Engineering Letters, 23:4, EL_23_4_02

Tone Reservation Based on Fourier Transformed Sequence for PAPR Reduction in OFDM Systems

Wisam F. Al-Azzo, Borhanuddin M. Ali, Sabira Khatun, and Thabit S. Mohammed

Abstract— **This paper presents a new technique to reduce the peak-to-average power ratio (PAPR) in OFDM system by insertion of extra semi-dummy sequence in frequency domain. The extra sequence is generated via Fourier transform of a number of the data modulated symbols. The proposed technique provides instant frequency domain process for the PAPR problem solution. For the 16PSK-OFDM system using 512 subcarrier, the new technique achieved reduction in PAPR at CCDF≤10^{-4} by up to 8 dB at a cost of drop in data rate by only 0.4%. With adaptive operation, the proposed PAPR technique restrains significantly the transmission power when the PAPR reduction gain is limited by 2.5 dB.**

Index Terms— **complementary cumulative distribution function (CCDF), OFDM, peak-to-average power ratio (PAPR), dummy sequence insertion (DSI), Fourier transform sequence (ITSC).**

I. INTRODUCTION

Orthogonal frequency division multiplexing (OFDM) technique has received a lot of interest in the field of wideband communications due to its efficient solution to the multipath phenomena. The major drawback of OFDM, however, is its inherent high peak-to-average power ratio (PAPR) compared to single carrier communications systems. The long-lasting PAPR problem is an active research area because it might offset the potential benefits of OFDM systems [1], [2].

Many techniques to reduce PAPR have been proposed. Some of these techniques reform the constellation shape by processing signals in the frequency domain. The process of signals in the frequency domain for PAPR reduction has attracted the researchers because it does not produce out-of-band radiation at the OFDM output. The most important examples of such process are: active constellation extension (ACE), selected mapping (SLM), tone reservation (TR), and tone injection (TI) [3]-[6].

The reduction in PAPR provided by these techniques is achieved on the account of time and power consumption, due to recursive application of the inverse fast Fourier transform (IFFT) operation. Statistical solutions in the frequency domain were applied to either decrease the number of iterations as given in [7]-[10], or to achieve immediate PAPR reduction as suggested in [11], [12]; when the degradation in error performance is of less impact than processing time for PAPR reduction purpose. Our proposed technique uses, in general, the basis of tone reservation methods, where the original constellation points do not leave their positions; but, instead the constellation shape is reformed by scattering the external generated dummy (non-data bearing subcarriers) sequence among them. In TR techniques, there is no side information but the data transmission rate is reduced due to extra sequence [12]. An optimum PAPR reduction is demanded in TR techniques.

Here is to reduce PAPR, insertion of transformed sequence (ITSC) technique is proposed. The inserted sequence is produced at the frequency domain by Fourier transformation a number of the data modulated symbols (Constellation points). The transformed sequence is used to reform the constellation shape by distributing new points among the original ones. Although it is generated from the data modulated symbols, it is not, however, carrying information (semi-dummy). This scheme reduces PAPR at a cost of some drop in data transmission rate and increase in transmission power; whereas, its adaptive mode of operation restrains efficiently the average consumed power.

This paper is organized as follows. Section two presents, in brief, the generation of OFDM signals, PAPR formulation, and statistical properties of OFDM signals. Section three explains the proposed insertion of transformed sequence technique for PAPR reduction in OFDM systems. Section four and section five the simulation results and conclusions are presented, respectively.

II. OFDM SYSTEM AND PAPR

In OFDM systems, a fixed number of successive input data samples are modulated first (e.g., PSK or QAM), and then jointly correlated together using IFFT at the transmitter side to produce orthogonal data subcarriers. Mathematically, IFFT combines all the data modulated symbols of the frequency domain OFDM vector to produce each element of the output OFDM symbol. The time domain complex valued OFDM symbol is given as [1]

$$x_n = \frac{1}{\sqrt{N}} \sum_{k=0}^{N-1} X_k \, e^{j2\pi \frac{n}{N} k}, \ (0 \le n \le N-1) \tag{1}$$

where x_n is the *n*-th OFDM output signal, X_k represents the *k*-th complex valued data modulated symbol in a block of N OFDM frequency domain vector $\mathbf{X} = [X_0, X_1 \ldots X_{N-1}]^T$.

The signal processing performed by IFFT in the OFDM transmitter changes the geometric layout from homogeneous distribution of the constellation points generated from the

Manuscript received January 26, 2015; revised May 09, 2015.

Wisam F. Al-Azzo is with department of Electrical and Computer Engineering, Dhofar University, Salalah, Oman, phone: 00968-98822217; fax: 00968-23237000; e-mail: wism66@ hotmail.com

Borhanuddin M. Ali is with department of Computer and Communication Systems Engineering, University Putra Malaysia, Serdang, Malaysia, e-mail: borhan@eng.upm.edu.my

Sabira Khatun is with Faculty of Engineering, University Malaysia Pahang, Kuantan, Malaysia, e-mail: drsabirak@yahoo.com

Thabit S. Mohammed is with department of Electrical and Computer Engineering, Dhofar University, Salalah, Oman, e-mail: thabitsm@yahoo.com

modulation scheme (QAM or PSK) into a non-homogeneous distribution with wide envelope variation. However, PAPR is widely used to evaluate such variation of the OFDM output envelope. PAPR is an important factor in designing power amplifier and digital-to-analog converter for error free (or with minimum errors) transmitted OFDM symbol. The PAPR, expressed in dB, is defined by [1]

$$PAPR = 10\log_{10}\left\{\frac{P_{Peak}}{P_{avg}}\right\} \tag{2}$$

where P_{peak} and P_{avg} are the peak and average power of output OFDM symbol, respectively, and they are computed as

$$P_{peak} = \max_{0\le n\le N-1} |x_n|^2 \tag{3}$$

and

$$P_{avg} = \frac{1}{N}\sum_{n=0}^{N-1} |x_n|^2 \tag{4}$$

The statistical distribution of OFDM signals through the transmitter is changed because of IFFT from uniform distribution at the frequency domain to complex Gaussian distribution at the time domain [13]-[16]. Therefore, PAPR of the OFDM output is usually higher than that of the single carrier communications systems using the same modulation format [17]. PAPR is a random variable, and its values vary widely from zero to maximum value, 10 $\log_{10}$ N. Thus, PAPR is analyzed statistically via calculation of the complementary cumulative distribution function (CCDF) by determining the probability of occurrence of a set of PAPR levels as follows [18]

$$CCDF = \frac{1}{m}\sum_{i=1}^{m} c_i \tag{5}$$

where, $c_i = \begin{cases} 1 & \text{when} \quad PAPR_i > \lambda \\ 0 & \text{otherwise} \end{cases}$

m is the total number of OFDM symbols used in the simulation test, and λ is a threshold value. Also, CCDF in a conventional OFDM system is analytically computed by

$$CCDF = \Pr(PAPR > \lambda) = 1-(1-e^{-\lambda})^{\beta N} \tag{6}$$

Equation (6) gives approximate value of CCDF, and β is suggested to be one when N is relatively small or 2.8 for large N, and the latter value was founded imperially [19]. However, finding the CCDF values via (5) by using simulation's PAPR outcomes remain preferable.

III. PROPOSED PAPR REDUCTION TECHNIQUE

The proposed ITSC technique is based on the constellation shape reformation in the frequency domain to reduce the PAPR at the OFDM output. Intuitively, a reduction in PAPR is possible if the constellation shape is modified to be exact or nearly similar to the constellation shape of the IFFT output. By this way, the effect of IFFT is neutralized partially or even completely due to the reciprocity property of Fourier transformations. This objective is achieved, to some extent, in this work by insertion of Fourier transformed sequence of a copy of number of data modulated symbols to the original data modulated subcarriers vector X. Note that, from now on, Fourier transformed sequence will be referred to as transformed sequence. Fig. 1 depicts the conceptual diagram of baseband OFDM transmitter using ITSC technique.

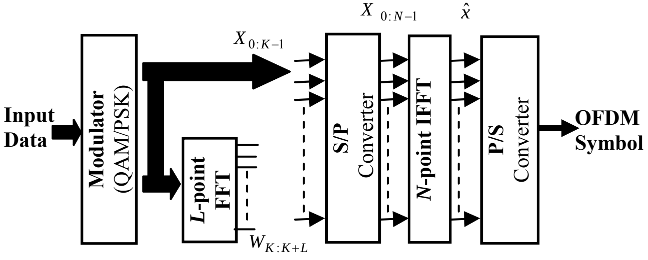

Fig. 1 Block diagram of OFDM transmitter using ITSC technique

ITSC-OFDM system employ additional L-point FFT operation in front of the N-point IFFT, the core unit to generate OFDM symbol. The L-transformed sequence produced by FFT is expressed as

$$W_p = \sum_{k=0}^{L-1} X_k e^{-j2\pi\frac{p}{L}k}, \quad (0\le p\le L-1) \tag{7}$$

The new vector $\hat{X}$ is constructed from K-data modulated symbols $\{X_k\}_{k=0}^{K-1}$ followed by L-transformed sequence elements $\{W_p\}_{p=0}^{L-1}$, N=K+L, as follows

$$\hat{X} = \begin{cases} X_k, & (0\le k\le K-1) \\ W_k, & (K\le k\le N-1) \end{cases} \tag{8}$$

The possible values of L are ranged from minimum L=2 to maximum L=K. Minimizing L decreases the effect of the transformed sequence on the drop of data rate. The value of L is recommended to be power of two for efficient implementation of fast Fourier transformations (FFT and IFFT) for W and $\hat{X}$, respectively. The time domain signals in ITSC-OFDM system is produced by

$$\hat{x}_n = \frac{1}{\sqrt{N}}\sum_{k=0}^{N-1} \hat{X}_k e^{j2\pi\frac{n}{N}k}, \quad (0\le n\le N-1) \tag{9}$$

The transformed sequence is generated using FFT on the first L subcarriers of the original X data modulated vector $W = FFT\{X_k\}_{k=0}^{k=L-1}$, adjusted to the required power value, and then appended to the X vector, as shown in Fig. 1, to form $\hat{X}$ in the frequency domain. The value of L, and the power ratio γ of them to the data subcarriers control the performance of the ITSC-OFDM system

$$\gamma = \frac{P_{\widetilde{W}}}{P_{X_k}} = \frac{\sum_{p=1}^{L} |\widetilde{W}_p|^2}{\sum_{k=1}^{K} |X_k|^2} \tag{10}$$

where $\widetilde{W}$ is the power adjusted transformed sequence.

The power of the transformed sequence, after FFT, is set to achieve a pre-defined γ value. It can be done by multiplying W by a scaling factor α, $\widetilde{W} = \alpha W$. α is computed for each OFDM block as follows

$$\alpha = \sqrt{\frac{\gamma . P_X}{P_W}} \tag{11}$$

where, $P_W = \sum_{p=0}^{L-1} \left|W_p\right|^2 = \sum_{p=0}^{L-1} \left|\left(FFT\{X_k\}_{k=0}^{k=L-1}\right)_p\right|^2$ is the power of the transformed sequence before adjustment.

The ratio of the number of transformed sequence to the total number of subcarriers (*TSR*) in each block of an ITSC-OFDM system is defined, and used to evaluate the influence of the insertion process on the transmission rate efficiency

$$TSR = \frac{\text{No. of Transformed Sequence}}{\text{Total No. of Subcarriers}} = \frac{L}{N} \tag{12}$$

The Transmission efficiency is defined as

$$\begin{aligned} \text{Transmission Efficiency}(\%) &= \left(\frac{K}{K+L}\right) \times 100 \\ &= (1 - TSR) \times 100 \end{aligned} \tag{13}$$

At the receiver, the transformed sequence is striped off after FFT stage; therefore, there is no need to send side information to the receiver to retrieve the original data.

IV. NUMERICAL RESULTS

To evaluate the PAPR reduction capacity and the transmission efficiency of the proposed ITSC technique, given in Fig. 1, we consider an OFDM system with 512 subcarrier and 16-PSK modulation scheme, simulated by 100,000 independent randomly generated data frames each with 512 real valued data samples.

A. *Number of Transformed Sequence and PAPR Reduction Capacity*

Fig. 2 shows the effect of number of transformed sequence *L* on the PAPR reduction capacity, via the CCDF curves, of the proposed ITSC-OFDM system. Four different values and wide range of *TSR* ratios were used to investigate this effect. They are; 1/2, 1/4, 1/128, and 1/256. These values of *TSR* represent *L*=256, 128, 4, and 2 of transformed sequence giving transmission efficiencies of 50%, 75%, 99.2%, and 99.6%, respectively. The power ratio of the transformed sequence was set to γ=20 dB at each *TSR* ratio. It can be noticed that the amount of reduction in the PAPR is nonlinear with respect to the number of transformed sequence, and it is improved by reducing their number.

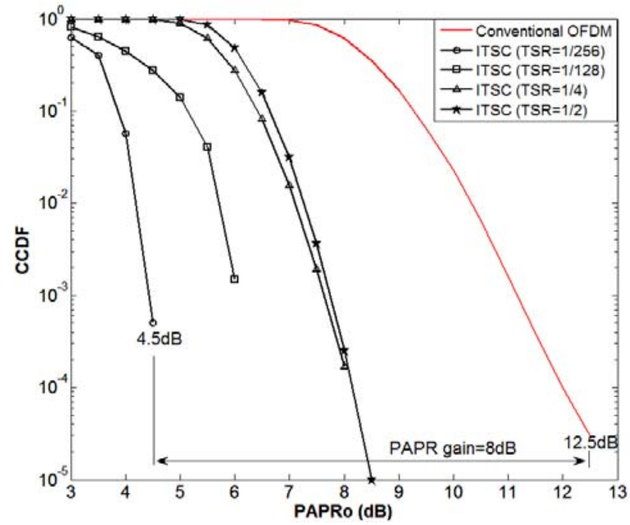

Fig. 2 Effect of number of transformed sequence on PAPR of the ITSC-OFDM system.

Also, the figure shows that the maximum reduction in the PAPR can be achieved by inserting only two of transformed sequence, the minimum possible number, in the ITSC-OFDM system. Up to 8 dB reduction in PAPR was achieved in this case (*TSR*=1/256) at low CCDF, when CCDF≤10^{-4}.

For other parameters of ITSC-OFDM system, the maximum reduction achieved in PAPR, as given in table I, is varied, in which the peak PAPR reduction gain is 8 dB. Furthermore, it can be concluded that PAPR performance is enhanced in large sized OFDM blocks, when *N*≥128.

TABLE I

PAPR REDUCTION CAPACITY OF DIFFERENT BLOCK SIZES IN ITSC-OFDM SYSTEM

Block size (*N*)	16	32	64	128	256	512	1024
PAPR Reduction Δ***PAPR*** (dB)	6.5	6.75	7.3	8	7.7	8	8

B. *Power Effect on PAPR Reduction Capacity*

Fig. 3 shows the PAPR reduction capacity of the proposed ITSC-OFDM system for four different power ratios; γ=0 dB, 3 dB, 10 dB, and 20 dB. Only two transformed tones are inserted for each test, *L*=2. In line with expectation, the figure shows that the capacity of PAPR reduction is improved with respect to increased value of γ. For high power, at γ = 20 dB, the CCDF curve tends to be vertical, marking the maximum possible reduction in the PAPR that can be achieved by the ITSC technique. The figure shows that for this system, the maximum achievable gain in PAPR reduction is about 8 dB at γ = 20 dB and CCDF≤10^{-4}.

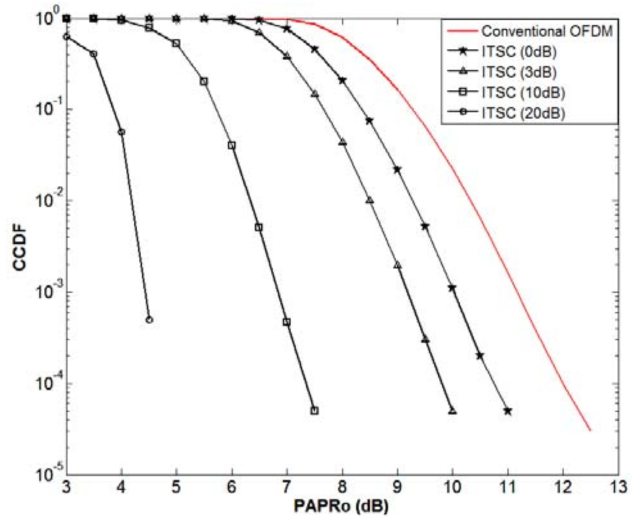

Fig. 3 Effect of power of transformed sequence on PAPR of the ITSC-OFDM system.

C. *Power Efficient Operation of ITSC Technique*

It's fortunate that high PAPRs are only taking place with low probability in conventional OFDM systems. Although the extreme value of PAPR of this system is 27 dB ($\text{PAPR}_{\max}$=10 $\log_{10}$ 512), but it happens only in M^2 blocks of the total M^N distinct data frames for an *N* subcarrier OFDM system with *M*-ary modulation. As it is illustrated in Fig. 2, the maximum PAPR from testing 10^5 different data frames is 12.5 dB which is far less than the extreme value, (i.e. PAPR$_{\max}$). It is, therefore, necessary to selectively implement PAPR reduction process only when PAPR is high. This can be achieved by executing the ITSC technique whenever an individual OFDM symbol exceeds a pre-defined threshold level. Intelligent adaptive execution of ITSC technique helps to restrain the increase in transmission power due to the ITSC signal processing. Table II presents PAPR threshold in adaptive ITSC-OFDM within 3 dB limit down the maximum value, the corresponding probability of occurrence (CCDF) in conventional OFDM system, PAPR reduction gain $\Delta PAPR$ (adaptive ITSC-OFDM system), the average increment in transmitted power, termed $\overline{TR}$, and increase in transmitted power due to the adaptive mode of operation of ITSC-OFDM system.

Table II

AVERAGE TRANSMISSION POWER RATIO OF THE ADAPTIVE ITSC-OFDM SYSTEM FOR DIFFERENT PAPR THRESHOLD LEVELS

PAPR (dB) **threshold (adaptive ITSC-OFDM)**	11.5	11	10.5	10	9.5
Probability of occurrence (conventional OFDM)	1.9×10^{-4}	8.7×10^{-4}	34×10^{-4}	115×10^{-4}	339×10^{-4}
PAPR Reduction $\Delta PAPR$ (dB)	1	1.5	2	2.5	3
$\overline{TR}$	1.04	1.16	1.64	3.25	7.46
Increase in transmission power (dB)-Adaptive	-14	-8	-1.9	3.5	8.1

CCDF given in the table is computed by (6); while, $\overline{TR}$ is computed by dividing the total power due to Intelligent execution of ITSC technique ($P_{T_{ITSC-OFDM}}$) by the total power needed for conventional OFDM system ($P_{T_{Conv.-OFDM}}$) as follows

$$\overline{TR} = \frac{\sum_{U} P_{T_{ITSC-OFDM}}}{\sum_{m} P_{T_{Conv.-OFDM}}} \tag{14}$$

where U and m are the number of ITSC processed OFDM symbols, and the total number of tested OFDM symbols, respectively. The power ratio of the transformed sequence (L=2) was set to $\gamma = 20$ dB for all PAPR thresholds given in the table.

In general, it can be noticed that the relationship between PAPR reduction capacity ($\Delta PAPR$) and $\overline{TR}$, as given in the table, is not constant. To show the impact of adaptive operation of ITSC on the transmission power, the increment in transmission power is also computed for non-adaptive operation of ITSC-OFDM system. From Fig. 3, simulations show that, in standard operation of ITSC technique a reduction in PAPR by 1 dB can be achieved by γ =0 dB, i.e. at the cost of increased transmission power by two times (increase in transmission power= $10^{(\gamma/10)} - 1$). On the other hand, when adaptive ITSC technique is applied with a PAPR threshold set at 11.5 dB, the same PAPR reduction gain (i.e. $\Delta PAPR$=1 dB), is achieved with a significant save in transmission power ($\overline{TR} = 1.04$, $10\log_{10}(\overline{TR}-1) = -14\,\text{dB} << \gamma = 0\,\text{dB}$). However, when the required PAPR reduction is less than or equal to 2.5 dB ($\Delta PAPR \le 2.5\,\text{dB}$), $\overline{TR}$ drops tremendously providing significant power saving. For example, 2 dB reduction in PAPR can be achieved by -1.9 dB ($10\log_{10}(\overline{TR}-1)$) extra increase in transmission power, and only -8 dB for 1.5 dB PAPR reduction.

The saving in transmission power will reduce the equivalent loss in signal to noise ratio and accordingly the error performance will be enhanced compared to the standard non-adaptive operation of the ITSC technique. Also, the transformed sequence can boost the error performance since they are produced from a copy of the data modulated symbols with high transmission power. However, the analysis and investigation of the error of ITSC-OFDM system is out of the scope of this article.

D. Computational Complexity of ITSC Technique

In the standard proposed ITSC-OFDM system, L-point FFT is added to the essential N-point IFFT of the conventional OFDM system; while, in its adaptive mode of operation two N-point IFFT and one L-point FFT operations are needed to be implemented during every loop to generate one OFDM symbol, as explained before. Theoretically, the computational complexity of each IFFT/FFT operation is in the order of $\mathcal{O}(N \log_2 N)$ represented by $\frac{N}{2}\log_2 N$ complex multiplication operation, and $N \log_2 N$ complex addition operation [20]. Therefore, the computational complexity of the standard ITSC-OFDM system is estimated as

$$\hat{n}_{mul} = \frac{N}{2}\log_2 N + \frac{L}{2}\log_2 L \tag{15}$$

and

$$\hat{n}_{add} = N\log_2 N + L\log_2 L \tag{16}$$

where $\hat{n}_{mul}$ and $\hat{n}_{add}$ are the complex multiplication and complex addition, respectively.

In adaptive mode of ITSC-OFDM system, the computational complexity is evaluated as

$$\begin{aligned}\hat{n}'_{mul} &= 2\frac{N}{2}\log_2 N + \frac{L}{2}\log_2 L \\ &= N\log_2 N + \frac{L}{2}\log_2 L\end{aligned} \tag{17}$$

and

$$\hat{n}'_{add} = 2N\log_2 N + L\log_2 L \tag{18}$$

when L<<N, we have $\frac{N}{2}\log_2 N >> \frac{L}{2}\log_2 L$ and $N \log_2 N$>>$L \log_2 L$, therefore the term $\frac{L}{2}\log_2 L$ can be removed from (15) and (17), and the term $L \log_2 L$ removed from (16) and (18). Table III presents the computational complexity data for conventional OFDM, and standard and adaptive ITS-OFDM systems using the same parameters applied to produce Fig. 2; N=512, and L=256, 128, 4, and 2. The numerical calculations show clearly that the difference between the concerned numbers of multiplications and additions are negligible when the number of transformed sequence is relatively small, at L=2 and L=4. As a result of that, the total computational complexity can be approximated in the standard ITSC-OFDM system to that of the conventional OFDM system, and double for the adaptive ITSC-OFDM system. Conversely, the approximation is not valid for large L as in L=128 and L=256.

Table III
COMPUTATIONAL COMPLEXITY OF STANDARD AND ADAPTIVE PROPOSED ITSC-OFDM SYSTEMS

System	Process Type	No. of Transformed Sequence (*L*)			
		256	**128**	**4**	**2**
Standard ITSC-OFDM	$\hat{n}_{mul}$	3328	2752	2308	2305
	$\hat{n}_{add}$	6656	5504	4616	4610
Adaptive ITSC-OFDM	$\hat{n}'_{mul}$	5632	5056	4612	4609
	$\hat{n}'_{add}$	11264	10112	9224	9218
Conventional OFDM	n_{mul}	2304			
	n_{add}	4608			

E. Comparison with IDRG PAPR Reduction Technique

Fig. 4 shows the comparison in PAPR reduction capacity between the proposed ITSC technique and the insertion of dummy random Gaussian sequence (IDRG) technique. Both techniques, ITSC and IDRG, insert dummy sequence to the data subcarriers in the frequency domain; but, they are different in the method of generation of their dummy sequences. IDRG, as given in [12], generates a set of random variable sequence $\{R_k\}_{k=0}^{k=L-1}$ in a complex Gaussian form with zero mean and variance $\sigma^2 = E\{|R_k|^2\}/2$ of their orthogonal components. The probability distribution function (PDF) of its amplitude $|R_k|$ is expressed by the Rayleigh distribution

$$f_{|R|}(r) = \frac{2r}{\sigma_R^2} e^{-\frac{r^2}{\sigma_R^2}} \quad , \quad r \geq 0 \tag{19}$$

where σ_R^2 is the variance. $\sigma_R^2 = E\{|R_k|^2\}$, $|.|$ denotes modulus, and $E\{.\}$ is the mathematical expectation. *R* is approximated as a complex Gaussian process when the number of samples *L* is large enough (e.g. $L \geq 64$).

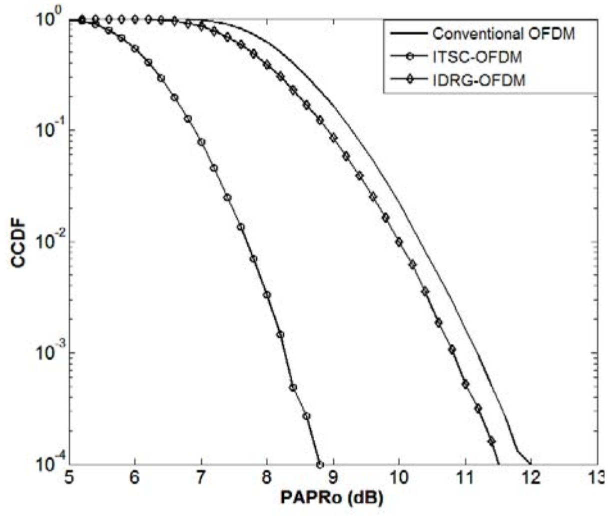

Fig. 4 PAPR Performance of the ITSC-OFDM and IDRG-OFDM systems.

The process in IDRG technique is data independent, and therefore, the same dummy sequence is used for each transmitted OFDM block. Thus, the dummy sequence *R* is generated initially once with zero mean and any value of variance, $R(0, \sigma_R^2)$. Then, the total power of the sequence is adjusted through its variance to achieve the required power ratio γ, for each OFDM block, before appending them to *X* as follows

$$\hat{\sigma}_R^2 = \frac{\gamma . P_X}{\sigma_R^2} \tag{20}$$

where $\hat{\sigma}_R^2$ is the adjusted variance of the random variable R ($\hat{R} = \sqrt{\frac{\hat{\sigma}_R^2}{2}} \times R$).

In the simulation, both ITSC-OFDM and IDRG-OFDM systems use; 16PSK modulation, 512 subcarrier, 64 dummy sequence, and $\gamma = 10$ dB. The simulation output shows clear outperform of ITSC technique over IDRG. Other simulation tests using different systems' parameters showed the same profile, where ITSC technique always provides better PAPR performance compared to IDRG technique.

V. CONCLUSION

The insertion of transformed sequence can achieve a significant reduction in PAPR with non-iterative low computational complexity, low or moderate drop in transmission efficiency, and no out-of-band radiation. Hence, the proposed ITSC technique for PAPR reduction is suitable for OFDM applications that are sensitive to spectral efficiency and computational complexity. For 16PSK-OFDM system using 512 subcarrier, the achieved reduction in PAPR at CCDF≤10^{-4} is 8 dB at a cost of drop in data rate by only 0.4%. The adaptive operation of ITSC technique improves considerably the penalty of power increment when PAPR reduction gain is limited by 2.5 dB. Thereby, using small number of transformed sequence with low extra power could be enough to achieve considerable improvement in the PAPR performance. Finally, the instant PAPR reduction solution of the proposed ITSC technique could be beneficial to other existing iterative PAPR reduction techniques, e.g. Partial Transmit Sequence (PTS), SLM, and ACE, to cut down their computational complexity in case of collaboration use.

REFERENCES

[1] S. H. Han, and J. H. Lee, "An overview of peak-to-average power ratio reduction techniques for multicarrier transmission," *IEEE Wireless Commun.*, vol. 12, no. 2, pp. 56-65, 2005.

[2] G. Wunder, R. Fischer, H. Boche, S. Litsyn, and J. No, "The PAPR problem in OFDM Transmission: new directions for a long-lasting problem," *IEEE Signal Process. Mag.*, vol. 30, no. 6, pp. 130-144, 2013.

[3] K. Bae, J. Andrews, and E. Powers, "Adaptive Active Constellation Extension Algorithm for Peak-to-Average Ratio Reduction in OFDM," *IEEE commun. lett.*, vol. 14, no. 1, pp. 39-41, 2010.

[4] L. Yang, W. Hu, K. Soo, and Y. Siu, "Swapped SLM scheme for reducing PAPR of OFDM systems," *Electron. Lett,* vol. 50 no. 22 pp. 1608–1609, 2014.

[5] O. Gouba and Y. Louët, "Adding signal for peak-to-average power reduction and predistortion in an orthogonal frequency division multiplexing context," *IET Signal Process.*, vol. 7, no. 9, pp. 879–887, 2013.

[6] J. Chen and C. Wen, "PAPR Reduction of OFDM Signals Using Cross-Entropy-Based Tone Injection Schemes," *IEEE Signal Process. Lett.*, vol. 17, no. 8, pp. 727-730, 2010.

[7] P. Varahram, W. F. Al-Azzo, and B. M. Ali, "A low complexity partial transmit sequence scheme by use of dummy signals for PAPR reduction in OFDM systems," *IEEE Trans. on Consum. Elect.*, vol. 56, no. 4, pp. 2416 – 2420, 2010.

[8] P. Varahram, B. M. Ali, and W. F. Al-Azzo, "Low Complexity ADRG-PTS Scheme for PAPR Reduction in OFDM Systems," in 2011 *ICACT2011 conference*, Phoenix Park (Korea), pp. 331-334.

[9] P. Varahram, B. M. Ali, and W. F. Al-Azzo, "IDRG–PTS Scheme with Low Complexity for Peak-to Average Power Ratio Reduction in OFDM Systems," *J. of Chinese Inst. of Engg.,* vol. 36, no. 6, pp. 677–683, 2013.

[10] S. Mohammady, R. M. Sidek, P. Varahram, M. N. Hamidon, and N. Sulaiman, "A Low Complexity Selected Mapping Scheme for Peak to Average Power Ratio Reduction with Digital Predistortion in OFDM Systems," *Int. J. of Commun. Sys.* vol. 26, pp. 481–494, 2013.

[11] W. F. Al-Azzo, B. M. Ali, S. Khatun, S. M. Bilfagih, and N. K. Noordin, "Insertion of Gaussian Dummy Sub-carriers for PAPR Reduction in OFDM Systems," in 2008 *IASTED (AsiaCSN 2008) Conference*, Langkawi (Malaysia), pp.130-133.

[12] W. F. Al-Azzo, B. M. Ali, S. Khatun, S. M. Bilfagih, and N. K. Noordin, "Reducing PAPR in OFDM Systems by Insertion of Dummy Random Gaussian Signals," in 2011 *ICCBN 2011 conference*, Kuala-Lumpur (Malaysia), pp. 762-768.

[13] L. Hanzo, M. Munster, B. J. Choi, and T. Keller, *OFDM and MC-CDMA for Broadband Multi-User Communications, WLANs and Broadcasting*, Wiley, 2003.

[14] H. Ochiai and H. Imai, "On the distribution of the peak-to-average power ratio in OFDM signals," *IEEE Trans. Commun.*, vol. 49, no. 2, pp. 282–289, 2001.

[15] H. Ochiai and H. Imai, "Performance of the deliberate clipping with adaptive symbol selection for strictly band-limited OFDM systems," *IEEE J. Sel. Areas. Commun.*, vol. 18, no. 11, pp. 2270–2277, 2000.

[16] M. H. Nerma, N. Kamel, and V. Jagadish, "Investigation of Using Dual Tree Complex Wavelet Transform (DT-CWT) to Improve the Performance of OFDM System," *Engg. Lett.*, vol. 20, no. 2, 2012.

[17] W. Y. Zou and Y. Wu, "COFDM: an overview," *IEEE Trans. broadcast.*, vol. 41, no.1 , pp. 1-8, 1995.

[18] E. Alsusa and L. Yang, "Selective post-IFFT amplitude randomising for peak-to-average power ratio reduction in orthogonal frequency-division multiplexing based systems," *IET Commun.*, vol. 2, no. 4, pp. 553–561, 2008.

[19] T. Jiang, M. Guizani, H. Chen, W. Xiang, and Y. Wu, "Derivation of PAPR Distribution for OFDM Wireless Systems Based on Extreme Value Theory," *IEEE Trans. on Wireless Commun.*, vol. 7, no. 4, pp. 1298-1305, 2008.

[20] Y. Rahmatallah and S. Mohan, "Peak-To-Average Power Ratio Reduction in OFDM Systems: A Survey and Taxonomy," *IEEE Commun. Surveys & Tuts*., vol. 15, no. 4, pp. 1567-1592, 2013.

Wisam F. AL-Azzo received his B.Sc. and M.Sc. in electronics and communications engineering from university of Mosul, Iraq in 1988, and 1993, respectively. His Ph.D in wireless communication engineering, from the University Putra Malaysia in 2009. He has 20 years of experiences in teaching and research. Presently, he is an assistant professor in electrical and computer engineering department in, Dhofar university, wireless communications, multicarrier digital communication systems, and modulation and coding.

Borhanuddin M. Ali graduated from Loughborough University, UK, in 1979 and M.Sc. and Ph.D. from University of Wales, Cardiff, in 1981 and 1985 respectively. Upon his Ph.D. graduation, he joined University Putra Malaysia as a lecturer, and became Professor in 2002, during which he served as Head of Departments, twice, and later the Director of Institute of Multimedia and Software, a centre of excellence within the same university. Over his tenureship, he also spent times with the R & D institutes in industry; Celcom R&D, Might (a government-industry group on high tech), and with Mimos (a government research lab in ICT). He also serves as committee member of various portfolios at ComSoc AP Board, and in the steering committee of APCC. He is currently the Director of the Institute of Advanced Technology, a university centre of excellence in engineering, science and IT. His research interest spans the broad area of wireless communications and networks technology.

Sabira Khatun received her B.Sc., M.Sc. in Applied Mathematics and Ph.D. on Hydromagnetic Stability from the University of Rajshahi, Bangladesh in 1988, 1990 and 1994, respectively. She received her second Ph.D. in Communications and Networking from University Putra Malaysia in 2003. She became a Lecturer at the Discipline of Computer Science and Engineering, University Khulna, Bangladesh in 1991 Assistant Professor in 1994. She joined as Senior Lecturer at university Putra Malaysia in 1998. She is a member of IEEE and her research interest in wireless communications and SDR.

Thabit S. Mohammed received his B.Sc. in Electrical & Electronic Engineering, University of Technology, Iraq in 1983, and M.Sc. and P.hD. in Computing Systems from Cranfield University, UK in 1988, and 1992, respectively. He has more than 20 years of experiences in teaching and research. Presently, he is an assistant professor in electrical and computer engineering department in, Dhofar university, Oman. His research interest spans information theory, error control coding, image and speech recognition, reliable software, and fault tolerant systems.