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Analysis of Optimum Technique for PAPR Reduction in UFMC System

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Abstract: The fifth Generation of communication has to support many applications like the Internet of Everything (IoE) and Machine Type Communication (MTC). The proposed universal filtered multi-carrier (UFMC) technique is one of the best techniques for fifth-generation (5G) communication. UFMC is expected to achieve low latency, robustness against synchronization errors and frequency offset, short-packet burst support, and reduce out-of-band (OoB) radiation that leads to higher spectral efficiency. Although the UFMC system offers many advantages as mentioned before, being a multicarrier transmission technology, it suffers from a high peak-to-average power ratio (PAPR), which degrades the efficiency of the High-Power Amplifier (HPA) and makes the UFMC transmitter inefficient. Therefore, an optimum PAPR reduction technique to reduce the high PAPR of the UFMC system has to be proposed. The proposed technique is a hybrid technique that consists of a combination of Generalized Chirp-Like (GCL) precoding and Selective-Mapping techniques (SLM). A comparative analysis of the performance of Generalized Chirp-Like precoding methods, SLM, and hybrid methods are by CCDF of the PAPR and the bit error rate (BER) and simulation results show that proposed SLM based GCL UFMC outperform the conventional techniques
Keywords: UFMC, PAPR, GCL, SLM, BER, 5G.

I. INTRODUCTION

Like 4G LTE, the fifth Generation is also Orthogonal Frequency Division Multiplexing based and will operate based on the same mobile networking principles. However, the recent 5G technology has to manipulate a distinct group of users with various demands. OFDM is one of the best choices but in addition to the PAPR problem, it is sensitive to offsets both time and frequency. The high PAPR problem causes serious issues like spectral efficiency loss. Due to low Out-of-Band (OOB) emission FBMC (Filter Bank MultiCarrier) and UFMC (Universal Filter MultiCarrier) has more spectral efficiency compared to OFDM. Among them, UFMC is better than FBMC due to its short-packet burst support. UFMC is the generalization of both OFDM and UFMC. Instead of filtering a full-band like OFDM and each subcarrier like FBMC, UFMC divides a full band into sub-band and filter each sub-band (group of sub-carriers). Like OFDM and FBMC, UFMC is less complex and has good spectral efficiency. When compared with FBMC, filter length is reduced in UFMC due to its grouping of sub-carriers. Even UFMC has different advantages, it also has high PAPR which is the major drawback.

There are several techniques were used to solve the PAPR issue. But only a few for UFMC are available in the literature. In [1], the clipping technique is used. Clipping is a plain technique to reduce PAPR but while transmitting the signal it gives rise to clipping noise and in-band and Out-of-Band (OoB) interference, which results in performance degradation. To reduce clipping noise in [2], they introduce filtering after clipping. But clipping followed by filtering cause some peak regrowth. Introduces distortions in the transmitted signal which reflects system BER. To overcome the peak regrowth in [3] enlipping is added after filtering (clipping-filtering-clipping). But, clipping based enlipping will cause an increase in average power, which will degrade IBO performance which will lead to overall system performance degradation.

In [4], the Companding technique is used to reduce PAPR. It is easy and less complex. It has two types: Mu-law companding and A-law companding.The Companding transform introduces some distortion and increases receiver noise. PTS (Partial Transmit Sequence) is used in [5] in which the main data block is split up into sub-blocks. The PAPR of the combination is minimized by rotating the subcarriers in each sub-block with the same phase factor. But PTS reduces PAPR with some complexity and spectral efficiency loss. In [6], SLM is used to reduce PAPR. Here it has two approaches: E-SLM and P-SLM. The disadvantage is that it requires side information which causes the spectral efficiency loss. In [7], the Non-Linear Companding Technique is combined with the precoding technique to reduce PAPR.

The hybrid technique shows the best result for PAPR reduction than others but the NLCT technique is difficult to implement. In this paper, an efficient SLM technique is combined with the GCL precoding technique to reduce the PAPR for UFMC. The proposed technique outrun the existing techniques. The rest of this paper is organized as follows; Section II presents the UFMC system model and a brief explanation about PAPR. Section III explains the proposed scheme. Simulation results are provided in Section IV and finally, section V concludes the paper.

II. UFMC SYSTEM MODEL

A. Conventional UFMC system Architecture

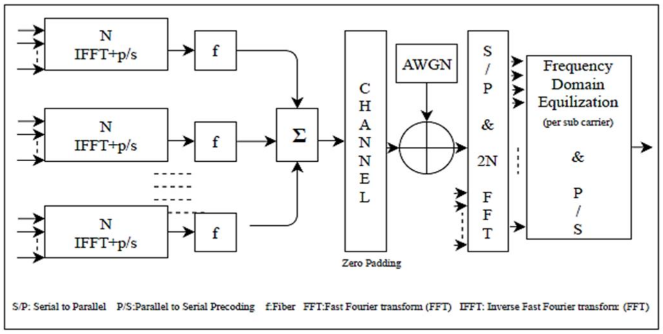

Fig.1 Conventional UFMC system model

Fig. 1, shows the block diagram of standard UFMC [8]. In UFMC, a full band is divided into sub-band, and by Inverse Fast Fourier Transform (IFFT) the frequency domain is converted into a time domain. After that filtering is applied to reduce spectral emission and Out-of-Band (OOB) radiation. Finally, the filtered signals are summed up and transmitted.

At the receiver side, to convert a signal from the time domain to the frequency domain it is processed by Fast Fourier Transform (FFT). After that equalizations are done to remove both channel filtering and band effects, respectively. Finally, to retrieve the data bits, the data is demapped.

B. Peak to Average Power Ratio

In a multicarrier system, when different sub-carriers are out of phase with each other PAPR occurs. At each instant, concerning each other at different phase values. When all the phase achieves the peak value similarly, it will cause the output envelope to suddenly increase which causes a 'peak' in the output. There are a large number of independently modulated subcarriers in the multicarrier system, and when they are added up for transmission purpose give a large peak value which is very large as compared to the average value of the sample [9]. The PAPR is the ratio of the maximum power of a signal transmitted to the average power of the signal transmitted. The PAPR can be represented as in (1)

$$\text{PAPR} = \frac{\max(|Z(n)|^2)}{E(|Z(n)|^2)} \qquad (1)$$

The efficiency of the PAPR reduction technique is analysed using CCDF. The higher PAPR causes saturation in the power amplifier which produces intermodulation products among sub-bands and also increases out-of-band radiation (OOB). So, it is necessary to reduce the peak to average power ratio to make system.

III.PROPOSED SCHEME

A. Selective Mapping (SLM)

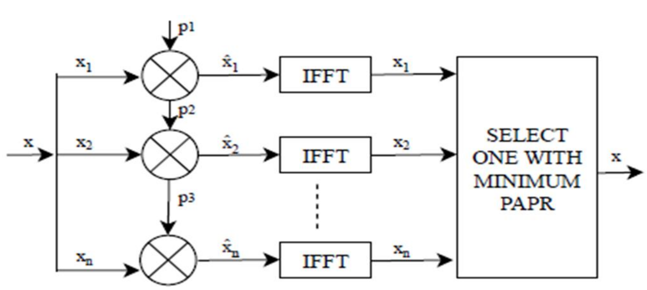

Fig. 2 SLM based PAPR Reduction Technique

Fig. 2, shows the Selective Mapping technique block diagram [10] & [11]. By introducing the random phase shifts SLM modifies the waveform without causing any signal distortion. In SLM, different phase rotation blocks are formed. The input signal is element-wise multiplied by different phase rotation factors. The recently formed blocks have identical information as the real ones. Among them, only one block with minimum PAPR is selected and transmitted. Side information is sent to the receiver side for phase re-rotation. The SLM method complexity depends on the number of phase rotations V used. Hence, V should be selected carefully.

B. Generalized Chirp-Like (GCL) precoding

Let $\{a_k\}$, k = 0, 1…, N - 1, be a Zadoff-Chu sequence of length N = sm^2, where m and s are any positive integers. Let $\{b_i\}$, i = 0…, m - 1, be any sequence of m complex numbers having the absolute values equal to 1. The generalized chirp-like sequence is a class of polyphase sequences, and can be defined as [12]

$$g(l) = z(l)y(l\ mod\ m), l = 0,1, \dots, N-1 \quad (2)$$

In Eq. (6), z(l) denotes the famous Zadoff–Chu sequences, can be expressed as [13]: -

$$z(l) = W_N^{\frac{l(l+N\ mod\ 2)}{2}+ql}, l = 1,2, \dots, N-1 \quad (3)$$

Both, Eq. (1) and Eq. (2) represents GCL and Zadoff-Chu sequences respectively. The g(l) and z(l) are perfect sequences of length equal to N with an Autocorrelation Function (ACF) R(p).

The ACF R(p) is an idealistic function and can be expressed as: -

$$R(p) = \sum_{l=0}^{N-1} g_l g_{(l+p)\ mod\ N} \quad (4) \quad = \begin{cases} N, P = 0(mod\ N) \\ 0, p \neq 0(mod\ N) \end{cases}$$

Followings are the special properties of the Zadoff-Chu sequence

1) This sequence has a constant amplitude.
2) Zero Autocorrelation.
3) Cross correlation of two Zadoff Chu sequence is 1/Sqrt.

The Generalized Chirp-Like kernel can be made by using the reconfigure equation k = mN+l; which will reconfigure the Generalized Chirp-Like sequences, where m is the row variable and l is the variable of the column.The resultant GCL matrix can be defined as [3]: -

$$G = \begin{bmatrix} g_{00} & \cdots & g_{0(N-1)} \\ \vdots & \ddots & \vdots \\ g_{(N-1)0} & \cdots & g_{(N-1)(N-1)} \end{bmatrix}$$

By multiplying G^{-1} with the received signal, the original sequences can be obtained.

C. SLM based GCL precoding UFMC

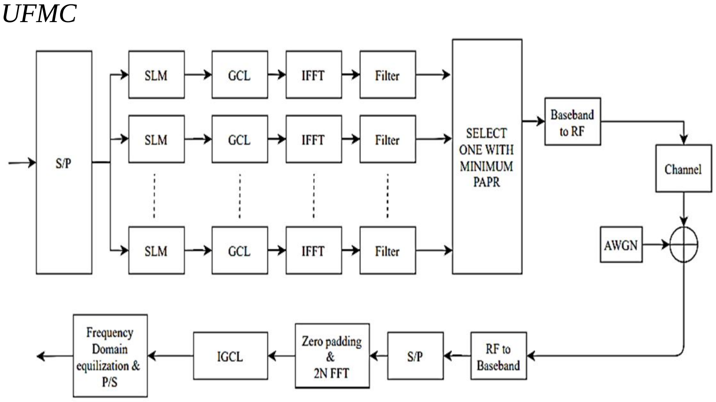

Fig.3 Proposed SLM based GCL Precoded UFMC System

A hybrid PAPR reduction technique is proposed to increase the UFMC system's efficiency and for PAPR reduction. A combination that consists of GCL precoding and SLM techniques is proposed to reduce the PAPR of a transmitted UFMC signal. The proposed SLM-based GCL precoding technique for the UFMC scheme contributes more towards both PAPR and SER gains. The proposed SLM-based GCL pre-coded UFMC (SLM-GCL-UFMC) scheme is shown in the following figure [6].

Let us consider X=[X0, X2,…, XN-1]T, is a data block. The X is multiplied with the V different phase sequences to get altered data blocks representing similar information. Mathematically, modified data block can be written as [6]: -

X(v)=X0bv,0,X1bv,1,…,XN-1bv,N-1 (5)

where b is the phase rotation factor.

After the phase rotation, GCL precoding is applied. The GCL matrix transforms the vector X into the vector Y that can be defined as

$$Y = GX^{(v)} = [Y_0, Y_1, \dots, Y_{N-1}]^T \quad (6)$$

where $X^{(v)}$ represent a vth data block and Y represents the SLM based GCL precoded input sequences to the IFFT's.
The SLM-GCL-UFMC time domain signal for the ith sub band can be written as follows:

$$\hat{x}_i[n] = \frac{1}{\sqrt{N}} \sum_{k=0}^{C-1} Y_k . e^{j2\Pi \frac{n}{c} k}, 0 \le n \le N-1 \quad (7)$$

where Y_k denote the SLM based GCL precoded QAM constellation symbols and C is a total number of sub-bands, respectively. After that, filtering is performed separately on each sub-band, the filtered SLM-GCL-UFMC signal can be defined as

$$x_i = \hat{x}_i * f \quad (8)$$

where (*) is convolution symbol, represent ith sub-band signal. After the convolution with filter coefficients, all the sub-bands are summed-up to generate a filtered time domain SLM-GCL-UFMC signal can be defined as:

$$x = \sum_{i=0}^{S-1} x_i, 0 \le n \le N-1 \quad (9)$$

where S denotes the total number of sub-bands and xi is a filtered sub-band signal. After the UFMC modulations, one of the signals with minimum PAPR i.e., x is selected for transmission with SLM side information.

By using the side information, a phase re-rotation is applied at the receiver. After that 2N point, FFT is applied to the received signal. The inverse of the matrix i.e., G^{-1} is applied to remove all the GCL precoding effects. Finally, per sub-carrier equalization process is carried out to remove the channel effects followed by data de-mapping to recover the original data bits.

IV. SIMULATION RESULTS

This section presents simulations to investigate the proposed SLM-GCL-UFMC scheme. QPSK is applied to data to perform the simulation analysis for both PAPR and BER.

The CCDF of the SLM-GCL-UFMC signal can be written as: -

P(PAPR>$PAPR_0$)=1-$(1 - e^{-PAPR_0})^N$ (10)

where $PAPR_0$ denotes the clipping level.

To evaluate and compare the performance of the proposed hybrid scheme, a MATLAB simulation is performed. In the MATLAB simulation, Monte Carlo iterations for sub-bands, and in each sub-band iteration random symbols are generated. The various parameters used in the simulation are summarized in Table 1.

TABLE. 1 Simulation parameters of proposed UFMC system.

IFFT Size	256
FFT Size	512
Sub-bands	16
Sub-carriers	16
PAPR reduction scheme	Precoding, SLM
FIR filter	Dolph Chebyshev
Filter length	73
Clip rate for CCDF & BER	10^{-1}

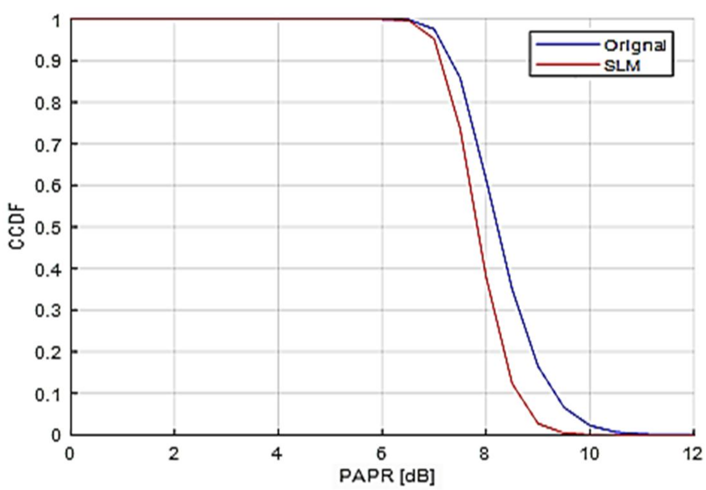

Fig. 4 CCDF comparison of the SLM-UFMC with original UFMC for phase rotation V=2

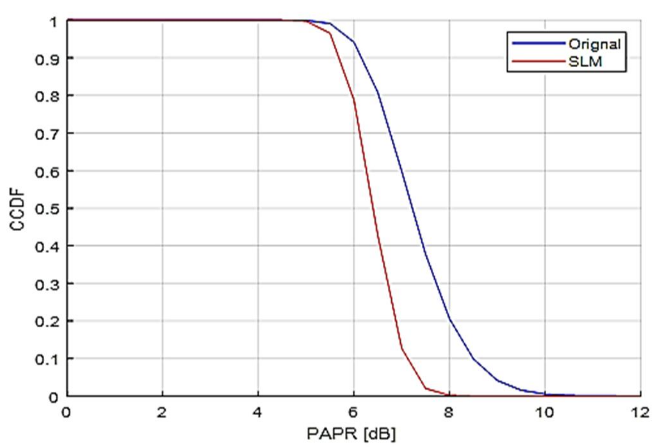

Fig. 5 CCDF comparison of the SLM-UFMC with original UFMC for phase rotation V=4

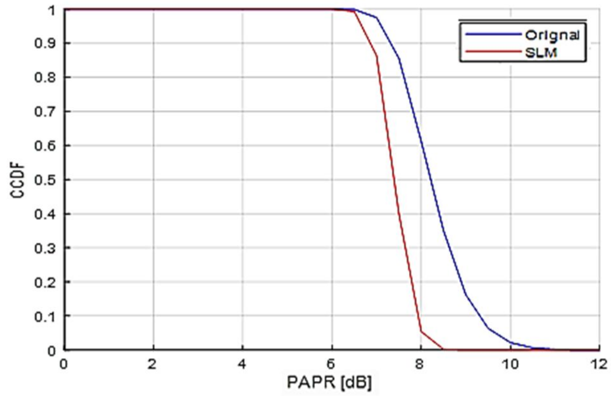

Fig. 6 CCDF comparison of the SLM-UFMC with original UFMC for phase rotation V=6

Fig. 4,5,6 shows the CCDF comparison of the SLM scheme used for PAPR reduction in a UFMC system for different phase rotations. Here, it is shown that the SLM UFMC system achieves a PAPR gain of 8.4 dB, 7.1 dB, and & 8 dB for phase rotation V=2,4 & 6 compared to a standard-UFMC system at CCDF 10^{-1}. Based on the above analysis, it can be observed that compared to the normal UFMC system both the GCL precoding and SLM improve the PAPR performance. However, a hybrid PAPR reduction procedure is proposed to further reduce the PAPR.

TABLE. 2 Comparison of PAPR for SLM's different phase rotation factors

SLM phase rotation(M)	PAPR (dB)
Original UFMC	8.4
2	8.4
4	7.1
6	8.0

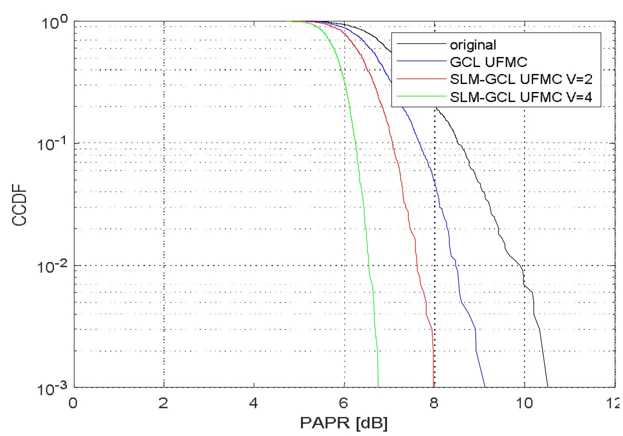

Fig. 7 CCDF Comparisons of the SLM based GCL precoded UFMC with GCL precoded UFMC and original UFMC.

Fig. 7, shows the CCDF comparison of the proposed technique with the original UFMC scheme, the GCL precoded UFMC scheme, the SLM-based GCL precoded UFMC scheme for M = 2, and SLM based GCL precoded UFMC scheme for M = 4, respectively by using QPSK modulation scheme. At 10^{-1} clip-rate, the PAPR is approximately 8.4 dB, 7.6 dB, 6.7 dB, and 6.2 dB, respectively for standard UFMC scheme, GCL precoded UFMC scheme, SLM based GCL precoded UFMC scheme with M = 2 and SLM based GCL precoded UFMC scheme with M = 4. It is clear from Fig. 5.4 that the PAPR gain of the proposed SLM-GCL-UFMC scheme is better than others. At a clip rate of 10-1, the PAPR gain of the proposed SLM-GCL-UFMC scheme is approximately 1.7 dB and 2.2 dB for M=2 and M=4 compared to the standard UFMC scheme Fig. 8 Comparison of the BER of the SLM technique and SLM-based GCL precoding technique with the standard UFMC signal.

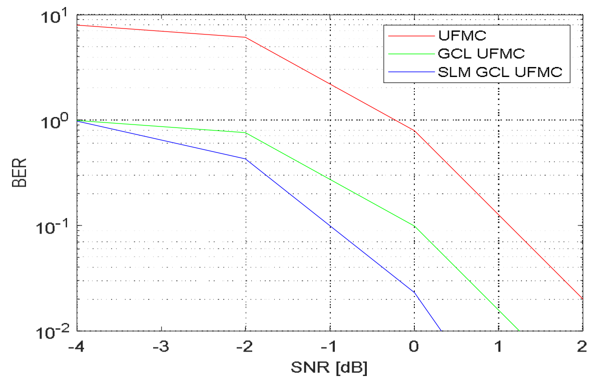

Fig. 8 Comparison of the BER of the SLM technique and SLM based GCL precoding technique with the standard UFMC signal.

Generalized Chirp-Like Precoding without Selective Mapping provides development in the CCDF of the PAPR of 1 dB, while degradation of the SNR at BER 10^{-1} is only 1.1 dB compared to standard-UFMC. The hybrid SLM-based GCL precoding provides an improvement in the CCDF of the PAPR of 1.7 dB and 2.2 dB for M=2 and 4, while degradation of the SNR at BER $10^{-1}$is only more than 2 dB compared to standard-UFMC. The proposed hybrid SLM-based GCL precoded method is proved to be an efficient method for reducing the PAPR in the UFMC system with better BER characteristics than conventional techniques. So, it is an optimum technique.

V. CONCLUSION

In this paper, to reduce the PAPR of the UFMC system a proposed hybrid PAPR reduction technique is used, which is an optimum technique. A comparative analysis of GCL precoding, Selective mapping, and SLM-based GCL precoding is implemented. The analysis proved that the hybrid technique improves PAPR reduction compared to a normal UFMC system. The proposed SLM-GCL- UFMC scheme performance was meticulously explored by using MATLAB simulations. Numerical results have shown that the proposed scheme outruns the precoding-based UFMC scheme, standard UFMC scheme, and standard OFDM, respectively. Furthermore, the proposed system utilizes linear precoding and SLM phase rotations to reduce the PAPR, which improves the robustness of the proposed scheme in fading multipath environment. Additionally, the proposed method improves the efficiency of the transmitter without any kind of power increase. As future work, the proposed SLM-based GCL precoded UFMC needs to be analysed to improve both the PAPR and BER characteristics of UFMC systems on a frequency selective channel.

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