A Papr Reduction of Companded Sc-Fdma for 5g Uplink Communications

GBSR Naidu, V. Malleswara Rao

Abstract*: *In cellular communication standards Long-Term Evolution (LTE), LTE-Advanced espoused single carrier-frequency division multiple access (SC-FDMA) which has been employed for uplink communication. Because of minor signal envelope vacillations in SC-FDMA has slight peak to average power ratio (PAPR) as well as bit error rate (BER) that is variety from OFDMA but there is scope to curtail the PAPR in SC-FDMA. The several techniques to curtail PAPR in single carrier FDMA sophisticated systems which are complex, or they essential side information to be communicated. The SC-FDMA receiver needs equalization which are zero forcing (ZF), minimum mean square equalizer (MMSE) to trade-off the complexity and performance. A projected nonlinear companding function (NCF) based on Exponential function performs better than Trapezoidal function, to reduce the PAPR and also BER under Q-PSK and 16-QAM of the Single Carrier- FDMA system. Computer simulations gives that the expected method decides better than the other functions like µ -law companding function.

Index Terms*: *BER, MMSE, NCF, OFDMA, PAPR, SC-FDMA, ZF.

I. INTRODUCTION

Single carrier- FDMA (SC-FDMA) has been implemented as an alternative to OFDMA in long-term evolution (LTE) for uplink transmission. Because of lesser signal envelope variations in SC-FDMA, minimum peak to average power ratio (PAPR) is obtained in comparison with OFDMA. However, it is essential and expedient to have additional drop of PAPR in SC-FDMA [1]. But there is scope to excess PAPR especially in higher order modulations [2]. It may be noted that the case in which PAPR is high for linear operation of PAPR result in degradation of its efficiency [3].

Several methods has been described to optimize the PAPR in SC-FDMA technology. These include clipping and filtering, companding techniques [4.5], Pulse shaping [6], Selective Mapping (SLM) [7], Partial Transmit Sequence (PTS) [8] and pre-coding practices [9,10]. The performance procedures are very intricate or require surplus bandwidth for broadcast of side information (SI). The ease of nonlinear companding functions (NCF) have been utilized in OFDMA for diminish PAPR and achieve better performance in BER. Moreover, such companding functions has less intricacy for employment and don't necessitate any bandwidth expansion. The companded the data signals via monotonically increasing function at transmitter. The recovery of the signals at receiver can be done through equivalent inverse operation. µ law companding function have been initiated [11] for minimizing PAPR in SC-FDMA technology. In this technique, the companding coefficient play a vital role; as companding coefficient and PAPR are inverse proportion which means gain the companding coefficient correspondingly diminish the PAPR, but performance in BER is degraded. The minimal numeric of µ at "4" has been choosed by authors because at this µ, PAPR is improved by 3.35 dB at CCDF= 10^{-4} for Localized FDMA. The power function (PF) and raised cosine-like (RC) functions has been used to diminish PAPR [12]. But it was finalized that companding functions like power function has well performance to optimize PAPR than the raised-cosine function has been discussed in literature [11,12]. Overall, the improvement in PAPR by the method discussed so far is not substantial, 3dB. In a [13-17] nonlinear companding technique (NCT) has been planned to reduce PAPR without affecting BER performance under adaptive digital modulation schemes.

This paper suggests a innovative companding based on Exponential function to lessen PAPR in single carrier -FDMA; BER performance is also taken into consideration. Additionally, this method is simple without any need of transmission of side information. The next sections are systematized as follows. The Single Ccarrier-FDMA model is presented in Section II. The expected model with Exponential companding (EC) function, µ-function are detailed in Section III. The PAPR and BER simulations of expected system including conventional SC-FDMA scheme are deliberated and analyzed in Section IV. Finally it was concludes that detailed in Section V.

II. SINGLE CARRIER-FDMA MODEL

With the insertion of an N-point FFT block before the N-point IFFT block, the cancellation of FFT and IFFT takes place and the net output is the exact input symbol stream i.e., corresponding to a single-carrier system is 0dB. To minimize the PAPR while still holding the properties of the OFDM system, the usage of M point FFT takes place instead of N point FFT where M<N. The usage of M point FFT instead of N point FFT gives the access to perform the zero padding in between the FFT and IFFT blocks. In the proposed SC-FDMA schematic which is shown in figure 1-2, the insertion of M point FFT block in SC-FDMA provides a possibility of reduction in PAPR. This is the prime principle of SC-FDMA process [18].

The CCDF $\bar{F}_x(x)$ of a random variable X is given as the probability that X>x expressed as

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$$\bar{F}_X(x) = Pr(X > x) \qquad (1)$$

Naturally, the CCDF is related to the CDF, i.e., cumulative distribution function $F_X(x)$ of X as

$$\begin{aligned} F_X(x) &= Pr(X \le x) \\ &= 1 - Pr(X > x) \\ &= 1 - \bar{F}_X(x) \end{aligned} \qquad (2)$$

2.1 Peak to Average Power Ratio

It is most critical issue in OFDMA and several techniques are used to minimize it but not yet reach the requirement. So further move for non-OFDMA or single carrier-FDMA with BPSK modulated symbols (is popularly known as LFDMA).

X(0) X(1) X(2) …………..
+a -a +a …………..

Power in each symbol = a^2
= peak power

Average power = $E\{|x(k)|^2\} = a^2$

Hence, in this single carrier system, both peak and average power = a^2
Ratio = peak/average = 1= 0dB.

Hence, there is no significant deviation from the mean power level.
PAPR in multicarrier system,

Information symbols X(0) X(1) X(2)
±a ±a ±a

The transmitted samples after IFFT is
= IFFT{ x(0) x(1) x(2)…..x(N-1)}
= X(0) X(1) X(2) …….X(N-1)

$$x(k) = \frac{1}{N}\sum_{i=0}^{n-1} X(i)\, e^{j2\pi ki/N}$$

Where x(k) is the kth IFFT sample
X(i) is information symbol.

Average power = $E\{|x(k)|^2\}$

$$= \frac{1}{N}\sum_{i=0}^{n-1} E\{|X(i)|^2\} E\left\{\left|e^{j2\pi ki/N}\right|^2\right\}$$

$$E\{|X(k)|^2\} = \frac{1}{N^2}\sum_{i=0}^{n-1} E\{|X(i)|^2\}$$

$$E\{|X(k)|^2\} = \frac{1}{N^2}\sum_{i=0}^{n-1} a^2$$

$$= \frac{1}{N^2} a^2 . N = a^2/N$$

Hence, average power of the transmission is a^2/N.
Therefore

$$PAPR = \frac{a^2}{a^2/N} = N$$

The PAPR in an OFDM technology can be suggestively complex.
In Supplementary the PAPR growths with number of subcarriers (N).

The most weakness in an OFDMA is its high PAPR essentially get up because of the IFFT at transmitter. Data symbols across subcarriers can add up to gather a high peak signal.

For BPSK, N=512, $PAPR_{OFDM}$ = as high as 10dB.

PAPR is characterized by CCDF which is
CCDF = Pr{PAPR > PAPRth}
The Effect of PAPR is show as in Fig. 1.

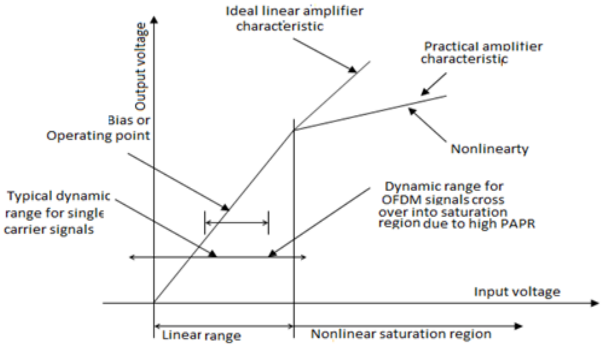


Figure 1. Non linear amplifier characteristic

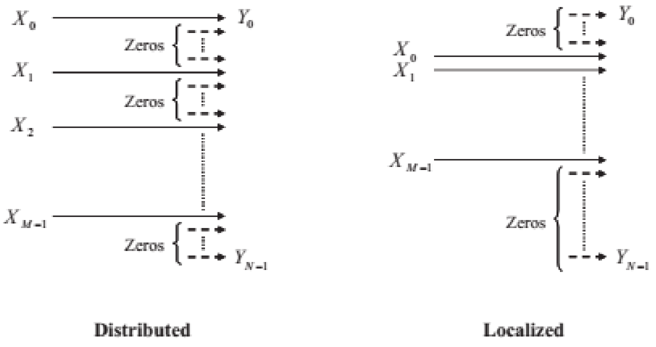
Typically, the amplifier operates around a bias point, as shown in Figure 7.16, which is roughly around the average power signal. Given that the signal amplitude is restricted to the dynamic range of the amplifier around this bias point, for which the amplifier characteristic is linear, there is linear distortion at the output. However, in the case of OFDM, since the peak power deviates significantly from the average power, there is a high chance that the signal crosses into the voltage region outside the dynamic range of the amplifier, thus resulting is a nonlinear distortion of the received signal. This nonlinear effect, arising out of amplifier saturation, leads to loss of orthogonality of the sub carriers and inter-carrier interference. the net result is a poor decoding performance and a rise in the bit-error rate. A slightly modified OFDM technique, which can significantly reduce the PAPR, is SC-FDMA, which is described next.
The PAPR can be is expressed as

$$PAPR(\tilde{x}_m) = \frac{max|\tilde{x}_m^2|}{E|\tilde{x}_m^2|} \qquad (3)$$

2.2 Subcarrier Mapping

There are methods for conveying the modulation symbols-M to subcarriers-N are represented to exposed in the Fig.1. The two subcarrier mapping methods are Localized mode and Distributed mode which are represented in the Fig.1. In case 1) In localized mode, the modulation symbols are dispersed to the M -adjacent subcarriers where as in case 2) In distributed mode, the symbols are equally spaced over the whole bandwidth. In both modes, at the transmitter section, assignment of zero magnitude to the N-M vacant subcarriers takes place. The Localized Single carrier-FDMA is denoted as localized FDMA (LFDMA) and Distributed Single carrier-FDMA as Distributed FDMA (DFDMA). In Distributed FDMA with reference to equation N=Q × M the equi-distance between occupied subcarriers is termed as Interleaved FDMA (IFDMA), [19,20].

In fact authoritatively that subcarriers allocation with equi-distance managing is difficulty over the entire band (IFDMA), meanwhile IFDMA necessitates additional resources such as guard band and pilot carriers.



Distributed **Localized**

Figure 1. Subcarrier mapping modes; distributed and localized.

III. COMPANDING FUNCTION

3.1 µ -Companding function

Companding is (quantization scheme) used for non-uniform quantization. The signal which has smaller amplitudes have higher accuracy (high probability low quantization error) and larger amplitudes have lower accuracy (low probability high quantization error). The size of interval relates the quantization error, finally lower amplitudes have smaller quantization intervals and higher amplitudes have larger quantization intervals. Width of the quantization interval is not uniform is known as non-uniform quantization. So companding is the way to achieve the non-uniform quantization.

A -law companding is popular in Europe and other countries (A =87.6 is companding parameter is defined by CCITT recommendations) where as µ -law is used more in the USA and Japan (µ =255 is companding parameter is defined by CCITT recommendations). µ -law gives dynamically sophisticated than A -law at the rate of worse proportional distortion in small signals. The companding and decompanding finctions are represented as [15]:

$$C_\mu = sgn(x)\left(\frac{1+\mu(x)}{1+\mu}\right) \qquad -1 \le x \le 1 \tag{3}$$

$$D_\mu = sgn(y)\left(\frac{(1+\mu)^{|y|}-1}{\mu}\right) \qquad -1 \le y \le 1 \tag{4}$$

µ -law is input-output mapping function (nonlinear mapping). Here, smaller signals are mapped to larger widths and large signals are compressed. The dynamic range of the signal is normalized and that samples lies 0 to 1.

$$\lim_{\mu\to 0}\left(\frac{1+\mu(x)}{1+\mu}\right) = |x|$$

At µ=0, it is linear curve like straight line and as the µ-companding coefficient increases curve shape becomes more concave. More companding gives more compression of large amplitude region and more expansion of smaller amplitude region.

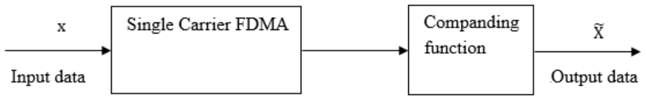


Figure 2. companded SC-FDMA schematic

The Fig.2 show companded SC-FDMA and other Fig. 3, 4 gives transceiver sections of SC-FDMA.

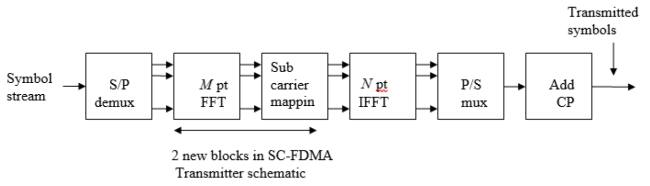


Figure 3. SC-FDMA transmitter schematic

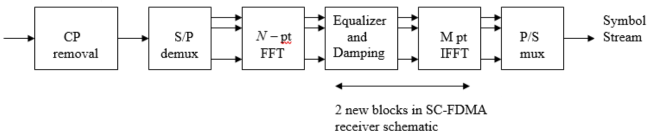


Figure 4. SC-FDMA receiver schematic

3.2 Exponential Companding (EC) function

A most sophisticated technique is presented in this section, namely Exponential companding 'EC -function' which can cut PAPR effectively by transforming the statistics of the amplitude of the signal into one of the uniform distributions [14-18]. The chief merit of this technique is that it maintains constant average power level in the NCT procedure. So that stringent linearity requirements can be partially slackened. Assuming that d^{th} power of magnitude of companded signal t_n as uniform distribution in the specified interval [0, ∞]. The exponent becomes the degree of specific EC -function. The CDF of $|t_n|^d$ can be expressed as

$$F_{|t_n|^d}(x) = \frac{x}{\propto}, \quad 0 \le x \le \alpha$$

The magnitude $|t_n|$ of the companded signal have CDF expressing as

$$\begin{aligned} F_{|t_n|}(x) &= Prob\{\,|t_n| \le x\,\} \\ &= Prob\{\,|t_n|^d \le x^d\,\} \\ &= \frac{x^d}{\propto},\ 0 \le x \le \sqrt[d]{\propto} \end{aligned}$$

The inverse function $F_{|t_n|}(x)$ given by

$$F_{|t_n|}^{-1}(x) = \sqrt[d]{\alpha x}, \qquad 0 \le x \le 1$$

So long as h(x) is a simple monotonically increasing function, is expressed as

$$\begin{aligned} F_{|s_n|}(x) &= Prob\{\,|s_n| \le x\,\} \\ &= Prob\{\,h(|s_n|) \le h(x)\,\} \\ &= F_{|t_n|}(h(x)),\ 0 \le x \le h^{-1}(\sqrt[d]{\propto}) \end{aligned}$$

by taking the phase of input, therefore companding function can be expressed as

$$\begin{aligned} h(x) &= sgn(x)F_{|t_n|}^{-1}\left(F_{|s_n|}(x)\right) \\ &= sgn(x)\sqrt[d]{\alpha\left[1-\exp\left(-\frac{x^2}{\sigma^2}\right)\right]} \end{aligned} \tag{9}$$

Here, sgn (x) declares the sign function and the α is constant that decides the mean power of output. To retain the input and output at communal average power level, it may be decided to assumed that

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$$\propto = \left(\frac{E\left[|s_n|^2\right]}{E\left[\sqrt[d]{\left[1-\exp\left(-\frac{|s_n|^2}{\sigma^2}\right)\right]^2}\right]} \right)^{\frac{d}{2}}$$

As in the receiver side, the inverse function can treated as decompanding is given by

$$h^{-1}(x) = sgn(x)\sqrt{-\sigma^2 ln\left(1-\frac{x^d}{\alpha}\right)} \quad (10)$$

The EC -function h(x) with the degree of parameter ‘d’ as mentioned in [16]. The companded signals take uniformly distributed the amplitudes in addition to the powers when d =1 & 2. In case d >= 2 the function h(x) compress large signals and expand small signals at the same time.

It may be noted that µ-law can only affects small signals by enlarging but don’t change signal peaks this simulations in greater average power levels [16-18]. It is observed that the difference between EC -functions are negligible for the case d>=8.

As seen, the EC -functions are ignorable after d is more.

IV. SIMULATION RESULTS

4.1 PAPR Performance

The CCDF of PAPR for Localized-FDMA and other companding functions is presented in Fig. 5-6 for Q-PSK vs 16-QAM and L=4. The simulation results show that, the proposed scheme can considerably reduce the PAPR are simultaneously achieve sharp dropping in CCDF for every modulation. Considering CCDF and Q-PSK, 16-QAM the important in PAPR by the proposed EC -function scheme 2.429 -4.466 dB. In comparison to original OFDMA by varying d from 1-2 in reduction of PAPR has been achieved in the proposed scheme. It is declared that maximum PAPR reduction in Q-PSK and 16-QAM (5.364-6.159dB) can be achieved at d =1 over for µ-Companding schemes (3.107-3.35dB). But it was comfortable at d=1.5 for better balanced PAPR as well as BER.

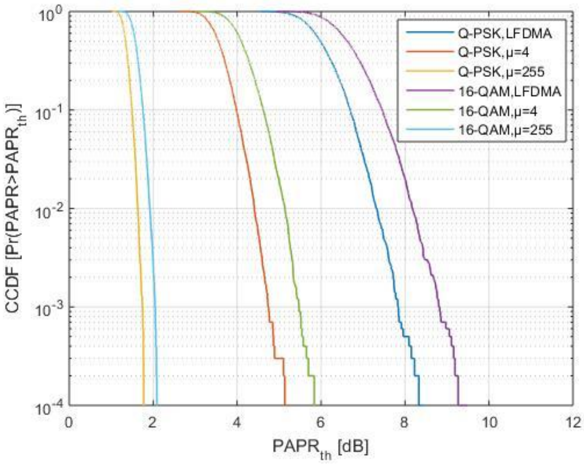

Fig.5 PAPR Analysis of µ-companding (µ =4 to 255) with Q-PSK vs 16- QAM, L=4

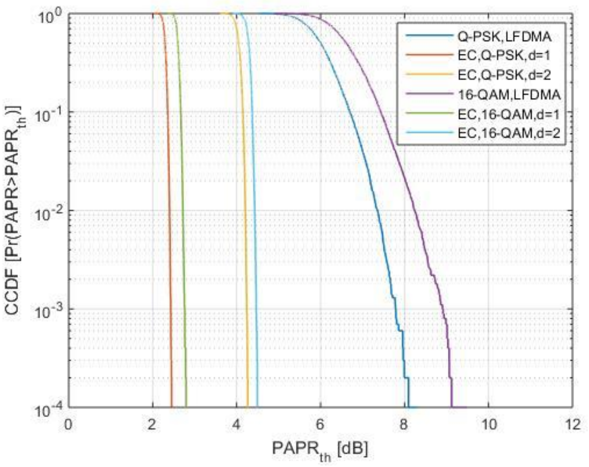

Fig.6 PAPR Analysis of EC-companding (d =1 to 2) with Q-PSK vs 16-QAM, L=4

It may be noticed from the computer simulations that optimum PAPR reduction can be obtained in Q-PSK, 16-QAM (worse performance occurs in 64-QAM).

The Table I show µ -companding coefficient 4 to 255 rises PAPR performance improves but BER bad performing.

As the same for EC, d=1 to 4 PAPR improves as well as the BER degrades and ‘d’ at maximum 8 outs the performance bound.

4.2 BER Performance

BER versus Eb/No plots with the above-mentioned companding functions and AWGN channel using QPSK and 16QAM have been shown in Fig. 7-8. It may be noticed that plot of original LFDMA signal represents the limit of idle performance. The presented scheme has developments BER performance for Q-PSK than 16-QAM (but it gives distortion less than Q-PSK). Additionally, it should be that BER performance is degraded for the compading techniques in comparison with the original OFDMA.

Finally SC-FDMA performs better than OFDMA as consider MMSE at receiver for the metrics PAPR and BER.

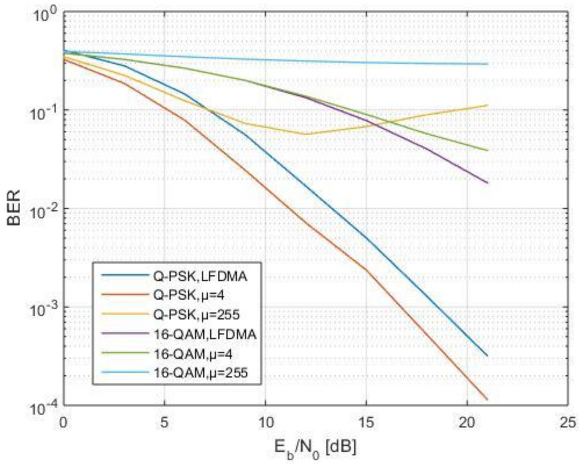

Fig.7 BER Analysis of µ-companding (µ =4 to 255) with Q-PSK vs 16-QAM , L=4

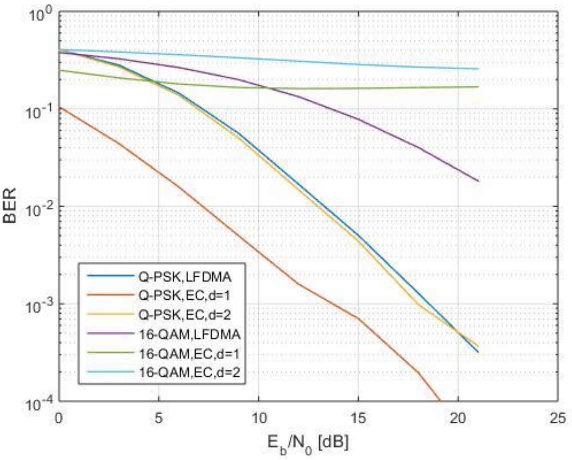

Fig.8 BER Analysis of EC-companding (d =1 to 2) with Q-PSK vs 16-=QAM, L=4

Here, Tables I & II describes all companding functions analyses the metrics 1) PAPR vs CCDF 2) SNR vs BER.

Table -I PAPR and BER for µ-Companding functions

	Q-PSK		16-QAM	
	µ=4	µ=255	µ=4	µ=255
PAPR in dB @ CCDF=10^-3	4.734	1.740	5.476	2.402
BER @ SNR=15dB	0.0023	0.0678	0.0901	0.3034

Table -II PAPR and BER for Exponential (EC) functions

	Q-PSK		16-QAM	
	EC,d=1	EC,d=2	EC,d=1	EC,d=2
PAPR in dB @ CCDF=10^-3	2.429	4.240	2.758	4.466
BER @ SNR=15dB	0.0007	0.0043	0.1623	0.2850

In the Table I&II it is confidently says that the expected scheme out scores the other schemes the metrics PAPR reduction for every modulation. Finally, table II illustrates how propose scheme is better than other techniques in every modulation.

µ -companding coefficient increases the PAPR cuts but the BER is degraded. In Exponential (EC) companding functions, out of all these functions EC-function outperforms better for metrics PAPR and BER. It well balanced the performance metrics i.e. PAPR and BER by controlling the parameter ‘d’. The d <=2 for better results other than this it performs out of boundary region.

In receiver, two types of FDE’s are operated that are zero forcing equalizer (ZF) and minimum mean square equalizer (MMSE). The MMSE performs better than ZF for both Q-PSK as well as in 16-QAM.

V. CONCLUSION

Most recent trend demands a critical issue and take it as a challenge for designed companded function with SC-FDMA to minimize the PAPR effectively and it balances the BER for uplink. In this paper, a innovative EC -function scheme was suitable to project and evaluates more suitable trade-off compromises the PAPR and BER metrics to meet the communication requirements. The mathematical formulae for the EC scheme is evaluated, which empowers to reach the anticipated performance. Instead, a reasonable analysis of EC -function and µ -function schemes is also offered thru Q-PSK and 16-QAM over the AWGN channel environment.

REFERENCES

1. H.G. Myung, J. Lim, D.J. Goodman, “Single carrier FDMA for uplink wireless transmission”, IEEE Veh. Technol. Mag. 1 (2006) 30–38.
2. Shri Ramtej Kondamuri , Anuradha Sundru, “Performance analysis of hybrid PAPR reduction technique for LTE uplink communications”, physical communication 29(2018), pp.103-111.
3. G. Wunder, R.F.H. Fischer, H. Boche, S. Litsyn and No J.-S, “The PAPR problem in OFDM transmission: New directions for a long-lasting problem”, IEEE Signal Process. Mag. 30 (2013) 130–144.
4. GBSR Naidu, V. Malleswara Rao, “Comparative Analysis of OFDM with reduced PAPR based on companding techniques”, international Journal of pure and applied mathematics, Vol. 114, No. 10, 2017, 363-371.
5. Rahmatallah, Y., Mohan, S, “Peak-to-average power ratio reduction in OFDM systems: a survey and taxonomy”, IEEE Commun. Survey. Tutoril. 15(4), (2013), pp.1567–1592
6. C.A. Azurdia-Meza, K. Lee, K. Lee, “PAPR reduction in SC-FDMA by pulse shaping using parametric linear combination pulses”, IEEE Commun. Lett. 16 (2012) pp.2008–2011.
7. V. Sudha, M. Syamkumar and D. Sriram Kumar, “A Low Complexity Modified SLM and Companding based PAPR Reduction in Localized OFDMA”, Wireless Pers Commun, May, 2017, pp1-20.
8. GBSR Naidu, V. Malleswara Rao, “Simulation and Analysis of SC-FDMA based cellular systems for LTE uplink transmission”, cluster computing, November, 2017, pp.1-10
9. C.H.G. Yuen, B. Farhang-Boroujeny, “Analysis of the optimum precoder in SC-FDMA”, IEEE Trans. Wireless. Commun. 11 (2012) 4096–4107.
10. Chen G, Song SH, Ben Letaief K, “A low-complexity precoding scheme for PAPR reduction in SC-FDMA systems”,Proc IEEE Wireless Commun and Networking Conf. 2011 Mar.pp. 1358–62.
11. F.E. Abd El-Samie, F.S. Al-kamali, M.I. Dessouky, B.M. Sallam, F. Shawki, “Performance enhancement of SC-FDMA systems using a companding technique”, Ann. Telecommun. - Ann. Des Télécommun. 65 (2010) 293–300.
12. E. Sun, R. Yang, Y. Zhang, “Raised cosine-like companding scheme for peak-toaverage power ratio reduction of SCFDMA signals”, Wireless. Pers. Commun. 67, (2012) 913–921.
13. J. Hou, J. Ge, D. Zhai, J. Li and Jun Hou, “Peak-toaverage power ratio reduction of OFDM signals with nonlinear companding scheme”, IEEE Trans. Broadcast. 56 (2010) 258–262.
14. Jun Hou, Jianhua Ge, Dewei Zhai, and Jing Li, “Peak-to-Average Power Ratio Reduction of OFDM Signals With Nonlinear Companding Scheme”, IEEE Transactions on Broadcasting, Vol. 56, No. 2, June 2010, pp.258-262.
15. K.S. Ramtej, S. Anuradha, “New error function companding technique to minimize PAPR in LTE uplink communications”, Twenty-Third Natl. Conf. Commun, IEEE, 2017, pp. 1–5.
16. T. Jiang, Y. Yang and Y.-H.Y.H. Song, “Exponential companding technique for PAPR reduction in OFDM systems”, IEEE Trans. Broadcast. 51 (2005) 244–248.
17. J. Hou, J. H. Ge, and J. Li, “Trapezoidal companding scheme for peak-to-average power ratio reduction of OFDM signals,” *Electron. Lett.*, vol. 45, no. 25, pp. 1349–1351, Dec. 2009.
18. S. S. Jeng, and J.M. Chen, “Efficient PAPR reduction in OFDM systems based on a companding technique with trapezium distribution,” IEEE Trans. Broadcast., Vol. 57, no. 2, pp. 291–8, Jun. 2011.
19. H.G Myung, D.J. Goodman, “Single Carrtier-FDMA a new air interface for long term evaluation”, John Wiley & Sons, 2008.
20. F. El-Samie, F. Al-kamali, A. Al-nahari and M. Dessouky, “SC-FDMA for Mobile Communications”, CRC Press, 2013.