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PAPR Reduction in Universal Filtered Multicarrier Systems with Companding Transform

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***Abstract*—Universal filtered multi carrier (UFMC) is an alternative waveform for both orthogonal frequency division multiplexing and filter bank multi carrier. High spectral efficiency is the attractive feature of 5G UFMC system. However, UFMC undergoes with high peak-to-average power ratio (PAPR), which affects the efficiency of power amplifier. Companding techniques are simple and proficient to reduce the PAPR of UFMC signals. In this paper, a linear nonsymmetrical companding transform (LNST), which reduces PAPR of UFMC signals without changing the average power of the companded signal, is proposed. In LNST scheme, the large and small amplitudes of the UFMC signal are companded with different scales depending on an inflexion point. Hence, more flexibility is available for choosing of companding parameters to get the optimal performance interms of PAPR, average power level and BER. Simulation results confirm that the LNST scheme offers better PAPR reduction and BER characteristics when compared to original UFMC signal and clipping technique. The netgain of the UFMC system with LNST companding is 3.5 dB. Also, the BER of the proposed LNST scheme is assessed for higher order modulations and it presents better BER characteristics when compared to original signal.**

***Index Terms*—UFMC, Companding, PAPR, OFDM**

I. INTRODUCTION

Orthogonal frequency division multiplexing (OFDM) is a popular multicarrier transmission scheme, which divides the high data rate input streams into low data rate streams thus achieves high bandwidth efficiency. The use of cyclic prefix (CP) successfully eliminates the inter symbol interference between OFDM subcarriers [1]. Hence, OFDM can be employed in digital audio broadcasting and video broadcasting applications. However, OFDM undergoes with strict synchronization, high out-of-band (OOB) emission levels, high spectral efficiency and high peak to average power ratio (PAPR). To overcome the limitations of OFDM, the attention is focused on 5G multicarrier waveforms such as generalized frequency division multiplexing (GFDM), filter bank multicarrier (FBMC), and universal filtered multicarrier (UFMC) [2].

In GFDM, a prototype filter is employed to each block, which eliminates OOB levels. However, both ISI (inter symbol interference) and ICI (inter carrier interference) is exist in GFDM due to the non-orthogonal sub-carriers [3] . Complex algorithms are required to avoid the self interference in GFDM system. FBMC, another 5G waveform uses filter to each subcarrier thus achieves less side lobe levels and reduced ICI. But the narrow band filter response requires long filter length, which makes the FBMC system more complex. UFMC is a promising waveform for 5G networks due to its attractive features. It inherits the robustness of FBMC and simplicity of OFDM. The filter is used to each sub-band, which eradicate the inter block interference (IBI), reduce OOB levels, and reduce the filter length [2], [4], [5]. Moreover, spectral efficiency of UFMC is high when compared to OFDM due to no use of CP in UFMC. However, UFMC also undergoes with high PAPR.

PAPR is one of the performance metric of high power amplifier. High PAPR shrinks the efficiency of power amplifier. Additionally, high PAPR needs high resolution quantizer for analog to digital converter thus complexity and power requirement increases at the receiver front-end. Therefore, PAPR reduction is necessary in multicarrier techniques to achieve the high power efficiency. Many schemes are available to reduce PAPR such as clipping, companding, selective mapping (SLM), partial transmit sequence (PTS), and active constellation shaping for OFDM systems [6]. The PTS [7] and SLM [8] proposed for OFDM systems are more complex than clipping and companding schemes. However, for UFMC only some PAPR reduction schemes such as PTS [9], an optimal hybrid scheme [10], enhanced μ-law companding scheme [11] are proposed. The clipping approaches are simple but the performance degrades for higher order modulation schemes. Therefore, companding functions are favorable than clipping.

Many companding techniques are available for OFDM systems such as μ-law [11], exponential companding (EC) [12], and LNST companding [13]. The μ-law increases the power level and EC degrades the bit error rate (BER) of OFDM signals. The LNST scheme of OFDM is assessed only for DQPSK scheme. In this paper, a linear nonsymmetrical companding transform (LNST) is proposed to reduce the PAPR of UFMC systems. The LNST scheme is assessed for higher orders of QAM. An inflexion point is used to compand both the small and large amplitude values of the UFMC signal. Simulation results illustrate that the proposed LNST scheme offers better PAPR reduction and BER characteristics when

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compared to clipping schemes.

II. UFMC SYSTEM MODEL WITH COMPANDING

The transmitter section of UFMC system is modeled in Fig 1. The total available bandwidth is partitioned into J sub-bands. Every sub-band contains k number of carriers. The modulation is performed on each sub-band using quadrature amplitude modulation (QAM). The time domain signal is acquired by applying N-IFFT to the frequency domain modulated signal. One of the important sub blocks in UFMC is band-pass filter, which eliminates OOB emissions and reduces ISI. The filter length of UFMC is considered as L, which is small when compared to FBMC.

The transmitted UFMC signal is mathematically expressed as

$$y_n = \frac{1}{N} \sum_{i=1}^{J} \sum_{l=0}^{L-1} \sum_{k=J^i} X_k^i f_l^i \exp^{\frac{j2\pi(n-l)k}{N}} \qquad 0 \le n \le N+L-1 \tag{1}$$

where y_n is the UFMC signal, N denotes as number of subcarriers, X_k^i is frequency domain modulated signal, and f_l^i denotes the l^{th} filter coefficient.

The UFMC signal comprises of high peak amplitude values as number of subcarrier components are added through an IFFT operation. The high peak values of the UFMC signal corresponds to the high PAPR, which can be defined as the ratio of maximum power of the UFMC signal to the average power of the signal.

$$PAPR = \frac{max\left\{|y_n|^2\right\}}{E\left\{|y_n|^2\right\}} \tag{2}$$

The signal y_n is passed through the companding block to reduce the PAPR of UFMC signal. The signal after companding can be illustrated as

$$b_n = h\left(y_n\right) \tag{3}$$

where b_n is the companded signal. Then the signal b_n is affected by the channel. The received signal t_n with channel noise w_n can be denoted as

$$t_n = b_n + w_n \tag{4}$$

The receiver section of the UFMC system is shown in Fig 2. The companding function at the receiver is nullified by performing the decompanding at the receiver. Then the received time domain signal is converted to frequency domain by employing 2N-FFT. To eradicate ISI in the received signal, miminum mean square error (MMSE) equalization is performed. The final signal is recovered by de-mapping the equalized signal.

III. PAPR REDUCTION WITH LNST COMPANDING

Companding function is a familiar scheme to reduce PAPR with no restrictions on side information such as constellation type, frame format, and number of subcarriers. Hence, complexity of the companding schemes are less when compared to SLM and PTS schemes. However, companding technique is a signal distortion technique, which affects the BER performance of the system. Therefore, the selection of companding parameters is an important task to retain a trade-off between the performance characteristics of system BER and PAPR.

In the proposed linear nonsymmetrical transform, desired performance gains are achieved by altering the small and large amplitude values of the UFMC signal depending on an inflexion point. In LNST scheme, the large amplitudes of the UFMC signal are compressed by the factor u whereas the small amplitudes of the UFMC signal are expanded by the factor $\frac{1}{u}$. Therefore, the PAPR of the UFMC signal is reduced extensively. The mathematical representation of the LNST scheme is

$$b_n = \begin{cases} \frac{1}{u}\ y_n & |y_n| \le \beta \\ u\ y_n & |y_n| > \beta \end{cases} \tag{5}$$

The signals y_n and b_n are original UFMC signal and companded UFMC signal respectively. The companding parameter u must be less than one ($u < 1$), and the inflexion point β is less than max $|y_n|$ ($\beta < max|y_n|$).

The LNST de-companding at receiver section can be represented as

$$g_n = \begin{cases} u\ t_n & |t_n| \le \beta \\ \frac{1}{u}\ t_n & |t_n| > \beta \end{cases} \tag{6}$$

The expanded signals in the transmitter are compressed at the receiver by the factor of u and the compressed signals in the transmitter are expanded at the receiver by the factor of $\frac{1}{u}$.

IV. PERFORMANCE EVALUATION

The UFMC system was simulated with considering the number of sub-bands J=8, each sub-band carriers k=10 subcarriers, N=512, and QAM as modulation scheme. The performance of PAPR of LNST companding with different values of u can be illustrated in Fig 3. As the parameter u changes the PAPR varies.

The BER characteristics of LNST companding with different values of u are presented in Fig 4. The BER degrades for the value of u is 0.7 and 0.6 whereas for u is 0.8 and 0.9, the LNST companding presents better BER characteristics for UFMC system. Therefore, from Fig 3 and Fig 4, the proper choice of companding parameter u amid PAPR and BER has been determined. The BER performance of LNST scheme is better at u=0.9 but the PAPR reduction is low. At u=0.8, LNST gives better PAPR and BER characteristics for UFMC system.

The performance evaluation of PAPR of original signal, proposed LNST companding, μ-law companding, and clipping schemes are exemplified in Fig 5. The PAPR of original signal, clipping scheme, μ-law scheme, and the proposed LNST scheme are 11.5 dB, 9.8 dB, 10.1 dB, and 8.5 dB respectively. Therefore, the LNST scheme presents better PAPR performance when compared to clipping scheme, μ-law, and original signal. The PAPR reduction of LNST scheme has improved 3 dB, 1.6 dB, and 1.3 dB when it is compared with original signal, μ-law, and direct clipping schemes respectively.

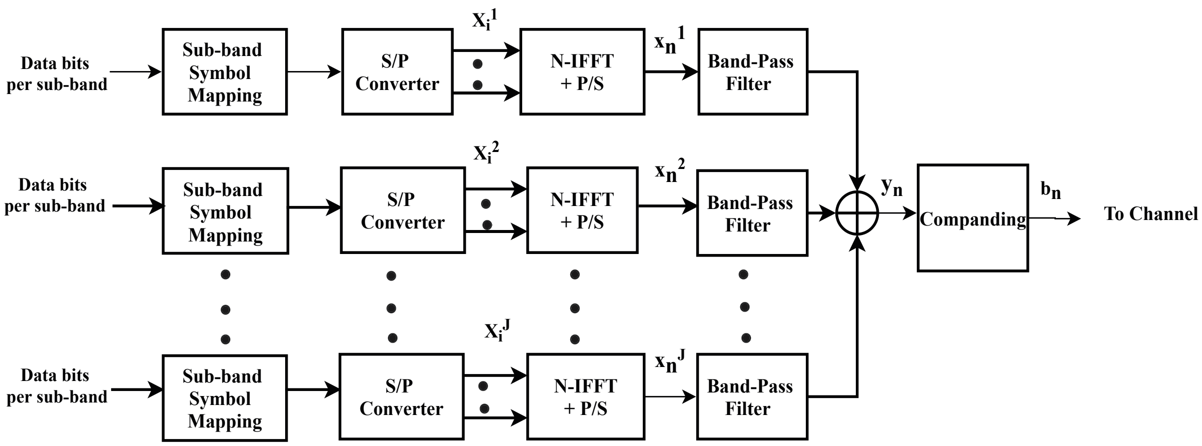

Fig. 1. UFMC transmitter section with companding

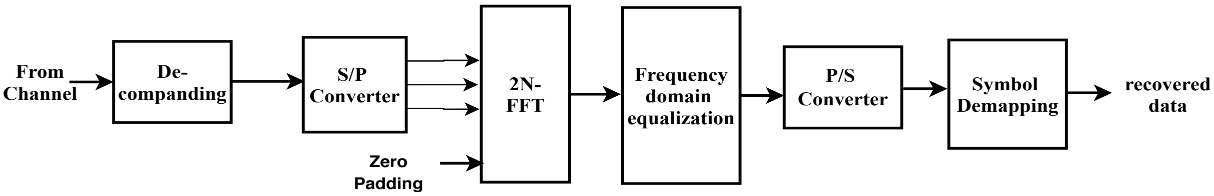

Fig. 2. UFMC receiver section with de-companding

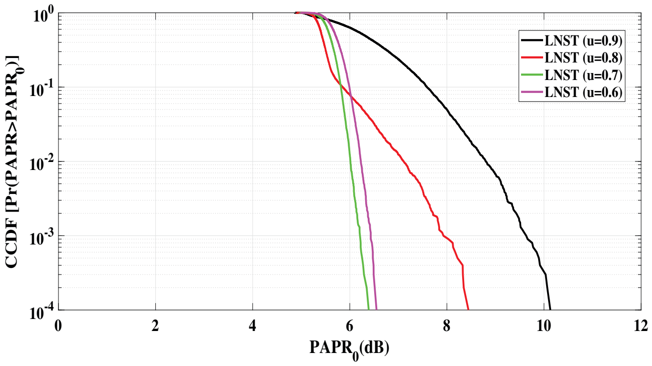

Fig. 3. PAPR of LNST companding for different values of u

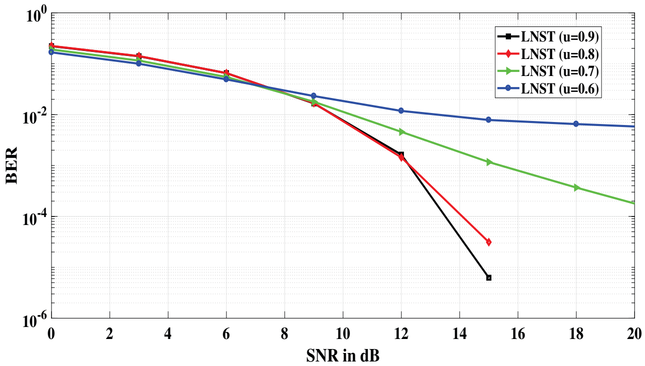

Fig. 4. Characteristics of BER of LNST companding for different values of u

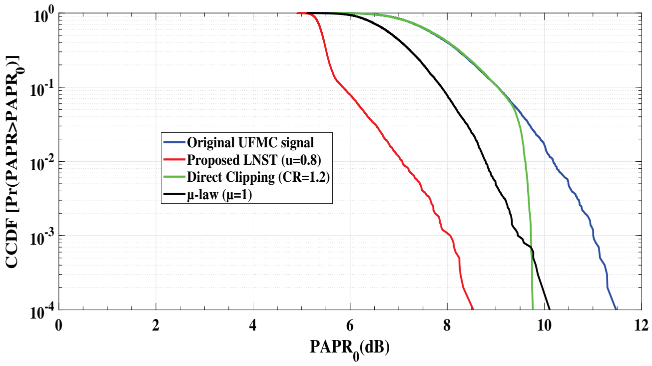

Fig. 5. Assessment of PAPR of original signal, clipping and LNST companding

The original transmitted signal, companded signal, and clipping signal waveforms are exemplified in Fig 6. The average power level of companded signal is almost constant as original signal. The evaluation of BER performance of original signal, clipping scheme, μ-law, and the proposed LNST scheme are presented in Fig 7. The proposed LNST scheme provides better performance characteristics than clipping scheme, μ-law, and original signal.

The proposed LNST scheme is also evaluated for higher order modulation schemes. The comparison of BER characteristics of LNST companding with original UFMC signal for different orders of QAM are exemplified in Fig 8. At higher order modulations also, the LNST scheme proffers better BER

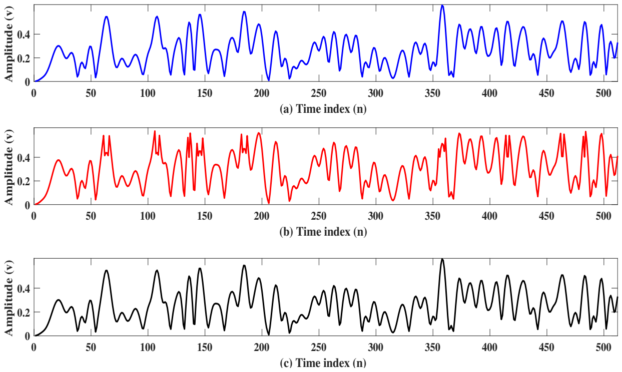

Fig. 6. Waveforms of original signal, companded signal, and clipping scheme (a) UFMC signal with no companding (b) LNST Companded signal (c) direct clipping signal

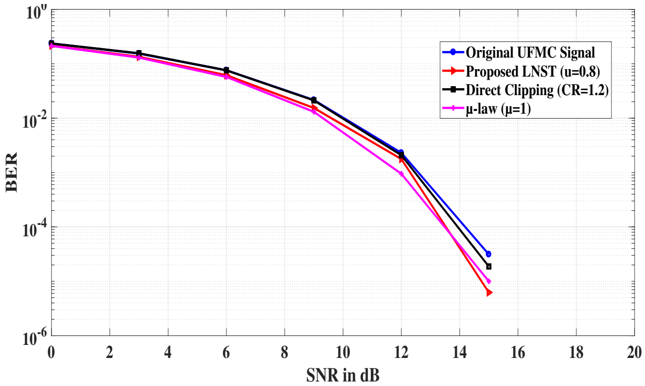

Fig. 7. Assessment of BER of original signal, LNST companded signal, and direct clipping signal

characteristics.

V. Conclusion

High PAPR is the most harmful issue in multicarrier systems. Companding transforms reduce the PAPR with low complexity. The LNST scheme with an inflexion point has been proposed for UFMC system. The proposed LNST scheme magnifies the small amplitudes and attenuates the large amplitudes of the original UFMC signal. The most favorable companding parameter u of the LNST scheme was determined. With this proper choice u=0.8, the proposed transform for 5G UFMC system proffers better PAPR performance than clipping scheme. The LNST scheme reduces PAPR with invariable of average power level. The introduction of inflexion point in LNST offers more freedom to obtain the required system performance characteristics. Also, the performance of BER of the LNST scheme has been improved than clipping scheme. Moreover, the LNST scheme for UFMC system has been assessed for higher orders of QAM and it presents better performance characteristics when compared to original signal.

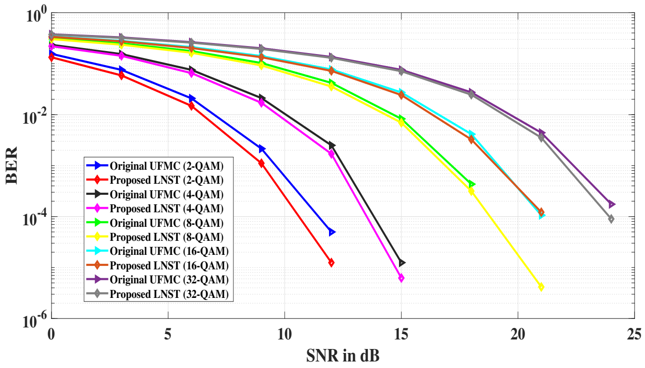

Fig. 8. Assessment of LNST companded signal with original signal for different orders of QAM scheme

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