Turbo Decision Aided Reconstruction of Clipping Noise in Coded OFDM : TURBO DAR

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Abstract—High Peak Average to Power Ratio (PAPR) is one of the main drawback of the OFDM systems currently used in high rate communication standards. One way to reduce PAPR consists in clipped the amplitude of the OFDM signals introducing an additional noise that degrades the system performances. This paper presents an iterative reconstruction of the clipped samples in coded OFDM systems in presence of channel noise. Our algorithm combines, a classical DAR procedure with an iterative decoding of the channel code in a turbo-like way.

I. INTRODUCTION

Multicarrier modulations are good candidates for the emerging high rate transmission systems, either wired, wireless, single or multi-users. Several standards have chosen OFDM modulations [1] because they allow a very simple mitigation of Inter Symbol Interferences (ISI) using guard interval which could be very destructive when the information rate is high. Moreover, the channel equalization is easily performed in OFDM systems by a simple gain control. However, a well-known drawback of Multicarrier modulations is that transmitted signals exhibit a Gaussian-like time domain waveform with some relatively high peaks. One way to reduce the Peak to Average Power Ratio (PAPR) consists in generating an OFDM signal with low PAPR [2]. A second way consists in clipping the amplitude of the transmitted signal leading to non-linear distortion which cannot be efficiently corrected with a classical linear receiver even using an error correcting code (ECC)[3]. In [4], Kim and Stuber propose an iterative non-linear decoder that corrects the clipping effect on OFDM transmission called Decision Aided Reconstruction (DAR). Our method is inspired by the DAR procedure but also takes advantage of the error correcting code present in the high rate coded-OFDM (COFDM) transmissions in a Turbo-like way. The two blocks that exchanges information iteratively are the DAR receiver and a Viterbi decoder. That is why in the following, we call it Turbo-DAR. In addition to the high improvement of the performances in clipped OFDM signaling, the Turbo-DAR is a low computational cost receiver which converges generally within three iterations.

This paper is organized as follows. Section II outlines the system model. Section III presents the proposed algorithm and Section IV evaluates the performances of Turbo-DAR on both AWGN and frequency selective channel. The results are compared with a receiver implementing a classical DAR procedure followed by an ECC decoding using Viterbi algorithm and another one implementing a single ECC decoding using Viterbi algorithm. Some comments are given in Section V and finally conclusions are provided in Section VI.

II. SYSTEM AND CHANNEL MODEL

A binary sequence $U_k$ is encoded via a convolutional code to obtain a coded binary sequence $C_k$. Then, $U_k$ is mapped into a QAM symbol $Y_k$ and modulated using IFFT in an $N$-points output sequence such as:

$$y_k = \frac{1}{\sqrt{N}} \sum_{n=0}^{N-1} Y_n \exp \left(\frac{2j \pi nk}{N}\right), \quad 0 \leq k \leq N - 1$$  \hspace{1cm} (1)

where $(Y_n)_{n=0}^{N-1}$ is the transmitted symbol sequence and $N$ is the OFDM block size. The clipping operation is performed on the IFFT-output sequence as:

$$y'_k = \begin{cases} y_k & |y_k| \leq A \\ A \exp(\arg y_k) & |y_k| > A \end{cases}, \quad 0 \leq k \leq N - 1$$  \hspace{1cm} (2)

where $y_k$ is the clipped output sequence and $A$ is the clipping amplitude. The Clipping Ratio (CR) is defined as

$$CR = 20 \log \frac{A}{\sigma} \text{ dB}$$  \hspace{1cm} (3)

where $\sigma$ is the standard deviation of $y_k$.

A guard interval is added to the clipped output sequence as:

$$y'_k^G = y_{(k+G)N}, \quad 0 \leq k \leq N + G - 1$$  \hspace{1cm} (4)

where $G$ is the length of guard interval (also called cyclic prefix), and $(k)_N$ is the residue of $k$ modulo $N$. The samples $y_k$ are transmitted through the channel. Throughout the paper, only time invariant channels are considered and perfect carrier and timing synchronization of the receiver are assumed.
At the receiver side, after removing the cyclic prefix, the signal can be written:

\[ r_k = \sum_{m=0}^{M} h_m y_{(k-m)\times} + b_k, \quad 0 \leq k \leq N - 1 \]  

(5)

where \( h_m \) is the channel coefficient at the lag \( m \) and \( b_k \) is a zero-mean AWGN with variance \( N_0 \).

By FFT-processing on \( r_k \), we obtain:

\[ R_n = H_n Y_n^c + B_n, \quad 0 \leq n \leq N - 1 \]

(6)

where \( Q_n \) is the sum of the AWGN and the clipping noise and \( H_n \) represents the a priori-known complex channel gain on the \( n^{th} \) sub-carrier. Equalization is performed in the frequency domain using zero-forcing:

\[ Z_n = \alpha_n R_n \text{ with } \alpha_n = \frac{H_n^*}{|H_n|^2} \]

(7)

and these equalized symbols are used as the input of the Turbo-DAR algorithm.

III. TURBO DECISION AIDED RECONSTRUCTION

Although the DAR method [4] seems to be a good and easy solution to reconstruct the clipped samples when the clipping ratio is relatively high (above 4-5dB), the method has to be improved if one wants to operate at smaller clipping ratios. We propose then to include in the DAR loop the channel decoder so that the error correcting code could help to mitigate the clipping noise in a turbo fashion. Like in the DAR method, we focus on designing a simple receiver, which does not require a lot of additional computation delay compared to existing receivers. For the case of convolutional codes, we have therefore considered a Viterbi decoder in the turbo-loop instead of the BCJR algorithm (or SOVA algorithm), usually preferred in turbo-receivers because it provides soft extrinsic information. Using a hard decision decoder could seem inappropriate in a turbo loop, but this has two advantages in the goal of reducing the receiver complexity: (i) the Viterbi decoder is a lot less complex than BCJR decoder, and (ii) by propagating hard decisions between the receiver blocks, the number of iterations needed to achieve convergence of the receiver is greatly reduced. By using this kind of receiver, we do not focus on achieving the optimum performance, but we rather try to deal jointly with the AWGN noise and the clipping noise with the minimum complexity. We will see in the simulations that we still get a turbo-effect, despite the propagation of hard decided values. Our belief is that this effect comes from the fact that the decisions are separated by FFTs, and then are taken in different parameter spaces.

The clipping amplitude defined in (2) is assumed to be the real and imaginary parts of the channel noise and the clipping noise with the minimum complexity. We will see in the simulations that we still get a turbo-effect, despite the propagation of hard decided values. Our belief is that this effect comes from the fact that the decisions are separated by FFTs, and then are taken in different parameter spaces.

The clipping amplitude defined in (2) is assumed to be

\[ \frac{E_b}{N_0} = \frac{E_s |H|^2}{2R \sigma_b^2} \]

(9)

where \( R \) represents the global rate of the transmission (including mapping and error correcting code), \( \sigma_b^2 \) is the variance on the real and imaginary parts of the channel noise and \( |H|^2 \) represents the channel energy.
## A. AWGN channel

Figures 3, 4 and 5 show the performances of the three receivers for different Clipping Ratios equal to 1 and 3 dB. In all cases, the Turbo-DAR provides better results after only 2 iterations. For both 16- and 64-QAM, the improvement in BER compared to the initial BER (without Turbo-DAR) or even with DAR+ECC is particularly impressive for a high signal to additive noise ratio when the clipping level is relatively high ($CR = 1$ dB).

Table II shows the SNR loss (gap from the lower bound) at $BER = 10^{-3}$ for the above mentioned receivers at $CR = 1$ dB and 3 dB. We obtain an improvement of more than 2.9 dB with Turbo-DAR compared to the DAR+ECC receiver and more than 3 dB compared to the single ECC receiver for $CR = 1$ dB. Unlike Turbo-DAR, we can notice that ECC receiver exhibits an error floor at a $BER = 1.5e^{-4}$ dB due to clipping noise.

These good results are confirmed by Table III and Figure 5 for 64-QAM where Turbo-DAR achieves performances really close to the lower bound (0.6 dB) compared to the other receivers. Note that in this case also the Turbo-DAR converges within only three iterations.

Although not shown in this paper, Turbo-DAR gives better or equal results than other receivers when the clipping ratio is larger than 5 dB.
B. TIFS channel

Figures 6 and 7 show the performances of the 3 receivers for two different clipping ratio on a TIFS channel. If the clipping noise is large enough ($CR = 1$ dB), we notice that the results in term of BER are similar to the AWGN case with a slightly reduction of performances due to frequency selectivity. In the other case ($CR > 2$ dB) we can notice that the Turbo-DAR behavior depends on the signal to additive noise ratio. When the $E_b/N_0$ is weak, Turbo-DAR allows a significant improvement of the BER. However for high signal to additive noise ratio DAR+ECC receiver gives equivalent performances than Turbo-DAR.

V. CONCLUSION

A mitigation method for clipped COFDM signals called Turbo-DAR has been presented. The Turbo-DAR algorithm allows a relatively high improvement of the BER by combining the effect of error correcting code and decision taken in a frequency domain in a Turbo-like way.

Although only static channels are considered here, the Turbo-DAR receiver can be used on time-varying channel such in high rate Wireless applications with an adaptive channel estimator such in [5] or in [6].

REFERENCES