Universal Filtered Multi-Carrier Peak to Average Power Ratio Reduction

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Abstract **—**In the telecommunications field, multicarrier modulations attract a lot of attention among researchers and engineers, especially specialists in 5G domain. Several candidate waveforms have been proposed to be used in 5G systems. In this paper, Universal Filter Multi Carrier (UFMC) is recommended for 5G communications. UFMC is recommended because of its many advantages such as significant reduction of Out Of Band emissions OOB and support for data bursts. Nevertheless, UFMC is a multicarrier communication system, so it also suffers from high Peak to Average Power Ratio PAPR problem, which every multicarrier technique suffers from. In order to reduce the PAPR, many PAPR reduction techniques were proposed over the last few decades. Clipping and companding are two promising techniques, which are used in PAPR reduction of multicarrier communication system. In this paper a clipping and companding combined scheme is used, leading to significant performance improvement as a function of PAPR compared to the clipping and Companding techniques applied separately.

Index Terms—UFMC, PAPR, CCDF, clipping, companding

I. Introduction

Recently, fourth generation wireless communication systems 4G have been employed in most of the countries in the world. However, because of the explosion of wireless mobile services and devices, which cannot be handled even by 4G, day after day this technology is faced by challenges such as the spectrum insufficiency and high energy consumption [1]. 5G technology stands for fifth generation mobile technology which is the standard beyond 4G and LTE-advanced. 5G technology is required to support multi-Gbps transmission rates, low latency, and higher spectrum usage. Orthogonal frequency division multiplexing OFDM implemented in 4G is not suitable for 5G, because of its synchronization problem, low spectral efficiency, and high Peak to Average Power Ratio PAPR [2]. For that, new candidate waveforms were innovated and researched to implement in 5G.

Universal filter multi carrier (UFMC) is one of the promising multi carrier modulation techniques for 5G wireless communication systems. UFMC filters groups of subcarriers instead of per sub carrier like Filter Bank Multi-carrier FBMC or complete signal in single shot like OFDM. This allows UFMC to support low latency due to shorter filter length as compared to FBMC, and provides better spectral efficiency than OFDM because of significant OOB reduction [3]. Although UFMC provides advantages over other candidates, it still suffers from the drawback all multi-carrier waveforms suffer from, which is high PAPR.

In this paper a hybrid PAPR reduction technique CC-UFMC for UFMC systems is proposed. This technique is implemented by using Clipping and Companding PAPR reduction techniques. It is observed that this Hybrid technique provides better results when compared with the individual performances of Clipping and Companding techniques separately.

II. UFMC

OFDM has certain limitations such as cyclic-prefix overhead used to reduce ICI, resulting in more usage of the spectrum and thus spectral inefficiency, high OOB emissions, and high PAPR makes it an ineffective waveform to be utilized in 5G applications. To overcome the problems of the OFDM new waveform candidates have been studied for replacing OFDM in 5G physical layer.

The new waveform should achieve the asynchronous reception and transmission, better spectral efficiency, and low latency. In addressing scalable waveform on the same network, filtering to the OFDM symbols may be introduced to improve OFDM performance instead of developing a totally new technology. Among UFMC, FBMC, and other promising candidates, UFMC is the most adequate for 5G [4].

UFMC is the method that combines the advantages of orthogonality OFDM and filter bank in FBMC. Instead of filtering each carrier individually like in FBMC, a block of carriers called sub-band is filtered. Each sub-band contains a number of carriers; filter length will be depending upon the width of sub-band. In the UFMC system, the data symbols are converted to parallel stream, resulting in blocks of streams and given as input to the IFFT block which transforms the input from frequency domain to time domain. The N point IFFT output will be serialized block-wise and the output will be filtered with a pulse shaping filter of length L. Finally, the filtered signals are combined together to form the transmitted signal. This process is shown in Fig. 1. For the i^{th} sub-band ($1 \leq i \leq B$) the data blocks represented with $X_{i,k}$, IFFT matrix with $V_{i,k}$ and pulse-shaping filter with $F_{i,k}$.

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The final transmitted signal is given by the following equation:

$$x_k = \sum_{i=1}^{B} F_{i,k}.V_{i,k}.X_{i,k} \tag{1}$$

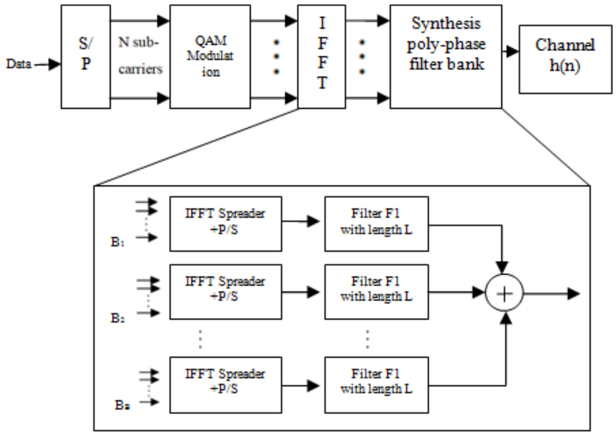

Fig. 1. Block diagram of UFMC transmitter

The block-wise filtering provides flexibility to the system and is used to avoid the main drawbacks of FBMC. UFMC supports short bursts data transmission, leading to support of low latency, and supports operation in fragmented bands. The filter protects the signal against inter-symbol interference (ISI), and provides robustness in supporting multiple access users which aren't perfectly time-aligned. Due to the possibility to reduce guard bands, and to avoid need of CP, UFMC is more spectral efficient than CP-OFDM [5]. The receiver processing is similar to CP-OFDM, where single-tap per-subcarrier frequency domain equalizers are used which equalize the impact of the radio channel and the respective sub band-filter, leading to similar complexity as CP-OFDM. So, it is clear that UFMC provides advantages of both OFDM and FBMC system.

III. Peak to Average Power Ratio

UFMC has obvious advantages over other candidate waveforms, but it also suffers from high Peak to Average Power Ratio (PAPR). The Peak to Average Power Ratio is the relation between the maximum power of a sample in a transmitted symbol divided by the average power of that symbol. PAPR occurs when the different sub-carriers in a multicarrier system are out of phase with each other. In multicarrier system there are a large number of independently modulated subcarriers, which are out of phase with respect to each other. If more than one subcarrier achieve the maximum value at the same time, the output envelope will increase causing a peak in the output, and when these peaks are added up for transmission, a large peak value is reached that is very large compared to the average value of the sample. This ratio of the peak to average power value is termed as Peak-to-Average Power Ratio PAPR [6]. PAPR is defined by the following equation:

$$PAPR = \frac{max\{|x[n]|\}^2}{E\{|x[n]|\}^2} \tag{2}$$

where $|x[n]|$ is the amplitude of x[n] and E is the expectation of the signal.

Higher PAPR level causes the power amplifier to act in the saturation region, leading to increases in errors and also increases in out of band radiation (OOB).

In the study of signal performance on the basis of power level, complementary cumulative distribution function (CCDF) curves are known to have great performance. CCDF is the probability that PAPR exceeds a given PAPR threshold.

$$CCDF = Pr_{PAPR} > Pr_{\text{PAPR0}} \tag{3}$$

Conventional PAPR Reduction Techniques

There are various PAPR reduction techniques which can be used to improve performance of multicarrier modulation systems. Some of these techniques are:

A. Selective Mapping (SLM) Technique

In SLM, several candidate data blocks are generated from the original data block and all the data blocks have the same information. Then phase rotation is applied to each block and the block with minimum PAPR is selected for transmission [7]. Selective mapping requires sending extra data to be utilized by the receiver in order to retrieve the original data, which leads to decreasing the bandwidth efficiency.

B. Companding

The basic idea of companding is to expand the small signals in the transmitter section, and then compression is carried out at the receiver side. In this technique, the small signals are enlarged while large signals are compressed to increase the immunity of small signals from noise. This process is applied at the transmitter end, after the output is taken from IFFT block. There are two widely known types of companders: $\mu-$law and A-law companders [8]. Others types of companders are investigated and applied in this paper.

C. Partial Transmit Sequence

In PTS original data block is partitioned into *N* disjoint sub blocks. The same phase factor is used to rotate the subcarriers in each sub so that the PAPR of the combination can be minimized. PTS scheme reduces PAPR with some additional complexity and it also affects spectral efficiency of the system because side information is also required to be transmitted. It does not produce any distortion in system [9].

D. Clipping and Filtering

Clipping and filtering is one of the simplest techniques for PAPR reduction. The principle of this technique is to define a clipping level for transmitting data above which the input signal is cut or clipped off and thus peaks of signal are reduced [10]. Suppose that signal $y[n]$ is the signal to be transmitted and $yc[n]$ is its clipped version. $y[n]$ can be denoted as:

$$y_c[n] = \begin{cases} -A & y[n] \leq -A \\ y[n] & |y[n]| < A \\ A & y[n] \geq A \end{cases} \quad (4)$$

where A is the clipping level. After clipping out of band radiations are produced this can be reduced by using filtering after clipping.

E. Tone Reservation

The term "Tone" represents the subcarrier, because TR was developed for a digital subscriber line DSL system and subcarriers are called tones in a DSL system. In most cases, peak reduction signals PRS, which are the parts of the tone responsible for reducing PAPR, do not contain any information data and they are added to original signals to generate new signals with lower PAPR.

So in this technique PRS are calculated and transmitted through sub-carriers that are reserved for PAPR reduction. The drawbacks of this technique are power increase and data rate loss [11].

Proposed CC-UFMC PAPR reduction technique

The proposed CC-UFMC technique combines two distortion techniques which are clipping and companding. First the UFMC signal is clipped on a predefined level, and then companding is applied, where multiple companding methods will be applied individually in this technique. The companding techniques chosen for this system will be μ-law companding, exponential companding, cosine companding, and new error function companding.

a) μ-law companding

In the μ-law companding, the compressor is made up of a linear segment for low level inputs and a logarithmic segment for high level inputs. The practical value of "μ" usually used is 255 [12]. The utilized μ -Law compression signal characteristic is defined as:

$$y(x) = V \frac{\log\left(1 + \mu \frac{|x|}{v}\right)}{\log(1 + \mu)} sgn(x) \quad (5)$$

where V is the peak amplitude of the signal, and x is the instantaneous amplitude of the input signal.

b) Absolute EXP companding

The proposed absolute exponential equation is derived based on exponential companding and trapezoidal power companding:

$$AEXP(x) = sgn(x) \sqrt[d]{1 - \exp(-\frac{|x|^2}{\sigma^2})} \quad (6)$$

c) Cosine companding

The new type of companding was proposed depends on cosine function. The proposed cosine companding equation is:

$$c(x) = sgn(x) \sqrt[y]{1 - \cos\left(-\frac{|x|}{\sigma}\right)} \quad (7)$$

d) NERF companding

This type of proposed companding depends on the new error function. The NERF companding equation is:

$$h(x) = \left|\left(2\sigma erf \frac{|x|}{\sqrt{2}\sigma}\right)\right| sgn(x) \quad (8)$$

In the proposed technique, each of these companding equations is applied individually after clipping is performed, in order to obtain 4 different processed signals. Each companding method will reduce the PAPR of the UFMC signal in a certain ratio. The goal is to find the technique with the best reduction efficiency when combined with clipping. Simulations were carried in MATLAB and the results are show in the next section.

IV. Simulation and Results

Table 1 provides the simulation set up to evaluate the performance of proposed PAPR reduction technique. The proposed technique (CC-UFMC) is implemented in different methods by applying the 4 equations mentioned above (Eqs 5, 6, 7, and 8). CC-UFMC is also compared with other techniques which are clipping and companding applied separately, and techniques proposed in [13] and [14], to analyze the PAPR reduction effectiveness of the proposed scheme in this paper.

TABLE I: SIMULATION SETUP

Parameters	***Values***
FFT size	512
Sub-band size	20
Number of sub-bands	10
Bits per subcarrier	4
Filter length	43
Sidelobe attenuation	40 dB

Fig. 2 shows the CCDF of the PAPR of the UFMC signal and compares it to the PAPR of the clipped UFMC signal using the parameters given in Table 1. The study of PAPR reduction in this paper is done at the CCDF value of 0.1, meaning that the goal is to study PAPR reduction when the probability that PAPR of the UFMC signal exceeds a given threshold PAPR is equal to 0.1 %. It can be observed that clipping technique is providing PAPR reduction to the UFMC signal, where PAPR reduced from 8.95dB to 7.85dB at 0.1 CCDF, yielding a PAPR reduction ratio of 13.8%.

Fig. 3 shows the CCDF of UFMC signal and of companded signals using multiple companding methods applied separately after clipping which are μ-law companding, exponential companding, cosine companding, and NERF companding. From figure 3, it can be clearly deduced that companding techniques have a better PAPR reduction effectiveness than the traditional clipping technique. These results will be compared to the CCDF of the UFMC signal after applying the proposed clipping-companding technique.

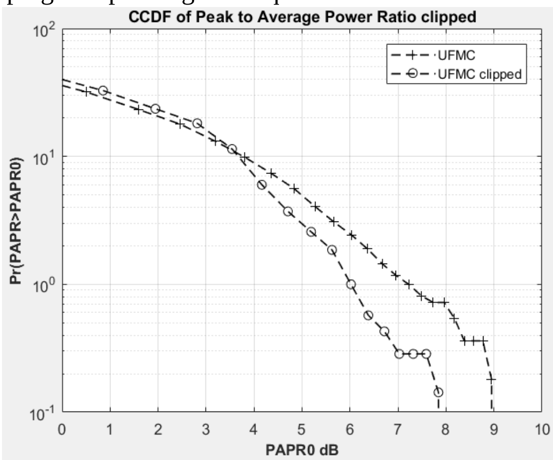

Fig. 2. CCDF comparison between UFMC signal and clipped signal

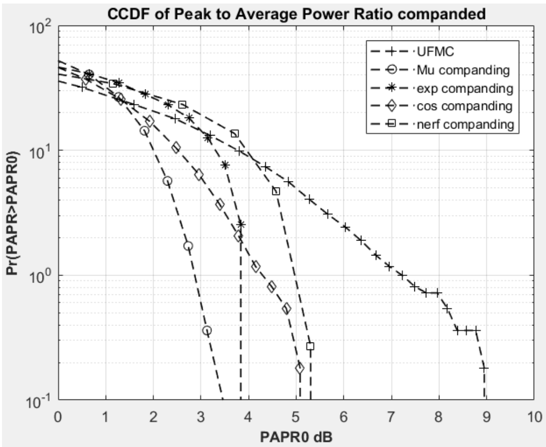

Fig. 3. CCDF of the UFMC, Mu, exponential, cosine, and NERF companded signals

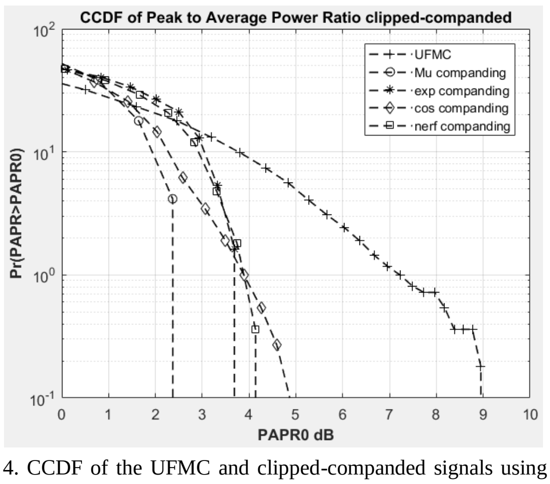

Fig. 4. CCDF of the UFMC and clipped-companded signals using the different companding methods

Fig. 4 shows the CCDF of the clipped-companded UFMC signal using the same companding methods shown in Fig. 3. It can be seen that the proposed technique had a better performance regarding PAPR reduction than clipping individually. Also, all used companding methods showed an enhancement in PAPR performance when companding is combined with clipping. The following comparisons were taken at 0.1 CCDF. For AEXP companding, there was only a slight improvement from 3.9dB to 3.8dB. For cosine companding, PAPR was slightly improved from 5.1dB to 4.85dB. For NERF companding, PAPR was improved from 5.3dB using companding, to 4.1dB in CC-UFMC, while μ-law companding had a PAPR of 3.5dB, which reduced to 2.4 dB when applying CC-UFMC. This shows that, the proposed CC-UFMC PAPR reduction technique is capable of reducing the PAPR of the UFMC signal more efficiently than applying the given companding techniques and clipping technique individually.

In [13], authors proposed a hybrid technique for PAPR reduction in UFMC by using SLM and clipping, called SC-UFMC. Simulations were performed to study PAPR and the results showed that the proposed scheme provided better PAPR reduction performance than the conventional SLM and Clipping schemes, where SC-UFMC PAPR reduction effectiveness was found increased by 27% than UFMC using 512 FFT size.

In [14], the authors used tone reservation algorithms by deep clipping for MIMO-OFDM PAPR reduction. After combining these two methods, PAPR level decreased from approximately 10.5 dB to 7.5 dB, yielding a PAPR reduction ratio of 28%.

In the study proposed in this paper, the PAPR reduction ratio turned out to be better than the mentioned techniques in [13] and [14], using any of the given companding techniques. Figure 4 shows that using μ-law CC-UFMC yielded a PAPR reduction ratio of approximately 74%, which is the highest amongst all other techniques. AEXP CC-UFMC had the second best PAPR reduction ratio, which reached 57%. As for cosine and NERF CC-UFMC, the PAPR reduction ratios turned out to be approximately 45.5% and 54.4% respectively. These results show clearly that the proposed CC-UFMC PAPR reduction technique has a better efficiency than the competing techniques compared to it. These results are illustrated in Fig. 5.

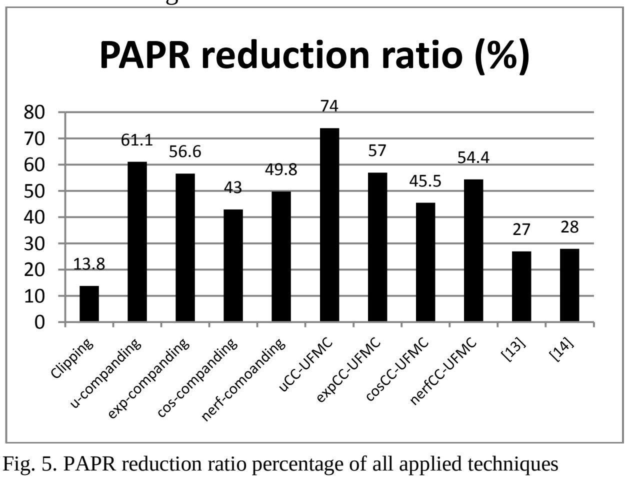

Fig. 5. PAPR reduction ratio percentage of all applied techniques

V. Conclusion

In this paper, a novel hybrid PAPR reduction technique CC-UFMC for UFMC signals is proposed. Multiple companding methods were used and each was combined with clipping technique. Simulation results and analysis shows that the hybrid scheme is an efficient PAPR reduction technique for UFMC systems, and it can provide better PAPR reduction performance than the conventional companding and clipping schemes individually, for all applied companding methods. Moreover, it was shown through comparison that the proposed scheme has a greater PAPR reduction efficiency than other techniques that were proposed to solve the high PAPR level problem.

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