INFLUENCE OF INTERFERENCES CAUSED BY NON-LINEAR POWER AMPLIFIER IN MULTI-USER GENERALIZED FREQUENCY DIVISION MULTIPLEX SCENARIO

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Abstract: This article is aimed to the problematic of interferences in multi-user scenarios which can occur in modern mobile communication networks. Hence of new modulation schemes as a Filter Bank Multi Carrier (FBMC), Generalized Frequency Division Multiplex (GFDM) or another modulation scheme with low out of band emission there can occur problems with interferences especially when user equipments are using non-linear power amplifiers. The non-linear system causes radiation into adjacent channel which can lead to interferences with another user transmitting in this channel. This paper explains impact of such interferences to Error Vector Magnitude (EVM) of demodulated signal for different frequency spacing between users and also describe influence of interferences for different signal noise ratio. To remove inter-carrier interferences, the self interference cancellation method is used.

Keywords: Power amplifier, amplifier modeling, distortion, interferences, FBMC, GFDM, 5G

1 INTRODUCTION

Demands for higher data rates in field of mobile communication lead to force network providers to increase their capacity and efficient use of spectrum. However Orthogonal Frequency Division Multiplex (OFDM) systems allow an efficient equalization and also they are robust to frequency selective channels, these systems are not well suited for next generation mobile communication waveform designs. In presence of carrier frequency offsets, the orthogonal sub-carriers of OFDM are extremely vulnerable to interference and makes the entire OFDM system very sensitive [1]. The second disadvantage of the OFDM waveform is rectangular pulse shaping filter with low Out Of Band (OOB) attenuation which makes it unsuitable for next generation of mobile network. Also requirement for using cyclic prefix limits spectral efficiency of the OFDM system [2]. One possibility to reach higher spectral efficiency is to use post-OFDM modulations. The main advantage of these modulation schemes is sharp spectral shape with low OOB emissions, sufficient to effective spectrum usage. There are several modulation schemes suitable for 5G systems. The FBMC is a very popular technique which using division of spectrum into multiple orthogonal sub-bands [3,4]. Each sub-band is filtered by a prototype filter which can satisfy regulatory requirements in its OOB leakage performance. The absence of cyclic prefix is also an important feature of FBMC [5]. Second effect is that the carriers may be not orthogonal because of the filtering which allow us to control bandwidth and the degree of overlap between sub-carriers. The third effect is that the FBMC sub-bands have not to be synchronized between themselves. This fact can solve problems of possible synchronization and dispersion [6–8]. The GFDM is another modulation scheme which can be possibly used in 5G networks. This modulation scheme is based on the circularly shifted prototype filter in time and frequency domain. Similarly as in the FBMC, the OOB emission is significantly suppressed. This fact allows that the modulation scheme is well suited for transmission on non-contiguous frequency bands with strict spectral mask constraints [9]. Another popular candidate for 5G network can be filtered OFDM (f-OFDM) with appropriately designed spectrum shaping filter [10].

In point of view of radio-frequency (RF) transmitters it is desirable to work close to saturation point of Power Amplifier (PA) to achieve high transmitter efficiency. Nevertheless because of non-linear characteristic of PA the main advantage of the post-OFDM waveforms-especially sharp spectral shape can be easily destroyed. Non-linear PA characteristic has significant effect on distortion of transmitted signal, but because of the OOB leakage it can also cause interference with another users transmitting in adjacent channels. Moreover in mobile networks scenario where user equipments (UE) are charged from the battery it can be problematic to employ some form of PA linearization, e.g. pre-distorter.

The paper is structured into few parts. The first part describes modulation and demodulation scheme. The second part describes PA model. The third introduces simulations results. Finally the last part rounds up this paper.

2 POWER AMPLIFIER MODEL

The PA is one of the most important parts of the transmitter. The PA properties in hand with Peak to Average Power Ratio (PAPR) of transmitted signal have significant influence to leakage signal into adjacent channel. To investigate the effects of the PA distortion on the transmitting signal we simulate the PA based on the estimation of the real class AB in house fabricated PA. The measurements of practical values of PA, were done with commercially available software defined radio USRP N210. The software radio is equipped with the modified front-end with synchronous receiver and transmitter which provides up to 100 mW of output power and a noise figure of 5 dB. The WBX provides up to 40 MHz of bandwidth in range from 50 MHz to 2.2 GHz. Transmitted signal is amplified by PA and then attenuated and received by the WBX input and corresponding USRP processing chain. In the experiment the sampling frequency was 6.25 MHz and the carrier frequency was 800 MHz. The motivation for the choice of such frequency lies in the prospective use of bands below 1 GHz (especially 700 MHz) for 5G machine-type and Ultra Reliable Low Latency Communications (URLLC). On the contrary, for the high bitrate-type communications, rather the spectrum in 1-6 GHz bands or even in millimeter-waves will be allocated. For PA modeling memory polynomial model [11] is used where discrete baseband PA output y is given by:

$$y(n) = \sum_{k=1}^{K} \sum_{q=0}^{Q} b_{k,q} x(n-q)|x(n-q)|^{k-1} \tag{1}$$

the equation describes non-linear system (e.g. PA), where x is input signal, K describes number the polynomial order and Q describes the memory length. Total number of coefficients is determined by definition $K(Q-1)$.

3 USED MODULATION

For further experiments, we decided to use the GFDM signal, because this particular scheme, or some of its very close alternatives, has been recommended as perspective waveform for 5G system. The GFDM modulator can be described by equation

$$\vec{y} = \mathbf{A}\vec{d} \tag{2}$$

where $\vec{d}$ is data vector consisting of data samples $d_{m,k}$ corresponding to the data element which is transmitted on m-th subcarrier and k-th sub-symbol. $\mathbf{A}$ is a matrix with dimension $[KM \times KM]$ where K is total number of sub-symbols and M is total number of sub-carriers which structure contains frequency and time shifted pulse shaped filters $\mathbf{A} = (g_{0,0} \ldots g_{M-1,0} \ldots g_{M-1,K-1})$. where g is described by equation:

$$g_{m,k}(n) = g[(n-kK) modN] e^{j2\pi \frac{m}{M} n} \quad (3)$$

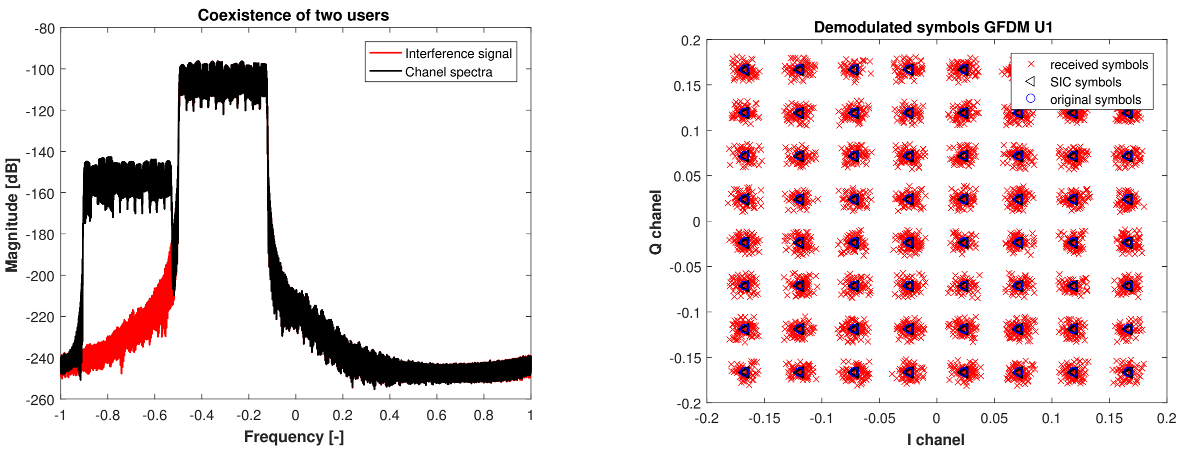
The demodulation can be described by equation:

$$\vec{d} = \mathbf{B}\vec{y} \quad (4)$$

where for zero-forcing receiver is matrix $\mathbf{B} = \mathbf{A}^{-1}$ and where y is received vector. Calculation of the inverse of a matrix $\mathbf{A}$ can be problematic, because matrix can be close to singular. The problem can be solved by using of Moore-Penrose pseudo-inverse. For matched filter demodulator, is $\mathbf{B} = \mathbf{A}^H$ where $\mathbf{H}$ is hermite transpose operator. In our experiment we used demodulator which operate as matched filter. Hence of Inter Carrier Interference (ICI) which is self-generated by the system itself due to the inherent non-orthogonality of the subcarriers because of Root Raised Cosine (RRC) pulse shaping [12], the double sided serial interference cancellation procedure is employed to match the theoretical performance of the well studied OFDM [1, 12]. The example of demodulated data in scenario with ideal channel is depicted on figure 1b. where red crosses depict demodulated symbol with residual EVM without using Self Interference Cancelation (SIC), black triangles depict demodulated signal with using SIC and blue circles depict origin transmitted symbols.

4 RESULTS

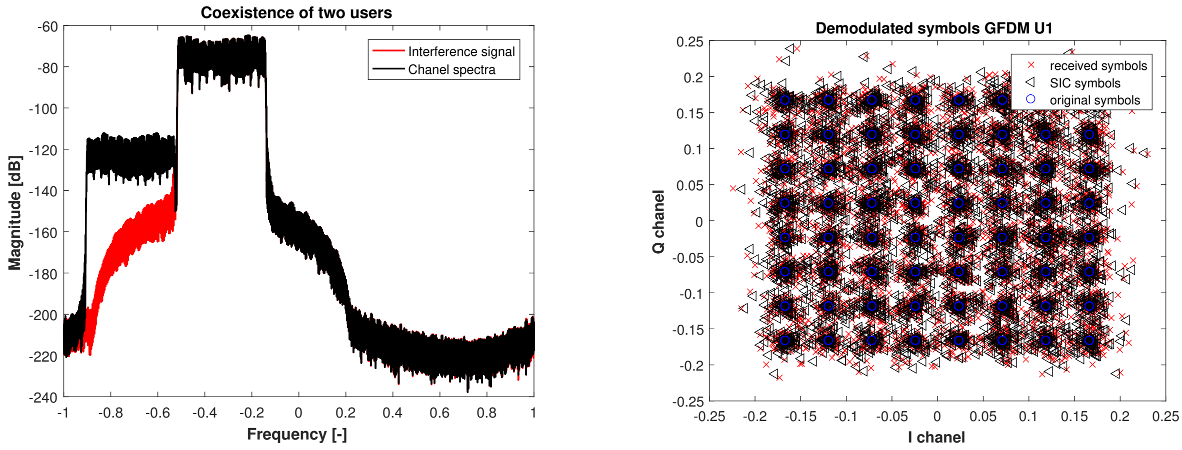
Main investigated metrics is EVM. The level of non-linearity of PA is defined by Adjacent Channel Power Ratio (ACPR) which define ratio of the transmitted power into adjacent channel to transmitted power in the main channel. We considered the normalized bandwidth of main channel 0.375 and frequency distance between sub-carriers is 0.03125. The both number are relative to the sampling frequency in range from -1 to 1, it follows that main channel of one user occupy approximately 20% of spectrum. The both users used same sub-carriers frequency distance. Hence of SIC implementation the oversampling factor is defined as $N = 8$. The influence of interferences to adjacent channel is simulated for two scenarios. For illustration let the figure 1a a depict ideal state when the stronger right user - user 2 transmits with linear PA. The second scenario differs by non-linear working point of the PA of right user. The influence of interferences to EVM of demodulated signal of weaker user - user 1 is depicted in figures 1b and 2b, where figure 1b a depicts ideal demodulated data and figure 2b depict demodulated data with interferences from user 2. It is shown that the interference by



(a) Two users scenario with ideal PA

(b) Demodulated symbols without interferences

Figure 1: Without interferences



(a) Two users scenario with non-linear PA

(b) Demodulated symbols with interferences

Figure 2: With interferences

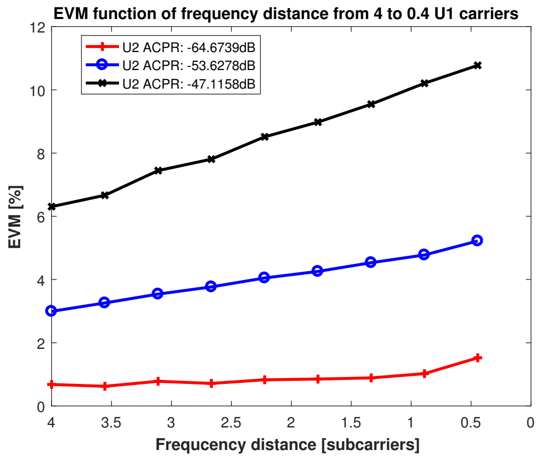


Figure 3: EVM as function of freq. spacing

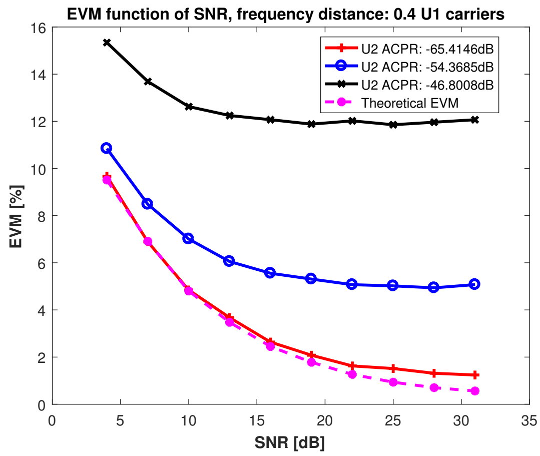


Figure 4: EVM as function of different SNR

non-linear user can have significant influence to EVM. The quantification of interferences for varying users spacing is depicted in figure 3, where the spacing between users is measured in multiples of sub-carrier width. The influence of interferences for varying SNR is depicted in figure 4.

5 CONCLUSION

In this paper, we have evaluated the influence of interferences from adjacent, non-linearly-distorted user to GFDM signal. The simulation results show the EVM as a function of the PA working point and spacing between two users (due to spectrum scarcity, this is an important aspects of future wireless communication networks). We have pointed out, that although in ideal case, the two users of filtered multi-carrier modulations (such as GFDM) can be allocated tightly to each other, in real systems this can result in increase of bit error ratios (measured in EVM). The steepness of EVM as a function of user frequency spacing depends on the adjacent channel emissions of the interfering user. The effect of interference can be suppressed by introducing guard band in cost of decreased spectral efficiency. As the alternative, we are currently working on the application of interference-cancellation techniques.

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