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Performance Evaluation of UFMC for Future Wireless Communication Systems

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Abstract: **One of the innovative waveforms for 5G networks is the Universal Filtered Multi-Carrier (UFMC) technology. Low latency, resilience to frequency offset, and a decrease in out-of-band (OoB) radiation are anticipated benefits of UFMC, which will raise spectral efficiency. As previously indicated, the UFMC system has numerous benefits; nevertheless, because it is a multicarrier gearbox technology, its Peak-to-Average Power Ratio (PAPR) is high. Companding, Precoding and Selected Mapping (SLM) methods are an easy and effective way to lower the PAPR of UFMC signals. This work proposes a Modified Mu-law Companding Transform (MMCT) that lowers the PAPR of UFMC approach without altering the companded signal's average power and a Discrete Sine Transform (DST) precoding PAPR reduction technique to reduce the complexity. These two techniques are combined with SLM separately and their performance is assessed in the matter of both PAPR and BER. The UFMC signal's big and small amplitudes are expanded using distinct scales in the MMCT scheme based on an inflection point. Also, the DST technique provides less PAPR by considering only the real components. As a result, there is greater freedom in selecting the compounding parameters that will yield the best results in terms of PAPR, average power level, and BER. The simulation findings verify that, in comparison to the original UFMC signal and OFDM technique, the proposed schemes offer higher PAPR and BER reduction characteristics.**

Index Terms: **Universal Filtered Multi Carrier, Selected Mapping, Modified Mu-Law Companding, Discrete Sine Transform, Peak to Average Power Ratio.**

I. Introduction

The Internet of Everything (IoE) is the main example of the many applications that future wireless telecommunication technology must serve [1], [2]. The Universal Filtered Multi-Carrier (UFMC) approach is suggested in [3] and [4] as the peculiar innovative possible waveforms for 5G systems. Its robustness in the case of frequency offset, low latency, and reduction of Out-of-Band (OoB) emission allows for improved spectral efficiency. Higher reductions in OoB radiation are achieved in UFMC systems by filtering each sub-band of subcarriers rather than the entire band. In general, the UFMC system combines the robustness of Filter-Bank Multi Carrier (FBMC) in case of interference with the straightforward construction of Orthogonal Frequency Division Multiplexing (OFDM). Furthermore, in the event of brief burst communications, the UFMC system is preferable to the FBMC system [5]. As previously indicated, the UFMC system has numerous benefits; nevertheless, because it is a multicarrier gearbox technology, its peak-to-average power ratio (PAPR) is high [6].

Numerous studies have been conducted on PAPR reduction improvement in OFDM systems; these works fall into two major categories: techniques using signal distortion and probabilistic ways. Signal distortion techniques, like the clipping and filtering approach described in [7], work by limiting the power of the transmitted signal by establishing a maximum level. The primary disadvantage of signal distortion techniques is that they distort the transmitted signal, which has a detrimental effect on Bit Error Rate (BER) performance. However, without resulting in signal distortion, the probabilistic techniques alter the transmitted signal by adding random phase shifts.

These strategies include the Partial Transmit Sequence (PTS) strategy in [8],[9], and the Selected Mapping (SLM) approach in [10]-[12]. Because the receiver receives side information to recover the original, the SLM and PTS techniques decrease spectral efficiency. However, several methods have been put out in the literature, such as in [13], to get the side information at the receiver without the recipient knowing. Since the SLM strategy reduces PAPR more effectively than the PTS approach, it is taken into consideration in this research [10]. Additionally, SLM is regarded as a distortion-free technique that does not adversely alter the transmitted signal's spectrum, in contrast to clipping and filtering approaches.

For OFDM systems, a variety of companding methods are available, including μ-law [11], exponential companding (EC) [12], and LNST companding [13]. The bit error rate (BER) of OFDM signals is degraded by EC and increased power level by the μ-law. Only the DQPSK scheme of the OFDM linear nonsymmetrical companding transform LNST system is evaluated. Using this method, the tiny signals are expanded while constricting the huge signals to make the little signals more resistant to noise.

To lower the PAPR of UFMC systems, a Modified Mu-law Companding Transform (MMCT) is suggested and it is combined with SLM. Higher order QAM is evaluated for this scheme. To complement the UFMC signal's large and small amplitude values, an inflection point is employed [14].

The precoding technique, sometimes referred to as the pulse shaping technique, is a strong and adaptable method of reducing PAPR [15]. This technique can lower the PAPR to that of a single carrier transmission technology and is compatible with all base-band modulation techniques. The outcomes of the simulation demonstrate that, in comparison to conventional methods, the suggested MMCT and DST

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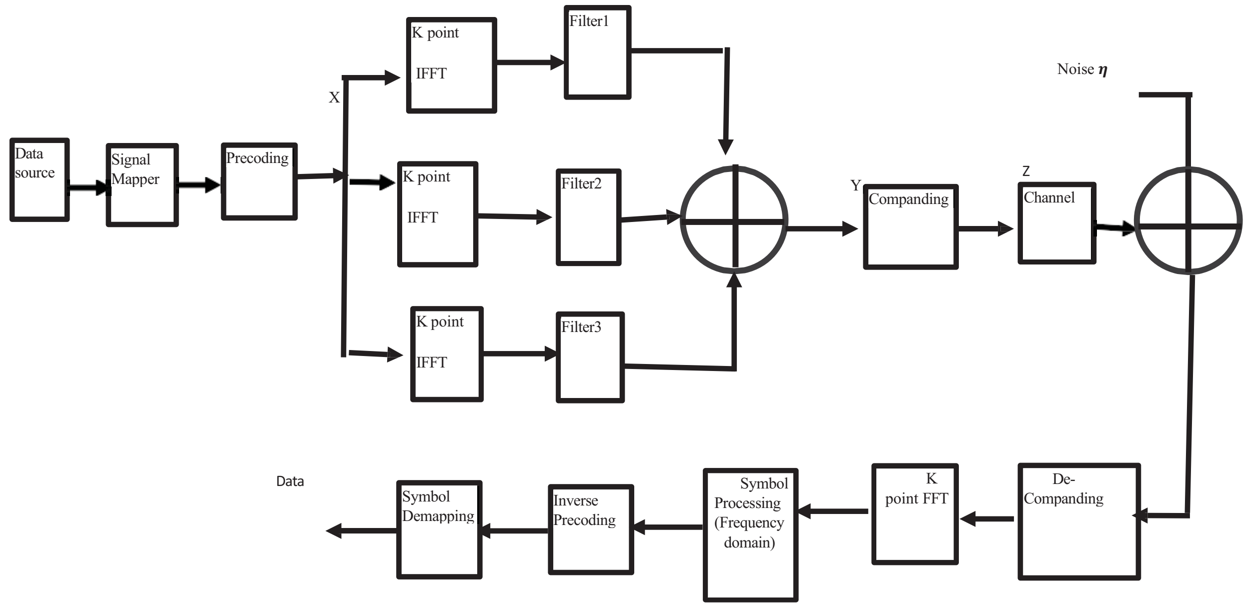

Figure 1. Block diagram of proposed UFMC- DST-SLM & UFMC SLM-MMCT technique

precoding schemes along with SLM provide superior PAPR reduction and BER characteristics [16]. A reduced complexity UFMC transmitter has been proposed by Thorsten et al. in [17]. According to the authors, the complexity of an OFDM transmitter is more than 100 times greater than that of a UFMC transmitter, but their suggested UFMC transmitter diminishes the complexity by 20% in comparison. In [18], Raymond et al. proposed an alternative architecture to the traditional UFMC transmitter, wherein the complexity is reduced to 25 times that of an OFDM transmitter for the filtering portion and the size of the Inverse Fast Fourier Transform (IFFT). Atif et al. in [19] introduced simplicity in all the UFMC transmitter blocks while conveying flexibility, using the most simplified UFMC transmitter in [18] as a baseline. The UFMC transmitter's complexity approaches that of an OFDM transmitter thanks to a reduction in complexity reported in [19]. U_m OFDM modulators are required in a typical traditional SLM-based OFDM system to produce U_w OFDM waveforms, where U_m is considered as U_w as covered in [20]. The bank of UFMC modulators required to apply the SLM and produce the necessary set of UFMC waveforms will be the primary source of complexity [21].

On the other hand, we can use the precoding and companding techniques in UFMC systems with less complexity like that of OFDM systems because of the reduced-complexity UFMC modulator suggested in [22]. These techniques not only reduce the complexity but also improve the performance using reduced BER.

II. UFMC System with Proposed Model

The UFMC modulation approach is a kind of multi-carrier technique that divides huge data rate signals into various parallel streams at a lesser rate. The UFMC system splits the entire band of M sub-carriers into B sub-bands each containing M_B sub-carriers, where $b = 1, 2, \ldots, B$. Then, each sub-band multiplies the data by U phase rotation factors and after that they are operated by N-point IFFT and finite sub-band impulse response filter, respectively and the signal with the lowest PAPR is selected. Finally, the sub band filtered signals are added together and the time domain representation of UFMC is generated. Figure 1 demonstrates the typical block diagram of the UFMC transceiver system. The operation of UFMC-DST-SLM is as follows. The output of this modulation technique is denoted as Q, where $Q = [q0\ q1\ q2\ \ldots\ QM\text{-}1]^T$, where q_i is the sub carrier index, i = [0 1 2 …… M-1]. This output Q is multiplied by the proposed DST precoding matrix P and can be represented as:

$$X = P\,Q \tag{1}$$

The order of the precoding matrix is M x M, and its equation is in the form of

$$P = \begin{bmatrix} p_{00} & p_{01} & p_{0(M-1)} \\ p_{10} & p_{11} & p_{1(M-1)} \\ p_{(M-1)0} & p_{(M-1)1} & p_{(M-1)(M-1)} \end{bmatrix} \tag{2}$$

$$\begin{bmatrix} X(0) \\ X(1) \\ \vdots \\ X(M-1) \end{bmatrix} = \begin{bmatrix} p_{00} & p_{01} & \cdots & p_{0(M-1)} \\ p_{10} & p_{11} & \cdots & p_{1(M-1)} \\ \vdots & \vdots & \vdots & \vdots \\ p_{(M-1)0} & p_{(M-1)1} & p_{(M-1)1} & p_{(M-1)(M-1)} \end{bmatrix} \begin{bmatrix} q(0) \\ q(1) \\ \vdots \\ q(M-1) \end{bmatrix} \tag{3}$$

Where M is the number of sub carriers. Using the above equation, the k^{th} sub carrier of X can be represented as:

$$X(k) = \sum_{m=0}^{M-1} p(k,m)q(m) \tag{4}$$

Where, k = *0,1…..M-1.*

The data vector of the precoding matrix whose order is *Mx1* is given by:

$X = [X(0), X(1) \cdots, X(K), \cdots, X(M-1)]^T$ and later it is sub divided into B sub bands and each sub-band consists of M_B number of sub-carriers which results in $M = BM_B$. The sub-band signals are applied to independent N-point Inverse Discrete Fourier Transforms (IDFTs) so that the resultant time-domain signal is appeared as

$$x_{Bi}(n) = IDFT\ [X_{Bi}] = \frac{1}{\sqrt{N}} \sum_{k=0}^{N-1} X_{uk}\ e^{j2\pi\frac{k}{N}n} \quad (5)$$

Where, $x_{Bi}(n)$ is the n[th] data symbol.

The equations of original DHT and Mu-Law are given by [6]:

$$R(n) = \sqrt{\frac{1}{N} \sum_{n=0}^{N-1} X_n\ Cas\left(\frac{2\pi kn}{N}\right)} \quad (6)$$

$$y(x) = V \frac{\log\left(1 + \mu \frac{|x|}{V}\right)}{\log(1+\mu)} sgn(x) \quad (7)$$

Where, *Cas* is the combination of Cos and Sin.

The proposed DST Precoding scheme's equation is given by:

$$H(k) = \sqrt{\frac{2}{N} \sum_{n=0}^{N-1} X_n\ Sin\left(\frac{2\pi kn}{N} + \frac{\pi}{4}\right)} \quad (8)$$

The proposed MMCT technique's equation is given by:

$$y(x) = V \frac{\log\left(1 + \mu \frac{|x|}{V}\right) 1^{/\beta}}{\log(1+\mu)} sgn(x) \quad (9)$$

III. Simulation Results

The UFMC signals are rotated by phase factors, then precoded by using the proposed DST transform and then the actual UFMC process will be done later. Similarly in the second method, first the UFMC-SLM process is done in which, the symbols are rotated by phase factors and the one with the lowest PAPR is selected for transmission and the output signal is fed to compander circuit to generate the output signal. For both the methods, the PAPR and BER are calculated and compared with the original OFDM, UFMC conventional Discrete Hartley Transform (DHT) and Mu-Law companding techniques. The simulation parameters are assumed to be 1024 symbols, 512 sub carriers by using the 32-QAM modulation technique with phase rotation factor U=8. The software used is MATLAB.

Figure 2 shows the PAPR graph of UFMC-WHT and proposed UFMC-DST-SLM technique. As shown, the PAPR of OFDM is 10.6 dB, UFMC is 10.5 dB, which are almost same. The conventional UFMC-WHT technique's PAPR is 9.6 dB, and the proposed UFMC-DST-SLM technique's PAPR is 9 dB respectively. Hence, compared to WHT technique, the proposed DST-SLM technique reduces the PAPR by 6.2%. The values are indicated in Table 1.

TABLE I

ANALYSIS OF PAPR OF UFMC-SLM-PRECODING TECHNIQUE

Method	PAPR (dB) at CCDF=10^{-2}
OFDM	10.6
UFMC	10.5
UFMC-WHT	9.6
UFMC-DST-SLM	9

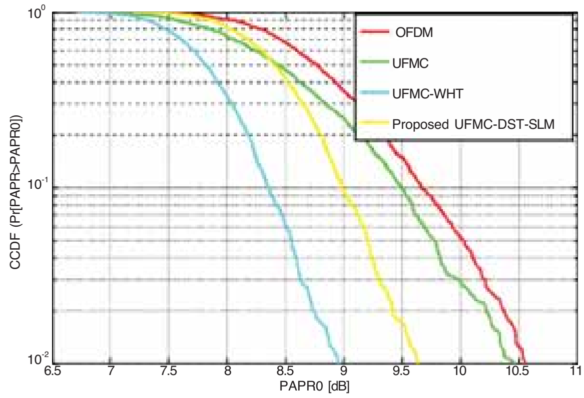

Figure 2. PAPR graph of UFMC WHT and proposed UFMC-DST-SLM

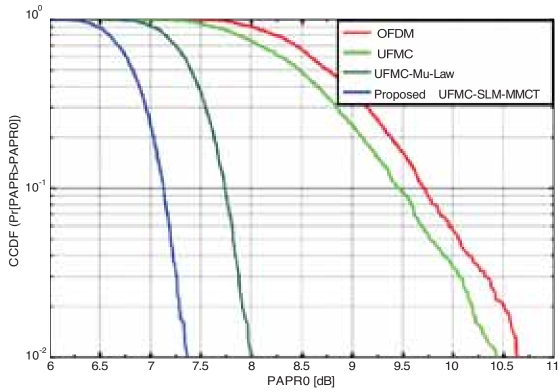

Figure 3. PAPR graph of UFMC-Mu law and proposed UFMC-SLM-MMCT

TABLE II
ANALYSIS OF PAPR OF UFMC-COMPANDING TECHNIQUE

Method	PAPR (dB) at CCDF=10^{-2}
OFDM	10.6
UFMC	10.5
UFMC-Mu-Law	8
UFMC-SLM-MMCT	7.4

Figure 3 shows the PAPR graph of UFMC-Mu-law and proposed UFMC-SLM-MMCT technique. As shown in Table II, the PAPR of OFDM is 10.6 dB, UFMC is 10.5 dB, which are almost same. The conventional UFMC Mu law companding technique's PAPR is 8 dB, UFMC-SLM-MMCT technique's PAPR is 7.4 dB respectively. Hence, compared to Mu-Law scheme, the proposed SLM-MMCT technique reduces the PAPR by 7.5%.

Figures 4 and 5 represent the BER graph of proposed UFMC-DST-SLM precoding and UFMC-SLM-MMCT companding techniques. As shown in Table III, the BER is evaluated for different values of Signal to ratio noise Ratios (SNR). As the SNR increases, the generated BER will be reduced. For both the techniques, the BER is assumed to be 10^{-4} and the SNR is evaluated for the proposed and conventional DHT and Mu-Law companding techniques.

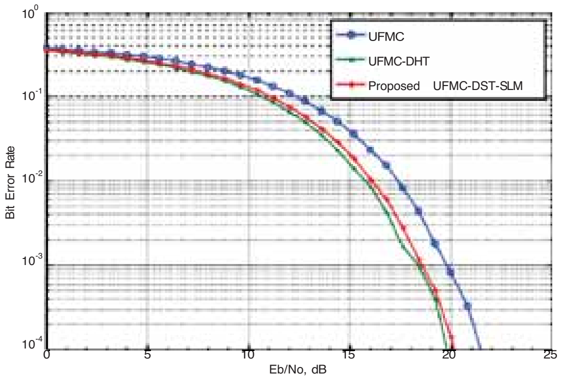

Figure 4. BER graph of UFMC WHT and proposed UFMC-DST-SLM

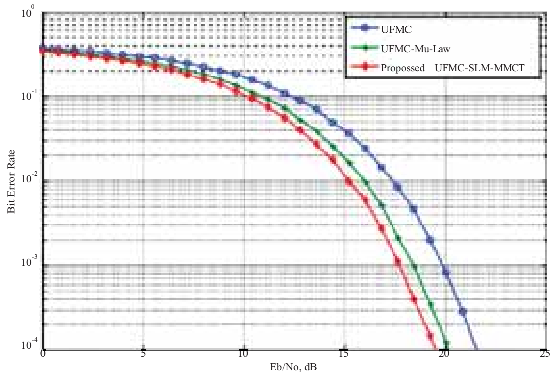

Figure 5. BER graph of UFMC WHT and proposed UFMC-SLM-MMCT

TABLE III
ANALYSIS OF BER OF UFMC-PRECODING & UFMC-COMPANDING TECHNIQUES

Method	SNR (dB)
UFMC	21.5
UFMC-WHT	20
UFMC-DST-SLM	19.5
UFMC-Mu-Law	20
UFMC-SLM-MMCT	19

From Table III, the UFMC technique's SNR is 21.5 dB, whereas the SNR of UFMC-DHT, UFMC-Mu-LAW techniques are 20 dB. The proposed UFMC-DST-SLM shows a 0.5 dB improvement in BER, and UFMC-SLM-MMCT shows an improvement of 1 dB. Hence the proposed techniques can be used for UFMC modulation techniques and for future technologies as it shows the improvement in both PAPR and BER.

IV. CONCLUSIONS

The most dangerous problem in multi-carrier systems is high PAPR. Low complexity expanding transforms lower the PAPR. For the UFMC system, the DST and MMCT schemes in combination with the SLM scheme have been suggested. The original UFMC signal's big amplitudes are attenuated, and its small amplitudes are magnified by the proposed MMCT system. The MMCT scheme's most advantageous expanding parameter, u, was identified. The proposed DST reduces complexity as it uses only real numbers instead of complex numbers with the same PAPR. The suggested transform for the 5G and future communications, UFMC system gives superior PAPR and BER performance than the conventional DHT and Mu-Law companding techniques with this appropriate choice. With a constant average power level, the MMCT system lowers PAPR.

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