Non linear power amplifier effects on post-OFDM waveforms

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Abstract

Any multi-carrier signals are known to be prone to high peak to average power ratios what is viewed as a salient shortcoming. As a result it is shown that their amplification with non linear components (as power amplifiers) yield large out of band regrowths and mitigate their spectral efficiency accordingly. As spectral regrowths have to be kept under a given thresold, the spectral effects of non linear amplification have to be carefully studied in the multi-carrier context. The considered waveforms are CP-OFDM, WOLA-OFDM, UFMC, Filtered OFDM, FBMC-QAM, FBMC-OQAM and FBMC-QAM. The two metrics to be investigated are their Power Spectral Densities and the Noise Power Ratio of the transmission by taking into account a real power amplifier modeled as a polynimial transfer function.

1 Introduction

Orthogonal Frequency Division Multiplexing (OFDM) has known a considerable success for the last decades due to many reasons (espacially its simple equalization step) and it appears that many standards are now OFDM-based. Nevertheless the rectangular window carrying the OFDM time symbol is not well localized in frequency as its side lobes are very high. As long as users are synchronous this doesn't affect inter carrier interference (ICI) ; but with asynchronous communications these side lobes genereate a high ICI. Then many proposals have been investigated to improve this issue and the native Weyl-Heisenberg OFDM waveform basis has been modified in a way to get a much better time and frequency localization. This gave birth to WOLA-OFDM, UFMC, Filtered-OFDM waveforms where the complex orthogonality remains and a windowing/filtering is applied to a group of subcarriers [1]. Following this idea applying well time-frequency localized filters on individual subcarriers provide very low side lobes at the cost of giving up either the complex orthogonality for FBMC-OQAM (only real orthogonality) or orthogonality for FBMC-QAM [2].
Many works investigated the performance of all these post-OFDM waveforms and put in light the benefit to filter individual subcarriers with well time-frequency localized filters. But a few papers dwell on their non linear amplification and the way side lobes behave. This is the objective of this paper.

2 System model : a coexistence scenario

In this study, we consider a scenario of two coexisting users sharing the available frequency band as depicted in Figure 1, where the dashed area and the red colored one correspond to the time/frequency resources allocated to the user of interest and the other one, respectively [3]. The useful signal occupies a frequency band of 540 kHz equivalent to 3 LTE resource blocks (LTE-RB bandwidth = 180 kHz) while 1.62 MHz (i.e. 9 LTE-RB) are allocated to the other user on each side of the useful frequency band.

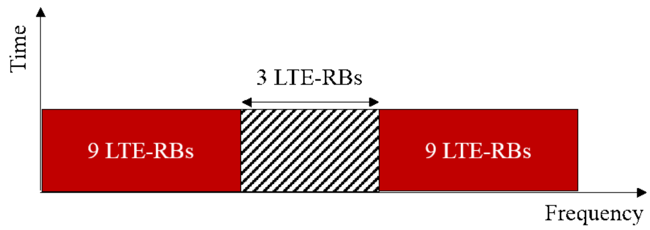

Figure 1. Coexistence scenario.

Our purpose is to identify the amount of the generated-noise power in the dashed area. For this reason, the output signal of each waveform spectrally localized on the red colored area is amplified using the PA model. Hence, a PSD-based comparison is firstly hold between the considered waveforms for different Input Back-Off (IBO)s. Then, the noise power ratio (NPR) variation with the IBO in the dashed area is analyzed.

3 Waveform parameters

In this section, we provide the general parameters of the scenario previously described as well as specific parameters related to the different othogonality types : waveforms with complex orthogonality, waveforms with real orthogonality and waveforms without any orthogonality. The parameters used for all waveforms are summarized in Tables 1 to 4.

4 Waveforms comparisons

All the aforementioned waveforms will be compared according to three metrics : the Peak to Average power Ratio

Table 1. General parameters

General	
RB bandwidth	180 kHz
Useful bandwidth of user of interest (UOI)	540 kHz
Input data	16-QAM
Subcarrier spacing	15 kHz
Sampling Frequency	15.36 MHz

Table 2. Waveforms with complex orthogonality

CP-OFDM / WOLA-OFDM	
FFT size	1024
CP length	72
Windowing	Raised cosine
Window length (W_e,W_r)	$(20, 32)$
UFMC (UF-OFDM)	
FFT size	1024
Filter	Dolph-Chebyshev
Filter length (L_{FIR} =ZP+1)	73
Zero padding length	72
Stop-band attenuation	40 dB
Receive windowing	Raised cosine
f-OFDM	
FFT size	1024
Filter	the same at both Tx and Rx sides
Filter length	512
CP length	72
Transition band	2.5×15 kHz
Burst truncation	CP/2 on each side

Table 3. Waveforms with real orthogonality

FBMC-OQAM	
Prototype Filter	PHYDYAS
Overlapping factor (K)	4
FFT size	1024

Table 4. Non orthogonal waveforms

FBMC-QAM	
Prototype Filter	Samsung Type I [4]
Overlapping factor (K)	4
FFT size	1024

(PAPR), the Power Spectral Density (PSD) and the Noise Power Ratio (NPR). For the PSD and NPR a non linear power amplifier will be included ih the transmission chain.

4.1 PAPR metric

The block size used for the PAPR computation is the same for all the waveforms and has been set to 1024 since it refers to the size of the traditional CP-OFDM block symbol as configured for LTE. We can observe from Figure 2, for a given number of subcarriers, that traditional CP-OFDM provides the best PAPR performance. This is in line with the litterature [5]. Nevertheless almost all considered waveforms have roughtly same PAPR behaviour what is important to be underlined in order to fairly compare their spectral behaviour when taking into account their non linear power amplification.

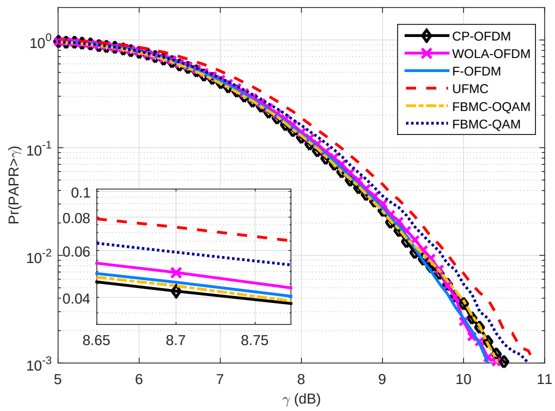

Figure 2. PAPR distribution comparison

4.2 PSD metric

4.2.1 Measured Non linear power amplifier

The HPA model used in this section is a polynomial model used to fit a 4 GHz realistic power amplifier introduced in[6]. It represents a HPA with both AM/AM and AM/PM characteristics. Let us consider $x(t) = \rho(t)exp(j\phi(t))$ the complex envelop of the input signal. In this case, the HPA output signal can be written as follows :

$$u(t) = F_A(\rho(t))\exp(jF_P(\rho(t)))\exp(j\phi(t)), \qquad (1)$$

where $F_A(\cdot)$ and $F_P(\cdot)$ are respectively the AM/AM and AM/PM HPA transfert functions modeled both by :

$$F_{\{A,P\}} = \sum_{n=1}^{L_{\{A,P\}}} a_n^{\{A,P\}} \rho^n. \qquad (2)$$

Here $\{a_n^{\{A,P\}}\}_{n=1,\cdots L_{\{A,P\}}}$ are the polynomial model coefficients either for $F_A(\cdot)$ or $F_P(\cdot)$. $L_{\{A,P\}}$ are the polynomial orders of $F_A(\cdot)$ and $F_P(\cdot)$. This model is denoted for the remainder of this document by 3GPP HPA. The measured AM/AM and AM/PM curves were approximated using 9^{th}

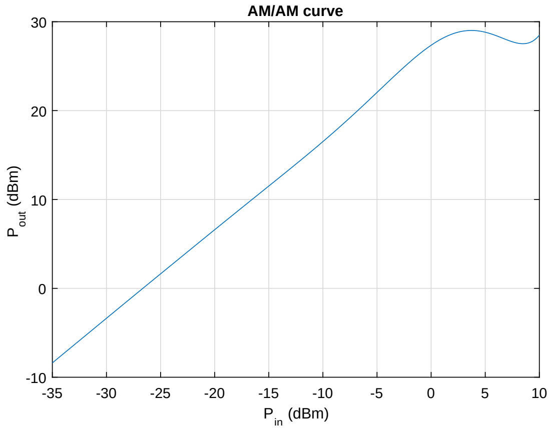

Figure 3. 3GPP HPA model: AM/AM conversion, input in dBm, output in dBm.

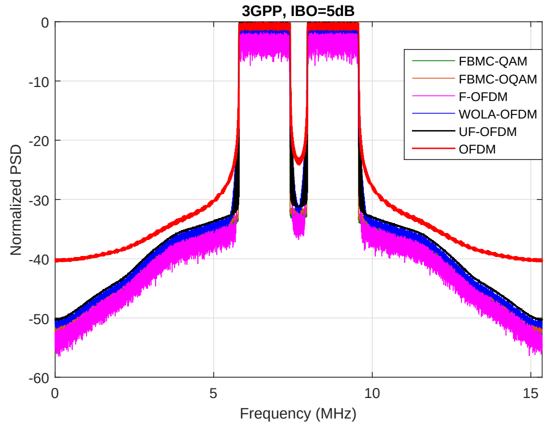

Figure 5. PSD-based comparison for IBO=5dB.

order polynomial. We obtained the AM/AM curve depicted in Figure 3. Similarly we obtain the AM/PM curve in Figure 4.

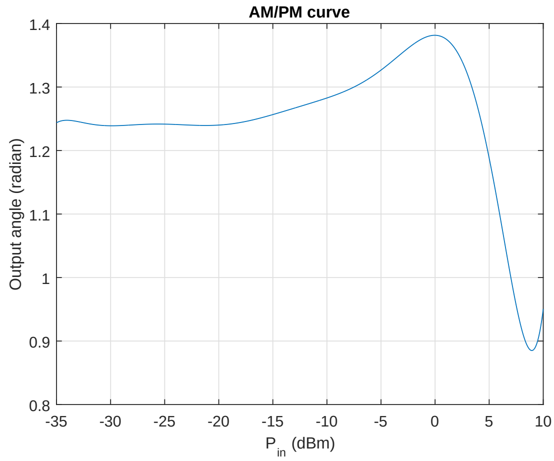

Figure 4. 3GPP HPA model: AM/PM conversion, input in dBm, output in radian.

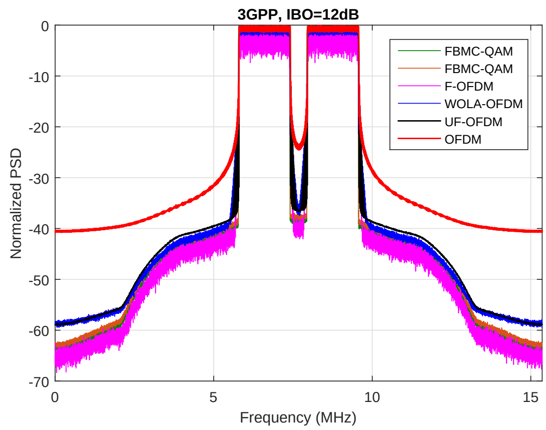

Figure 6. PSD-based comparison for IBO=12dB

4.2.2 PSD with 3 GPP power amplifier

It has been well established that CP-OFDM has poor frequency domain localization compared to the other waveforms. However, after non-linear power amplification, in-band and out-of-band radiations are introduced. Consequently, the PSD tails become higher. In this section, we focus on the frequency domain localization resistance to this phenomenon. Indeed, good or excellent spectral containment will be a key parameter for future 5G waveform in order to support neighboring and non orthogonal signals especially after power amplification.

For a 5 dB IBO operating point value, the 3GPP HPA generates high OOB as the non linearity remains significant. The considered WFs frequency-localization are distinguishable. WOLA-OFDM shows the highest PSD tails. As expected, the lowest PSD tails are given by FBMC-QAM, FBMC-OQAM and Filtered-OFDM. Indeed, their PSD tails are from the beginning very low compared to CP-OFDM and WOLA-OFDM. Therefore, as the amplification is becoming linear as IBO increases, the OOB emissions of each waveform decrease. As confirmed by Fig. 6, showing the PSD of the amplified signal at an IBO of 12 dB, there is no significant difference between the WFs OOB emissions at the output of the 3GPP HPA.

For IBO=12 dB (roughly equal to the PAPR value), the operating point is significantly far away from the compression region. However, there are still few AM/PM distortions. These distortions as said previously make the OOB emissions at the output of the 3GPP significant.

4.3 NPR metric

Two cases can be distinguished:

- IBO $\leq$ 4 dB: for all the considered waveforms, the NPR decreases with a slope of almost 2.5 when the IBO increases. In this region, the slope of the power amplifier is changing significantly from the non-linear to the linear behavior.
- IBO $\geq$ 4 dB: here the NPR decreases with a smaller slope when the IBO increases. In this case, the HPA behavior is already linear regarding the AM/AM distortions but still causing AM/PM distortions. This makes the NPR flat for the CP-OFDM and WOLA-OFDM. However, for FBMC-QAM, FBMC-OQAM , UF-OFDM and F-OFDM, their filtering systems protect them from these distortions.

The waveforms can be classified according to the NPR level from the best to the worst as: 1.FBMC-QAM, 2.FBMC-OQAM , 3.UF-OFDM, 4.F-OFDM, 5.CP-OFDM, 6.WOLA-OFDM. For FBMC-QAM and FBMC-OQAM a slight difference is noticed when the IBO is smaller than 6 dB. They show the same performance when the IBO is greater than 6 dB.

5 Conclusion

This paper covers the analysis of post-OFDM waveforms behaviors when considering non linear power amplifier characteristics (AM/AM and AM/PM). As OFDM, all studied waveforms have roughtly same PAPR but much lower spectrum out of band regrowth due to their filering properties. Considering PSD and NPR metrics, it appears that FBMC-QAM and FBMC-OQAM have very good performance due to their capability to filter individual subcarriers.

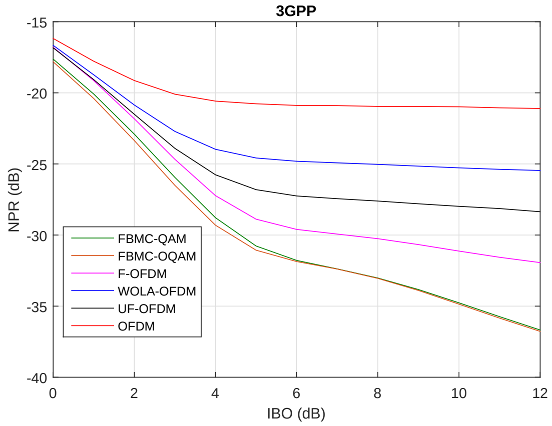

Figure 7. NPR comparison for 3GPP HPA model output

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