Depiction of Peak to Average Power Ratio Reduction Scheme and potentials for 5G

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Abstract — **Peak to Average Power Ratio (PAR or PAPR) is one of the most challenging issues in the operation of Orthogonal Frequency Division Multiplexing (OFDM) for multicarrier signals used in Fourth and Fifth Generation of broadband cellular network technology (4G and 5G). There are numerous PAPR reduction or also recognized as Crest Factor Reduction (CFR) techniques, for instance Clipping, Coding, Dummy Sequence Insertion (DSI), Tone Reservation, Active Constellation Sequence (ACE), Partial Transmit Sequence (PTS), and Selective Mapping (SLM) schemes. Among these methods, SLM-based techniques are very attractive solutions due to their good performance without additional out-of-band radiations or in-band distortions. This study demonstrates a performance analysis of an SLM-based method combined with adding randomly generated dummy sequences to power-free subcarriers. Simulation results show that the PAPR of the OFDM based signal can be reduced efficiently by using adequate number of dummies and tolerable number of iterations, and that is a potential scheme for 4G and 5G.**

Index Terms — ***CCDF, CFR, Dummy Sequence Insertion, OFDM, PAPR, SLM, 5G***

I. INTRODUCTION

Prospective Orthogonal Frequency Division Multiplexing (OFDM) is a popular modulation scheme that can be considered as a high order Multicarrier Modulation (MCM) system, which is beneficial compared to conventional systems such as FDM based technologies used in GSM. Some of the benefits of the OFDM system are minimized delay, stronger performance in fading phenomena of multipath settings and high Transmission Efficiency (TE) [1-3]. These characteristics are the intention that OFDM is considered as the most consistent choice for wireless systems with high correspondence rate, generally utilized as a part of numerous remote correspondence benchmarks, for example Digital Video broadcasting (DVB), Wireless Local Area Network (WLAN), Long Term Evolution (LTE), and 5G [2]. However, the OFDM's elevated PAPR condenses the receiver's recognition capacity when facing nonlinear components such as High Power Amplifier (HPA) [1-6]. Combining Sinusoids waves together in Inverse Discrete Fourier Transform (IDFT) in order to form OFDM signal, results in high peak to average power ratio (PAPR). The reason is that due to the constructive phenomena between waves and existence of very high peaks, the maximum of the signal, $Max\{S(t)\}$, will be high, and due to destructive interferences, the average of the signal, $E\{S(t)\}$, might be as low as zero. As shown in (1), the ratio between peak and average, known as PAPR or PAR will be high [5].

$$PAPR_{dB} = 10\,log\,((Max\{S(t)\})/(E\{S(t)\})) \qquad (1)$$

The $S(t)$ is the OFDM signal and t is the sample time. Therefore, minimization of PAPR is equivalent to minimization of $max\{S(t)\}$. According to the literature, peak reduction schemes, known as distortion-based methods, do not satisfy the constraints with respect to in-band errors and out-of-band emissions [7-9]. Considering the PAPR reduction performance, and overall difficulties involved with all conventional techniques, Partial Transmit Sequence (PTS) and Selective Mapping (SLM) are the most attractive approaches since they are distortion less. However, these techniques have concerns of computational complexity and Side Information (SI), which may result in lower Spectral Efficiency (SE) [10-13]. A brief comparison is presented in Table 1 as follows:

TABLE I
BRIEF COMPARISON OF CFR TECHNIQUES

Technique	Data rate loss	Distortionless	Transmitter Complexity	Receiver Complexity	Side info. Bits	PAPR reduction (dB)
Clipping	No	No	Low	Low	No	High
Coding	Yes	Yes	High	High	No	Medium
Tone Reservation	Yes	Yes	High	Low	Yes	Medium
PTS	Yes	Yes	High	Medium	Yes	High
SLM	No	Yes	High	Low	Yes	High
DSI	Yes	Yes	Low	Low	No	Medium

The main idea behind the design of DSI-SLM technique has been to use ease of application of DSI scheme and combine it with promising performance of SLM technique to achieve outstanding PAPR reduction without extra complication [14]. A frequently used performance measure for CFR scheme performance is called Complementary Cumulative Distribution Function (CCDF) [14], known as the possibility that PAPR of S exceeds a pre-defined threshold-level $PAPR_0$, i.e.

$$CCDF_{PAPR(S(t))} = Prob(PAPR(S(t)) > PAPR_0) \qquad (2)$$

Application of signals with high PAPR to a Radio Frequency (RF) Power Amplifier (PA) presents unwanted intermodulation products, spectral regrowth, and harmonics [6]. There are two main strategies to prevent interference to adjacent channels and spectral mask standard break. One is to control the input power to not to exceed the back-off value; another one is to use linearization scheme to increase the linearity of the PA [6]. The back-off technique avoids the saturation region in PA with cost of reduced Power Added Efficiency (PAE) and wasted power [7-9]. Though researchers have attempted to solve this issue by digitally

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reducing the PA nonlinearity, the single carrier linearization techniques are not sufficient to compensate PAPR of multicarrier OFDM signal. Previously, the authors of [14] presented a work done on DPD technique and PAPR reduction scheme for OFDM-based signal. Quadrature Phase Shift Keying (QPSK) modulation using 256 and 512 subcarriers based on IEEE 802.16e standard is used to create OFDM signal. The proposed PAPR reduction scheme was named DSI-SLM, which is functional for both multicarrier and single carrier systems. The results shows noticeable improvement in BE, SE, and the PA linearity when combined with the DPD method. In [11], a powerful DPD technique known as Complex Gain Predistortion (CGP) is discussed. The CGP scheme improves the linearity of PA by computing the inverse transfer function of the PA and introducing it into the signal before entering the PA. This algorithm also considers the memory effect of PA, by extraction of PA transfer function parameters iteratively [10-14]. However, here, the main attention is on the performance optimization of the PAPR reduction scheme by various parameters. This article extends the work in [14] by investigating the effect of applying random sequences with different length to power-free subcarriers in the OFDM signal. This process is known as Dummy Sequence Insertion (DSI), and it is presented that it achieves competitive results.

II. PAPR DECREASE BY DSI-SLM MODEL

A brief evaluation of OFDM PAPR reduction using DSI-SLM model is reviewed. The DSI-SLM algorithm is inspired from two models of DSI and the SLM, as shown in Fig. 1 [14]. The DSI-SLM method has numerous advantageous, in comparison with Ordinary DSI and Conventional SLM (C-SLM) methods due to its improved TE, low complexity, and reduced SI. An OFDM signal based on IEEE 802.16e standard with spectrum formed by 192 data, 8 pilots, 1 DC subcarrier, and 55 power-free subcarriers was generated and introduced to the system. The baseband OFDM signal is generated by randomly producing the information data and QPSK modulator. As presented in Fig. 1, serial data streams are paralleled and the dummy sequence, *D*, is inserted in power-free subcarriers. The signal *S* includes an *L* dummy sequence in its power-free subcarriers, and this procedure can be presented as:

$$S=\text{Multiplex}(X,D), \tag{3}$$

when L=10,30,and 50. Maximum value for *L* in this scenario is 55. Greater length dummy signal degrades the *BE* to some extent. In case if $L = 60$, then BE is degraded by 2%,

$$BE = (256/(201+L))\times 100\% \tag{4}$$

It should be noted that the dummy sequence is removed at the receiver side with no extra cost, thus by applying it to the main system, no extra complication is added. The BE behavior for different values of *L* is presented in Fig. 2, and it is perceived that 100% BE is achieved when L=55. However, to preserve the *BE*, by minor modification at the receiver side, the dummy sequence can be used to carry *SI* of the DSI-SLM scheme, to detect the transmitted candidate signal. This usually requires additional bandwidth and additional transmission security. If the total number of subcarriers is 256, if L<50, the remaining power-free subcarriers will carry zero or no data.

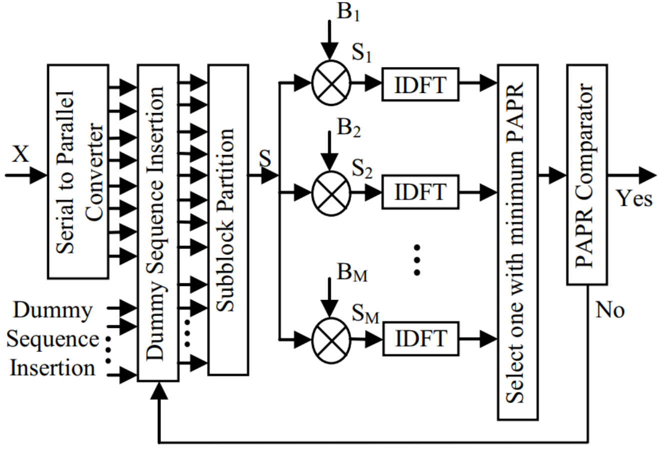

Figure 1 The block diagram of DSI-SLM technique [14]

If L=30, the applied dummy sequence consists 30 random bits and they are all placed in power-free subcarriers slot and the remaining 20 slot stay zero. To avoid occupying all of the 55 empty slots can be beneficial for spectrum shaping and error preventions however there is a trade-off between the performance of PAPR reduction and the *L* which is obtained from Fig. 2, and Fig. 4.

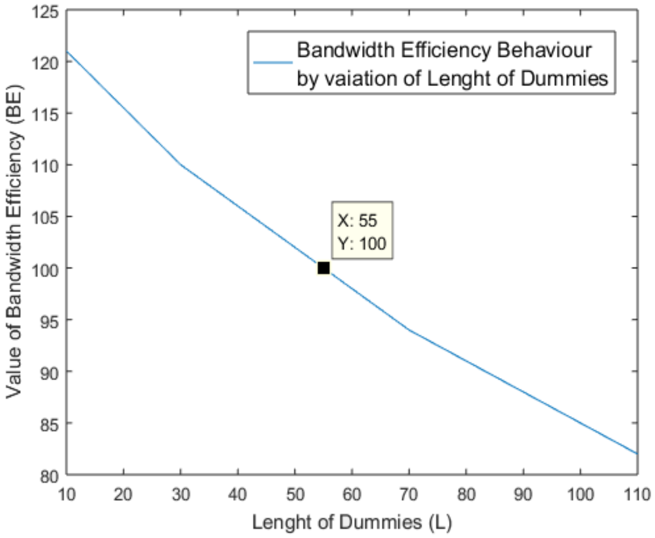

Figure 2 The BE behavior for various dummies (L=10, 30, …, 110).

Based on the PAPR performance, it is advised to use between 30-45 dummies and more than 4 candidate signals (M=4, L>30). As shown in Fig. 1, in the next step, phase rotations (B_1, B_2..., B_M) are multiplied to the input signal, *S*, to create S_1, S_2, ..., S_M known as candidate signals, which each can experience different PAPR probability. The multiplication procedure for producing candidate signals can be presented as follows:

$$S_i(n) = S \times B_i(n), while\ i = 1, 2, \dots, M$$

$$S_i(n) = \begin{bmatrix} S_i(1) \\ S_i(2) \\ \vdots \\ S_i(K+L) \end{bmatrix} and\ B_i(n) = \begin{bmatrix} B_i(1) \\ B_i(2) \\ \vdots \\ B_i(K+L) \end{bmatrix},$$

$$\text{When } n = 1, 2, \dots, K+L \tag{5}$$

Where $B_i(n)$ represents phase rotation or phase sequence, $S(n)$ is a copy of input signal, and $S_i(n)$ represents the candidate signal. The M is the number of generated signals, and the length of these candidate signals should fulfil the length of IFFT processors and it must be $K+L$. It should be noted that real and imaginary parts of the signal should be separately processed. The value of M has to be the power of 2, i.e. 2, 4, 8, 2^4, 2^5, as one of these sequences has the minimized PAPR and will be transmitted, and the receiver has to be informed about the selection. Thus, when M=2, one extra bit has to be transmitted, and this bit is called Side Information (SI). It should be noted that the security and acknowledgement of SI shall be studied for practical implementations. However, when it is zero, the receiver will know that the first sequence had minimum PAPR and is sent, and if it is one, the second sequence is selected. When M is increased to 4, 8, and 16, the SI is also increased to 2, 3, and 4 bits, and this increasing SI will degrade BE. On the other hand, increasing M will enhance the PAPR performance significantly; therefore, there is a trade-off between performance and SI. This is one of the main limitations of SLM-based methods. There is a restriction regarding the IFFT processor. It should be noted that by increasing M, the length of IFFT processors also increases. This indicates that extra computational complexity or extra hardware resource is added to the system. For further implementations, the time consumed and the amount of hardware consumed for practical implementation should be analyzed. The IFFT for M sequences are given by:

$$S = \begin{bmatrix} S_1 \\ S_2 \\ \vdots \\ S_M \end{bmatrix} = \frac{1}{N} \begin{bmatrix} \sum_{K=0}^{N-1} S_1(K) \exp\left(\frac{2\pi jnk}{N}\right) \\ \sum_{K=0}^{N-1} S_2\,(K) \exp\left(\frac{2\pi jnk}{N}\right) \\ \vdots \\ \sum_{K=0}^{N-1} S_M\,(K) \exp\left(\frac{2\pi jnk}{N}\right) \end{bmatrix} \tag{6}$$

where N is the OFDM length, and as mentioned before, the length of IFFT process, N is sum of the data length and dummy length, to K+L. Once the IFFT process of $\{S_1, S_2, \ldots, S_M\}$ is executed, the time domain vectors $\{s_1, s_2, \ldots, s_M\}$ are generated and their PAPR can be computed. Then the sequence with the smallest PAPR is designated. Therefore, the minimization of PAPR is stated as an optimization problem that can be deliberated as follows:

$$PAPR_{opt} = min\{PAPR[s]\}$$
$$= min\{PAPR[s_1, s_2, \ldots, s_M]\} \tag{7}$$

In [6], the authors proposed to use convex functions to minimize the PAPR, in which the peak power is minimized and the average power is maximized. However, any decrease in peak power leads to misuse the ability of the power amplifier and degrading the transmission efficiency. Yet, in the DSI-SLM scheme, the PAPR reduction is a probability-based algorithm and to optimize the PAPR, the $PAPR_{opt}$ is compared with a threshold, $PAPR_{th}$, as displayed in (8).

$$Optimum\ PAPR\ (PAPR_{opt}) < Predefined\ Threshold\ PAPR\ (PAPR_{th}) \tag{8}$$

If $PAPR_{opt}$ is less than $PAPR_{th}$, then the designated sequence with the minimum PAPR is transferred; else, the feedback line is activated in order to generate a new dummy sequence and repeating the process. The new dummy sequence will be placed in the same signal frame as before, thus the probability of decreasing the PAPR can be improved. The phase sequence multiplication stage can be kept the same as before, however it is obvious that if the phase sequences are also randomly changed, the probability is yet further increased. A new dummy sequence is injected and the processes of phase sequence multiplication and IFFTs are repeated. Subsequently, the PAPR is calculated another time and compared with the threshold again. This threshold can be defined based on the accuracy required for the design and rate. If a very low threshold is chosen, then more repetition of feedback is required to optimize the PAPR. For instance, if the captured PAPR for M=8 is $PAPR_{(S)}$ = (8, 6.5, 8.5, 7.9, 8.5, 7.2, 5.9, 6.9). Assuming that the $PAPR_{th}$= 6 dB, the $PAPR_{opt}$ will be 5.9 dB. As $PAPR_{opt} < PAPR_{th}$, the sequence with the $PAPR_{opt}$, which in this case means the 7th sequence, S_7, will be transmitted; If not, the process will be repeated.

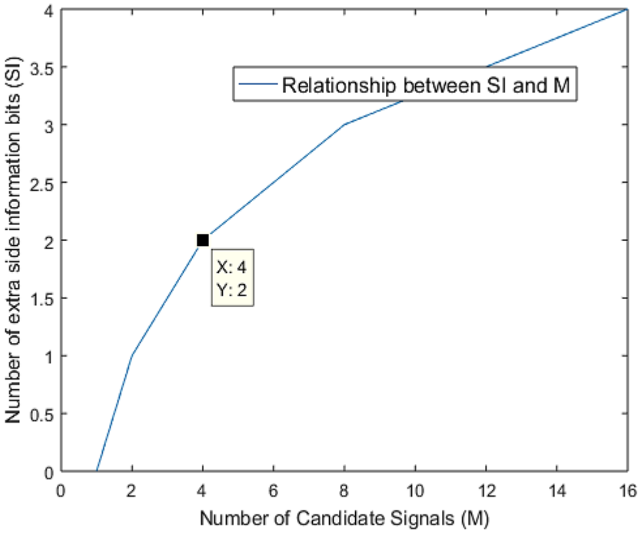

Figure 3. The association of SI and M

If I exceeds the limit, the sequence with the minimum PAPR will be transmitted. It should be noted that in case of M=8, if S_7 is closed to be transmitted, the SI would be 3 bits, and it should digitally indicate 7th sequence, i.e. "111". This correlation is illustrated in Fig. 3. It can be observed that as data cursor presents, for 4 number of candidate signals, only 2 extra bits (SI) are required.

Numerous models are simulated to investigate the effects of diverse values of dummy length, L (L= 10, 30, and 55). It has been witnessed that by increasing the number of dummies from 10 to 30 and 55, the PAPR reduction performance is enhanced. Though, to protect the spectrum reshaping, use of all the power-free subcarriers is not recommended.

There is another idea of adding dummy sequences to the main OFDM symbol, which results in an increase in the signal bandwidth and degradation of TE. According to (4), replacement of 55 power-free subcarriers of OFDM signal with the dummy sequences causes no degradation of BE, hence, here, L_{max} = 55.

III. PERFORMANCE EVALUATION

Here, performance evaluation of applying DSI-SLM scheme on the OFDM signal is presented. The reference OFDM 20 MHz signal was generated based on 802.16e IEEE standard. Matlab R2016b tools are used for simulation, and the length of IFFT or number of subcarriers are assumed to be 256, i.e. N=256, which consisted of 55 power-free subcarriers, and the remaining 201 subcarriers were allocated for a random data, presented in Fig. 3. In order to avoid complexity, the QPSK modulation and an oversampling rate of 1 were considered. Here, the $PAPR_{th}=PAPR_0$=7dB. The simulation in Fig. 5 is performed with 1024 subcarriers.

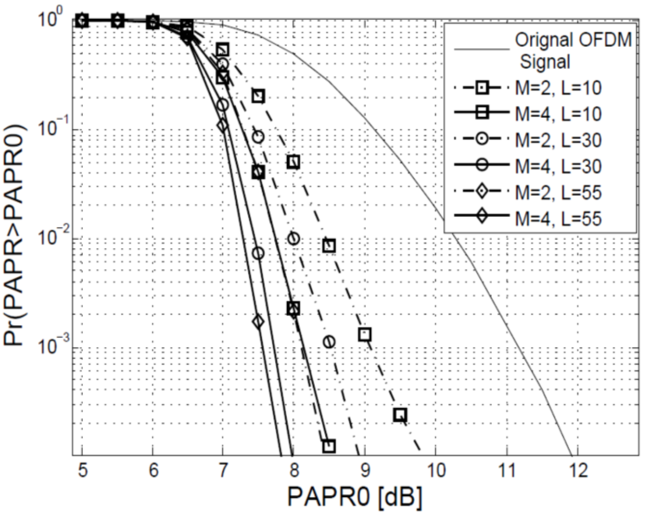

Figure 4. The CCDF of reference OFDM signal with 256 subcarriers (unmarked solid line) and the PAPR optimized signal with DSI-SLM scheme when M=2 (dashed line) and M=4 (marked solid lines)

However, the number of power free subcarriers are kept the same, meaning that although the length of signal is four times but the length of the dummies are varied only between 10, and 55. It can be easily observed from Fig. 4, that by increasing the length of dummies by four times to fulfil the IEEE standard frame, the performance of DSI-SLM technique will be improved. Fig. 5 and 6 present the PAPR performance obtained for the OFDM transmitter using DSI-SLM scheme, by repeating the DSI feedback for a maximum of 10 times, i.e. I=10.

It can be seen from Fig. 4 that 11.9dB PAPR was observed from the original reference OFDM signal, $Prob(PAPR>PAPR_0)=10^{-4}$. Fig.4 presents the PAPR of the OFDM signal without any CFR technique and when DSISLM technique is applied. It presents the probability of having a certain PAPR in similar condition and different techniques using CCDF.

The impacts of the candidate signals length, i.e. M=2, and 4, and the number of occupied power-free subcarriers, i.e. L=10, 30, and 55 are both inspected. Square marked dashed line in Fig. 4 shows, 2.1dB PAPR reduction when DSI-SLM scheme with M=2 and L=10 was simulated. In Fig. 4, when L=10, it means that only 10 power-free subcarriers were occupied with dummy sequences, and that the remaining 45 subcarriers were reserved for spectrum shaping and only two candidate signals, s_1 and s_2, were introduced to the minimum finder block in DSI-SLM. Its performance was improved in a similar manner with M=4 at about 1.3 dB, shown by square marked solid line in Fig. 4. It indicates that when L, is consistence, and only parameter higher number of candidate signals are generated, meaning M is higher, an average of 1dB upgrading is attained. In other hand, when M is fixed and L=10, 30, and 55 are tested, an average of 0.4dB improvement is achieved.

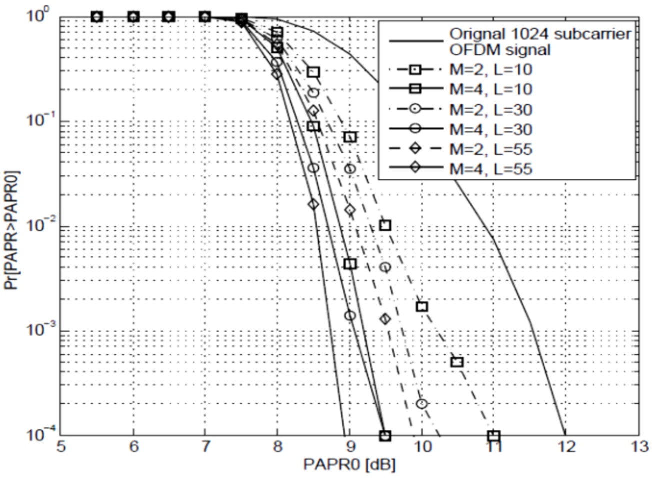

Figure 5. The CCDF of DSI-SLM model with several L, M (N=1024)

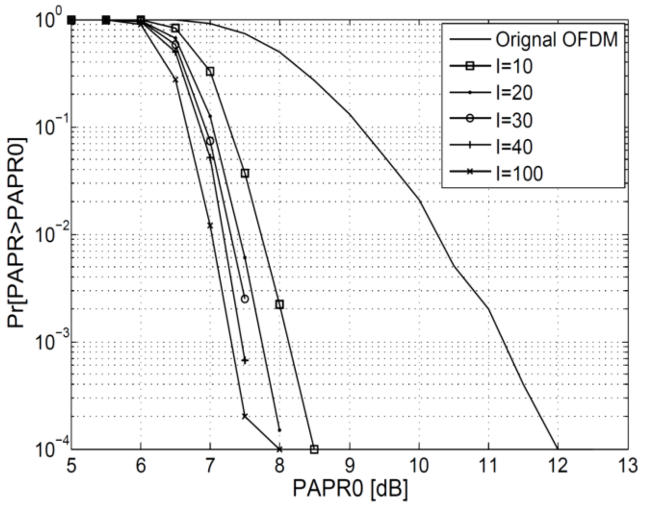

Figure 6. The CCDF of DSI-SLM model for numerous DSI iterations (I)

It is crucial to study the effects on computational complexity and TE by each setting, especially for real time applications. As stated before, once M is increased, more hardware resources are required, and as L is increased, higher signal bandwidth becomes essential. Fig. 5 presents the PAPR reduction performance of DSI-SLM scheme when N=1024, and altered values of M and L applied. When N=1024, the signal with 40 MHZ bandwidth is directly applicable for 4G and 5G technologies. It is observed that the performance is debilitated as the number of subcarriers, N is increased. It is also experienced that the PAPR reduction performance is enhanced through optimizing L and M to 55 and 16, respectively.

The performance is also improved when the DSI loop is repeated more, meaning that iteration (I) is higher. When the DSI feedback loop is repeated for more times, the chance of improving the PAPR is higher. As shown in block diagram of DSISLM, and results in Fig. 4, higher the I is, the PAPR is greater that the threshold more often, then the DSI feedback is activated and the loop is repeated again for more times. As a result, varied dummies are generated and entered to the input signal. Thus, the PAPR candidate signals are tested more times, and newly measured PAPR is more probable to have less PAPR compared with the $PAPR_{th}$. The model simulation outcomes obtainable in Fig. 2, and Fig. 3 are based on I=10, ten iterations of DSI loop is applied. At this point, the DSI-SLM model was simulated with varied number of iterations (I =10, 20, 30, 40, and 100) and fixed M=2 which is evidenced in Fig. 4. According to the accomplished PAPR of 8.5, 8, 7.8, 7.6, and 7.5 dB in Fig. 6, any increase in I improves the PAPR performance considerably.

It is experienced that a trade-off exists between the PAPR performance of the DSI-SLM method and the processing time for simulation. The higher number of iterations leads to higher PAPR performance but the data rate might be degraded. For practical implementations, time consumption and data rate or latency must be analyzed. As shown in Fig. 6, when I = 40 and 100, the number of iterations is increased by more than 2 times, but the PAPR performance is not improved extensively, therefore, based on this analysis less than 50 iterations are advised (I=50).

IV. CONCLUSION

This paper aims the PAPR reduction in the OFDM signal, and its potential for 4G and 5G technologies. The reduction performance of the DSI-SLM scheme was investigated by applying various dummy sequences to the power-free subcarriers by different approaches. The PAPR performance optimization was analyzed, and it was exhibited the potential to reserve BE by inserting the SI index of the mapped signals within the dummy sequences which can be done in future works. Additional consideration for this work would be to test it with different modulation schemes and also the Error Vector Magnitude (EVM) evaluation for diverse settings.

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