the world of the DVB-T2 commercial modulator suppliers is very low.

In this paper, we propose a novel PAPR TR reduction technique based on a kernel signal, simple to implement yet compatible with the DVB-T2 standard. This proposed kernel is defined to deal with the reduction of multiple peaks at each iteration while optimizing the phase computation of each reserved subcarrier. Already based on this new kernel, a PAPR reduction technique, individual carrier allocation for multiple peaks (ICMP) has been proposed in [4]. However, it cannot be applicable in ATSC3.0 and higher modes of DVB-T2. So, in this paper, we propose a novel algorithm named as grouped ICMP (GICMP), which improves the performance of ICMP in terms of latency and hardware implementation. An analysis is then carried out showing that the new algorithm offers a very good performance/complexity/latency trade-off. The simulations confirm the very high potential of this new algorithm, which is fully compatible with existing DVB-T2, DVB-NGH and ATSC3.0 standards.

II. Reminder on PAPR minimization issues

A. PAPR reduction and power control

The PAPR reduction feature for DVB-T2 standard is optional. When activated, the power allocated to each PAPR pilot changes at each iteration. Hence, a power control (PC) scheme is included to verify the power spectrum mask of the DVB-T2 standard. 1 % of the subcarriers are dedicated for PAPR reduction. In order to respect the DVB-T2 spectrum mask requirements, an iterative process should be implemented at the transmitter with a special need for a smooth control of the transmitted power on the dedicated subcarriers. To meet the DVB-T2 requirements, the reserved tones should be at a power level less than 10 dB with respect to the data subcarriers power.

$$\max_k |C_k|^2 = (A_{max})^2 \leq 10(A_{data})^2, \qquad (1)$$

where A_{max} and A_{data} are the square root of the maximum available power per reserved subcarrier and data subcarrier respectively.

III. PAPR Reduction using new kernel definition

The techniques presented in this section uses a new kernel definition and allocates power to the subcarriers individually in order to maximize the power used for PAPR reduction. We discuss IMCP reduction technique [4] and propose a novel technique termed as grouped ICMP (GIMCP).

A. New kernel definition based on individual reserved carrier

Instead of a Dirac-type kernel as suggested by DVB-T2, we aim at generating a comb-like one, for each reserved subcarrier. By phase-shifting the kernel, we try to reduce the peaks of the data signal. This kernel is defined for every iteration i, as below

$$C_k^i = \begin{cases} A_{max}, & k \in P_{i-1}, \\ 0, & else, \end{cases} \tag{2}$$

where P_{i-1} is the position of the reserved tone corresponding to the current iteration. The real-time generation of kernels in ICMP only requires a simple phase shift operation.

B. The ICMP solution

The main idea behind the ICMP technique is to target multiple peaks in one iteration. In ICMP, the maximum number of iterations (*Iter*) equals to the number of available pilots (R). In frequency-domain, the kernel amplitude is set to the power constraint A_{max} as per (2). It means no explicit power control is required at each iteration in ICMP approach since the power constraint is respected by design.

1) Optimization condition: In ICMP, the optimal phase is identified such that S multiple peaks are reduced in a single iteration. Mathematically, the ICMP optimization problem can be stated as

$$\min_{\phi} \sum_{s \in H} \left| \mathbf{d}_L + c_s . e^{-j\phi} \right|^2, \tag{3}$$

where H is the set of the S highest peak positions of $\mathbf{d}_L$ and c_s represents the additional samples of the current kernel corresponding to the H positions. The problem stated in (3) means, instead of reducing the peaks, we aim at reducing the energy above a particular threshold. By varying the size of S, we indirectly vary this threshold. So, a high value of S implies severe clipping leading to more PAPR reduction.

2) Optimal phase calculation: To solve (3), first, S highest peaks are identified. Then, the optimal phase ϕ has to be computed, which minimizes the sum of the squares of these peaks as follows

$$F(\phi) = \sum_{s \in H} \left| \mathbf{d}_L + c_s . e^{-j\phi} \right|^2, \tag{4}$$

By differentiating (4) and solving $\frac{\partial F}{\partial \phi} = 0$, to study the variation of $\frac{\partial F}{\partial \phi}$, we can find the optimal phase calculation. The computational complexity of H is $\mathcal{O}(N)$

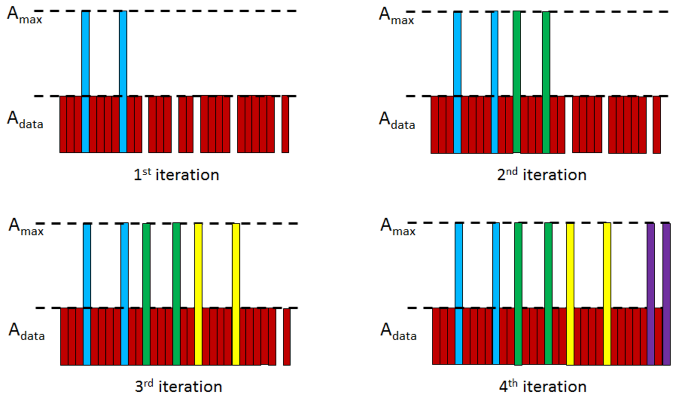

Fig. 1: Relation between the kernel definition and the iteration count in GICMP scheme in 4 groups, aiming to reduce two peaks at a time.

3) Latency: In ICMP, each iteration performs one peak search, every peak search traverses the whole signal. It means, the number of iterations executed by ICMP is equal to the number of available reserved subcarriers. So, lower modes in DVB-T2 such as 2K, 4K and 8K would not be a problem. Nevertheless, for higher modes of DVB-T2 and ATSC 3.0 such as 16K and 32K, where, 144 and 288 tones are reserved, it becomes increasingly challenging as induced latency is enormous.

C. The GICMP solution

To address the serious issue of latency in the ICMP, we propose an improved ICMP algorithm. It is achieved by dividing the reserved pilots into G groups as below

$$\mathcal{B} = \{\mathcal{B}_1, \ldots, \mathcal{B}_G\}, \tag{5}$$

$$\mathcal{B}_i = \left\{ P_{1+\frac{(i-1)R}{G}}, \ldots, P_{1+\frac{iR}{G}} \right\}, \text{ for } 1 \leq i \leq G. \tag{6}$$

Then, only one peak search is executed per group. Apart from this, the remaining steps of the algorithm, i.e. the optimization condition and optimal phase calculation remains unchanged. As these steps are now uncorrelated and if needed, can be executed in parallel to further reduce the latency. The relation between the kernel definition and the iteration count in GICMP is illustrated in Fig. 1.

In classical ICMP, the number of iterations is equal to the total number of reserved subcarriers, while in GICMP it is equal to number of groups. This explains the substantial decrease in the latency of implementation.

IV. Simulation Results and Conclusion

We have simulated a DVB-T2 system in 32K mode with GICMP with $S = 100$ and different set of groups $G = \{1, 2, 4, 8\}$ and plotted the MER with a Rapp model of HPA with smoothing factor $p = 10$, as shown in Fig. 2. 64 QAM constellation is considered. We have chosen 32K mode as it is to the best of our knowledge, the preferred mode for the deployment of the terrestrial broadcast. Even with only one peak detection being performed, GICMP

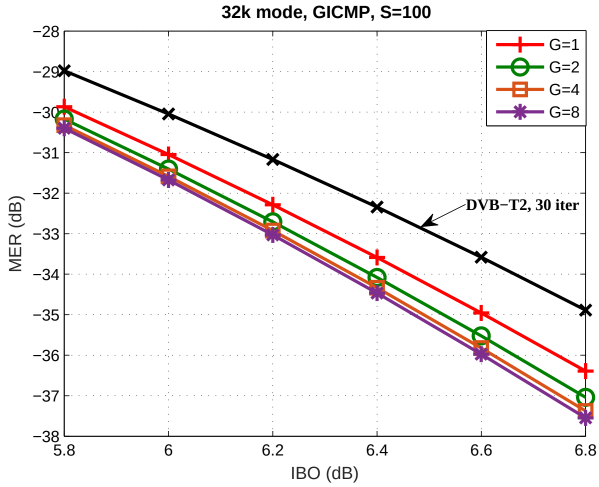

Fig. 2: MER plot for a DVB-T2 system in 32k mode with GICMP.

$G = 1$ outperforms the classical TR scheme suggested in the DVB-T2 standard, which allocates 30 iterations, both in terms of latency and IBO gain by 0.2 dB at −33 dB of MER. This translates into a huge reduction of processing delay for GICMP, since the peak detection process is one of the longest. As the G size increases, we can notice that GICMP offers more IBO gain as shown in Table I.

TABLE I: IBO gain at −33 dB of MER for GICMP with different G w.r.t. DVB-T2 PAPR scheme for 32k mode.

G	**Relative IBO gain at −33 dB of MER**
1	0.2
2	0.25
4	0.29
8	0.5

In the final paper, a detailed description of the novel GICMP algorithm along with some additional results in terms of CCDF and MER shall be given. These results show this PAPR reduction technique offers a very good complexity/performance/latency tradeoff, to the implementation in future DVB-T2 and ATSC 3.0 transmitter.

Acknowledgment

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