Zero-Padding Techniques in OFDM Systems

Yasir Amer Al-Jawhar[1, 3], Khairun Nidzam Ramli[1], Montadar Abas Taher[3], Nor Shahida Mohd Shah[2], Lukman Audah[1], and Mustafa Sami Ahmed[1]

[1]Faculty of Electrical and Electronic Engineering, Universiti Tun Hussein Onn Malaysia, Parit Raja, Batu Pahat, 86400, Johor, Malaysia

[2]Faculty of Engineering Technology, Universiti Tun Hussein Onn Malaysia, Hab Pendidikan Tinggi Pagoh, KM1, Jalan Panchor, 84600 Panchor, Johor, Malaysia

[3]Department of Communications Engineering, College of Engineering, University of Diyala, Ba'aqubah, Diyala, 32001, Iraq. Iraqi ministry of communications, Baghdad, Iraq.

ge160127@siswa.uthm.edu.my, free_cccc@yahoo.com

Abstract: Although the OFDM system has been gaining importance in recent years, the high peak to average power ratio is considered the main limitation of the system. The oversampling operation in the frequency-domain plays an essential role in the PAPR calculations precisely. The main purpose of the paper to draw attention to zero-padding methods which are used to oversampled baseband OFDM signals. Moreover, to study the influence of the zero-padding methods on the accuracy of the PAPR calculations, and the spectral spreading of the OFDM signals. Simulation results show that the zero-padding method which inserts the zeros at the center of the baseband OFDM signal is better than the other zero-padding methods in terms of both accuracy PAPR calculations and spectral distribution.

Keywords:
OFDM, PAPR, PTS, Oversampling, Zero-padding, PSD

1. Introduction

OFDM is considered the promising multiplexing technique for high data rate communication systems. The OFDM system distinguishes many features compared with the other multicarrier systems such as robustness against multipath delay spread [1], high data rate [2], and efficient bandwidth utilization [3]. Therefore, OFDM is widely used in many communication systems,

Received: December 2th, 2017. Accepted: December 15th, 2018
DOI: 10.15676/ijeei.2018.10.4.6

such as Long Term Evolution (LTE) standard which uses the OFDM system for downlink [4], IEEE. 802.16 standard which applies the OFDM system for uplink and downlink [5] and OFDM is also adopted in the Cognitive radio systems [6]. Quite recently, considerable attention has been paid to optimal OFDM releases as reliable waveform candidate in the 5^{th} generation (5G) technology such as Filtered-OFDM (F-OFDM) [7], universal filter-OFDM (U-OFDM) [8], and Filter Bank Multicarrier (FBMC) [9].

Although OFDM has many advantages in the communication environments, the high peak-to-average-power-ratio (PAPR) is considered the main drawback of the OFDM system [10]. The high PAPR runs the amplifiers less efficient and produces intermodulation that interferes with the adjacent channels [11]. To calculate the PAPR value precisely, the baseband signal should be sampled multiple the Nyquist rate (oversampling). This operation is done by inserting a set of zeros within the baseband data sequence to catch some peaks that may be missed without using the oversampling operation [12]. The previous studies indicate that the oversampling operation is an integral part of OFDM system because of its influence on the PAPR calculations precisely and the spectral spreading of the signal. The most interesting study in this issue has been proposed by Tellambura [13], where he evaluated the PAPR performance of the discrete time sequence and continuous time sequence in order to choose the optimal oversampling factor. Also, Tellambura found that oversampling the baseband OFDM signal by four times the Nyquist rate is sufficient to get the PAPR accurately. In [14], the authors showed that oversampling the input data by four is enough for estimating approximately a continuous OFDM signal in the time-domain. Moreover, Qinghua [15] studied the effect of the oversampling factor on the system in terms of the performance and complexity. Muquet in [16] studied the influence of inserting zero-padding instead of the cyclic prefix in the time-domain, he found that the zero-padding operation is better than the cyclic prefix in terms of the complexity level at the expense of increasing the nonlinearity distortions. In a recent paper by Jawhar [17], the author discussed the parameters that affect the PAPR performance, and he indicated that increasing the oversampling factor more than four has a bit influence on the PAPR calculations precisely.

Based on the approaches that presented in the previous studies, the purpose of this paper is to indicate the influence of the zero-padding types on the accurate of the PAPR calculation and the power spectral density (PSD) spreading. Also, five of the zero-padding methods are analyzed in order to determine the best zero-padding method which satisfies the precise of both PAPR calculation and signal spectral spreading. The remainder of the paper is organized as follows: In Section 2 we explain PAPR in OFDM system. In Section 3 we introduce the zero-padding methods. The PAPR reduction technique has been introduced in Section 4. The results and

discussion are presented in Section 5. Section 6 summarizes the results of this work and draws concludes.

2. PAPR in OFDM System

In an OFDM system, the input high-rate symbols are mapped by using one of the modulation techniques such as Phase-shift keying (PSK) or Quadrature amplitude modulation (QAM). After that, the input data sequences are converted from the serial to the parallel pattern. Let $X = [X_0, X_1, X_2, ..., X_{N-1}]^T$ is the baseband complex representation vector, where N is the total number of subcarriers. The baseband signal is sampled by multiple of the Nyquist rate before applying inverse fast Fourier transform (IFFT) to approximate the amplitude of the discrete time signal to the continuous time signal. Therefore, the transmitted signal in the time-domain can be written as [18]

$$x(n) = \frac{1}{\sqrt{NL}} \sum_{k=0}^{NL-1} X_k e^{j2\pi kn/NL} \quad , 0 \le n \le NL-1 \tag{1}$$

where $j = \sqrt{-1}$, and L denotes to oversampling factor. In the time-domain, the OFDM signal is generated by summing multiple sinusoidal functions so that the instantaneous power of some samples may be increased much larger than the average power of the signal and may be up to N times of the average power [19]. Therefore, the ratio between the maximum powers of the signal and its average power is defined as the PAPR value of the signal and can be written as [20]

$$\mathrm{PAPR} = \frac{\max |\mathrm{x(n)}|^2}{\mathrm{E}\{|\mathrm{x(n)}|^2\}} \tag{2}$$

where $E\{.\}$ denotes the expected value. On the other hand, to evaluate the PAPR of transmitted samples, the complementary cumulative distribution function (CCDF) is employed to measure the probability of the PAPR value exceeds a certain threshold value, as shown below [21].

$$\mathrm{P_r}[\mathrm{PAPR(x(n)} \ge \mathrm{PAPR_0}] = 1 - (1 - \mathrm{e}^{-\mathrm{PAPR_0}})^{\mathrm{NL}} \tag{3}$$

where $PAPR_0$ is the threshold value.

3. Zero-Padding Methods

In the OFDM system, the zero-padding operation is implemented on the transmitter side before applying IFFT transformation. The sampling rate is the Nyquist rate or multiple times of the Nyquist rate, this operation named oversampling the baseband data signal in the frequency-

domain. The oversampling factor (L) is equivalent the number of multiple times of the Nyquist rate [14]. In OFDM, the benefit of the oversampling operation can be determined as follows:

1. To approximate the discrete time signal to the continuous time signal.
2. To make the IFFT operation is more density and has more details which are useful graphically.
3. To ensure a symmetrical spectrum of the signal.
4. To make the input data sequence length is closer to N-IFFT length, and the N-IFFT points are a power of two to reduce the computational complexity.
5. To spread the spectrum of the symbols uniformly.

In the OFDM system, the high PAPR value is the main problem of the system, therefore; the PAPR value should be calculated accurately. Because the baseband OFDM signal represents the discrete time signal in the time-domain, some peaks of the signal may be missed, and the PAPR performance will not be accurate. Oversampling the baseband OFDM signal in the time-domain ensures the PAPR calculation to be more precise [22]. Zero-padding is done by inserting (L-1) N zeros within the samples of the baseband OFDM signal in the frequency-domain. The oversampling factor L = 4 is sufficient to catch the peaks of the signals and to ensure the PAPR is calculated precisely [23].

As mentioned earlier, the zero-padding operation is essential to calculate the PAPR value accurately. Moreover, the localization of zeros within the dada symbols also important to spread the spectrum of the signal uniformly [24]. Therefore, five types of the zero-padding methods are utilized to oversample the transmitted OFDM signal, as follows:

A. Zero-padding method-1

In this method, the oversampling of the baseband data symbol is done by inserting (L-1) N zeros between the samples of the baseband OFDM signal. In other words, the zeros insert at the center of the OFDM signal, whereas the data samples will be divided into two parts, each part localizes at the terminals of the signal. Let $X = [X_0, X_1, X_2, ..., X_{N-1}]^T$ is the baseband data vector, and the oversampling factor L= 4. Accordingly, the expanded baseband data vector can be expressed as

$$X_{Z-1} = \left[X_0, X_1, X_2, \dots, X_{\frac{N-1}{2}}, \overbrace{0,0,0,\dots,0,0}^{(L-1)N}, X_{\frac{N-1}{2}+1}, X_{\frac{N-1}{2}+2}, \dots, X_{N-1} \right]^T \quad (4)$$

Mathematically, the input data sequence is $\{X(k)|k = 0,1,2,\ldots,N-1\}$, Let $M = N \times L$, and $M > N$; then the Zero-padding method-1(ZeroPad-1) can be represented as

$$\text{ZeroPad-1}_{M,m}(X) \triangleq \begin{cases} X(m), & 0 \le m \le \frac{N}{2} - 1 \\ 0, & \frac{N}{2} \le m \le (M - \frac{N}{2}) - 1 \\ X(m), & M - \frac{N}{2} \le m \le M - 1 \end{cases} \quad (5)$$

B. Zero-padding method-2

In this method, the zeros are inserted at the extreme ends of the baseband symbol vector, while the data symbol is positioned at the center of the baseband OFDM signal. This type of zero-padding is implemented by adding (L-1) N/2 zeros before the data symbol, and the same quantity of the zeros are added after the data symbol so that the length of the vector equals to ($L \times N$). Let $X = [X_0, X_1, X_2, ..., X_{N-1}]^T$ is the baseband data vector, and the oversampling factor L= 4. Therefore, the baseband data vector after the oversampling operation can be written as

$$X_{Z-2} = \left[\overbrace{0,0,0,\ldots,0,0}^{(L-1)N/2}, X_0, X_1, X_2, \ldots, X_{N-1}, \overbrace{0,0,0,\ldots,0,0}^{(L-1)N/2} \right]^T \quad (6)$$

Mathematically, the Zero-padding method-2 (ZeroPad-2) can be represented as

$$\text{ZeroPad-2}_{M,m}(X) \triangleq \begin{cases} X(m), & \frac{M-N}{2} \le m \le \frac{M+N}{2} - 1 \\ 0, & \text{otherwise} \end{cases} \quad (7)$$

C. Zero-padding method-3

In this method of the zero-padding, the zeros are embedded only at the end of the data symbol, so that the (L-1) N zeros are added after the last data sample within the baseband data vector. Let the oversampling factor L= 4, and $X = [X_0, X_1, X_2, ..., X_{N-1}]^T$ is the baseband data vector. Accordingly, the new baseband data vector can be given as

$$X_{Z-3} = \left[X_0, X_1, X_2, \ldots, X_{N-1}, \overbrace{0,0,0,\ldots,0}^{(L-1)N} \right]^T \quad (8)$$

Mathematically, the Zero-padding method-3 (ZeroPad-3) can be represented as

$$\text{ZeroPad-3}_{M,m}(X) \triangleq \begin{cases} X(m), & 0 \le m \le N - 1 \\ 0, & \text{otherwise} \end{cases} \quad (9)$$

D. Zero-padding method-4

This method is opposite the method 4, where the zeros are embedded only at the first of the data symbol, in which the (L-1) N zeros are added before the first data sample of the baseband OFDM vector. Let $X = [X_0, X_1, X_2, \ldots, X_{N-1}]^T$ represents the baseband data vector, and the oversampling factor L is set to 4. Hence, the expanded baseband data vector can be set as

$$X_{Z-4} = \left[\overbrace{0,0,0,\ldots,0}^{(L-1)N}, X_0, X_1, X_2, \ldots, X_{N-1}\right]^T \tag{10}$$

Mathematically, the Zero-padding method-4 (ZeroPad-4) can be represented as

$$\text{ZeroPad-4}_{M,m}(X) \triangleq \begin{cases} X(m), & M - N \le m \le M - 1 \\ 0, & \text{otherwise} \end{cases} \tag{11}$$

E. Zero-padding method-5

This method also named up-sampling operation, and it is performed by inserting (L-1) zeros between every two samples within the baseband data vector so that the zeros stuff between the data samples uniformly. Let the oversampling factor L= 4, and the baseband data vector is $X = [X_0, X_1, X_2, \ldots, X_{N-1}]^T$. Therefore, the oversampled baseband data vector can be written as

$$X_{Z-5} = \left[X_0, \overbrace{0,0,0}^{(L-1)}, X_1, \overbrace{0,0,0}^{(L-1)}, X_2, \overbrace{0,0,0}^{(L-1)}, \ldots, X_{N-1}, \overbrace{0,0,0}^{(L-1)}\right]^T \tag{12}$$

Mathematically, the Zero-padding method-4 (ZeroPad-4) can be represented as

$$\text{ZeroPad-5}_{M,m}(X) \triangleq \begin{cases} X(m), & m = kL, 0 \le k \le N - 1 \\ 0, & \text{otherwise} \end{cases} \tag{13}$$

4. PAPR reduction techniques

In the OFDM systems, several PAPR reduction techniques have been proposed to tackle the high PAPR value such as partial transmit sequence (PTS) [25], selective mapping (SLM) [26], and the interleaving method [27]. Among the PAPR reduction techniques, PTS is one of the non-distortion methods that effectively reduces the PAPR issue without adding any distortion in the OFDM signal [28]. The PTS technique depends on dividing the input data signal by one of the

partitioning schemes into several subblocks, transformation these subblocks by utilizing IFFT, and rotation the transformed subblocks by a set of phase factors before combining them again.

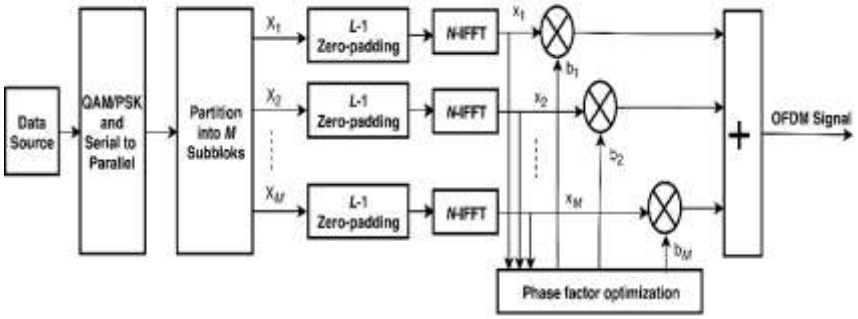

Figure 1. PTS block diagram

Figure.1 illustrates the OFDM system based on the PTS technique. In this system, the input data sequence, *X*, is divided into *M* subblocks,

$$X = \sum_{m=1}^{M} X_m. \tag{14}$$

After that, the subblocks are oversampled by inserting zeros between the samples of each subblock, and then the oversampled subblocks are converted from the frequency-domain to the time-domain by applying IFFT operation. Therefore, the discrete baseband signal in the time domain can be given by

$$x(n) = \sum_{m=1}^{M} \text{IFFT}\{X_v\} = \sum_{m=1}^{M} x_m. \tag{15}$$

The transformed subblocks are rotated by a set of the phase factors $b = [b_1, b_2, \ldots, b_M]$, and the elements of rotation phase factor can be selected within $(0, 2\pi)$; therefore, the phase rotation vector is generated by [29]

$$b_m = e^{j2\pi m/A}, \quad \{m = 0,1,.....,A-1\} \tag{16}$$

where b_m is the phase factor of *m*th subblock, $j2\pi m/A$ is the angle of phase rotation factor, and *A* is the number of the allowed phase factors, which is usually constricted by {±1} or {±1, ±j} to avoid the complicated multiplication operations. Each subblock in the time-domain is rotated by the phase factor vectors, and then the weighted subblocks are combined to produce a set of candidates. Last but not least, the PAPR value of each candidate is calculated, and the phase rotation factor that achieves the lower PAPR value is elected to rotate the combined subblocks to generate the OFDM signal that will transmit to the receiver,

$$x'(n) = \sum_{m=1}^{M} b_m x_m \ . \tag{17}$$

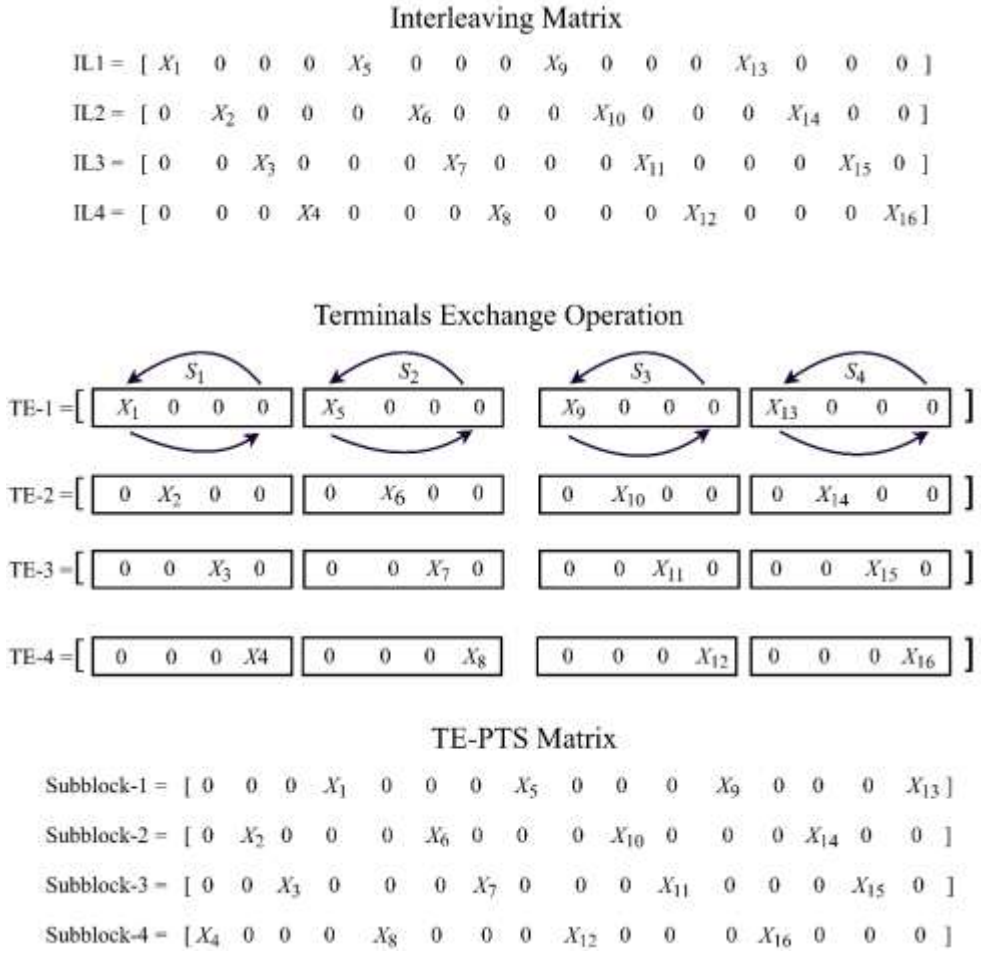

Figure 2. TE-PTS scheme when N= 16 and M= 4

The purpose of the phase rotation factors is to equilibrium the directions for combining signals to reduce the PAPR value of the OFDM signal; with the consideration that the index of the optimum phase factor should be sent to the receiver as side information (SI) to ensure recovering the data [30].

On the other hand, there are three common kinds of the subblock partitioning schemes have been adopted; pseudo-random scheme (PR-PTS), adjacent scheme (AD-PTS), and interleaving scheme (IL-PTS) [25]. All the subblocks dividing schemes have their own PAPR reduction performance different to others depending on distributing the data within the subblocks. In PR-PTS, the subcarriers are assigned randomly in the subblocks, while the AD-PTS scheme allocates

N/*M* successive subcarriers inside each subblock, sequentially. However, the IL-PTS scheme assigns *N*/*M* subcarriers with a specific distance interval of *M* within each subblock.

In [31], we proposed a new dividing scheme named terminal exchanging segmentation (TE-PTS) scheme in order to improve the PAPR reduction performance better than that of the IL-PTS scheme. The proposed algorithm depends on subdividing the IL-PTS scheme into subsets and exchanging terminal samples of each subset with each other, as shown in Figure.2 [31]. The TE-PTS method will utilize to evaluate the PAPR performance with and without using zero-padding operation.

5. Results and Discussion

In this section, the PAPR performance and the PSD shape of the OFDM system are evaluated and simulated with various zero-padding methods. The parameters for the simulation are: the number of the subcarriers N is chosen 128, and the oversampling factor L is set from 1 to 10, while the number of subblocks is 4, and $W = 4$. Moreover, 16-QAM is employed as a modulation technique, and 1000 symbols are evaluated by using CCDF function.

Firstly, the discrete time PAPR (without zero-padding) and continuous time PAPR (with various zero-padding methods) are evaluated for a set of oversampling factors 1, 2, 4, and 10. Figure.3 shows the PAPR performance of the OFDM signal when applying zero-padding method-1. It is clear that the PAPR value when $L = 1$(without zero-padding) is lower than the PAPR value when $L > 1$, where the PAPR value was 10.18dB for $L = 1$, 10.58dB for $L = 2$, 10.91dB for $L = 4$, 11.08dB for $L = 10$. The results show that PAPR value increases when the oversampling factor is increased, and the PAPR performance has a small effect when $L > 4$. A similar approach can be found when applying zero-padding method-2, 3, and 4 as the oversampling operation on the baseband symbols. The differences in the PAPR value when setting $L = 1$ and $L = 4$ are 0.9dB, 0.6dB, and 0.7dB, as can be seen from Figure.4, Figure.5, and Figure.6, respectively. Therefore, the zero-padding methods work to approximate the discrete time PAPR like the continuous time PAPR; thus the PAPR calculations can be calculated more precise when $L \geq 4$.

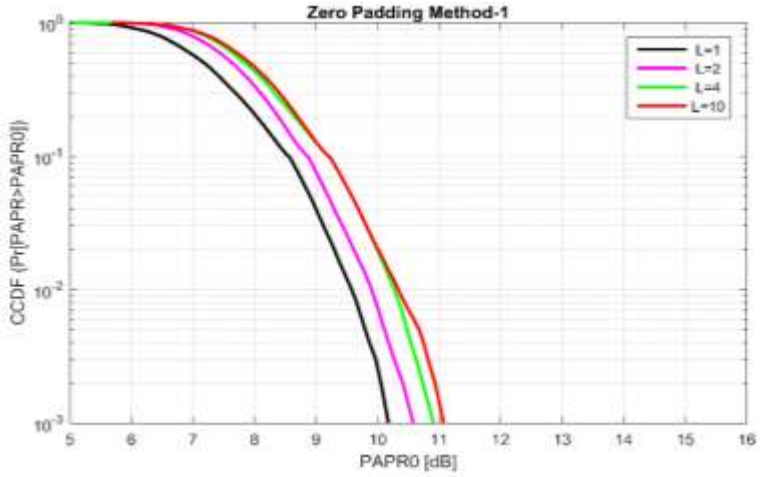

Figure 3. Zero-padding method-1 with various number of the oversampling factor

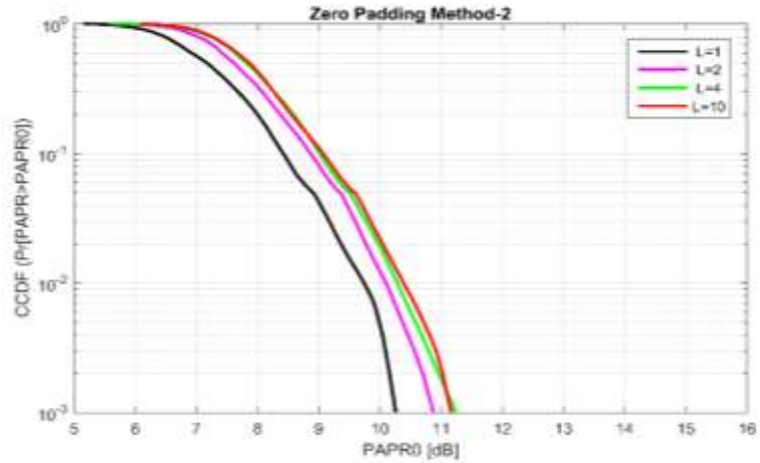

Figure 4. Zero-padding method-2 with various number of the oversampling factor

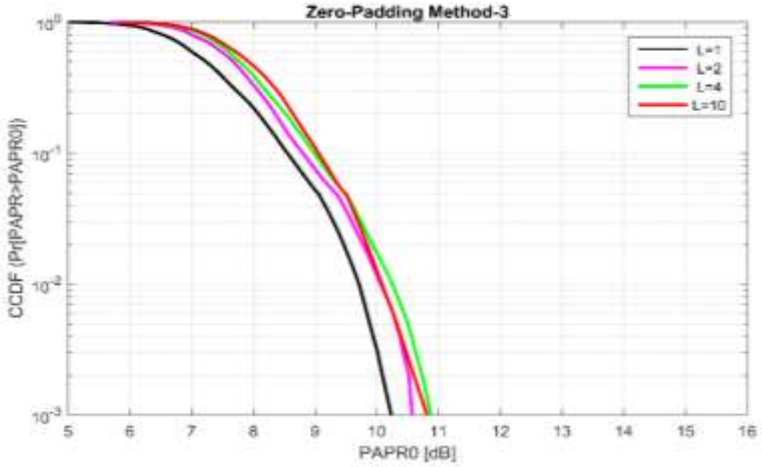

Figure 5. Zero-padding method-3 with various number of the oversampling factor

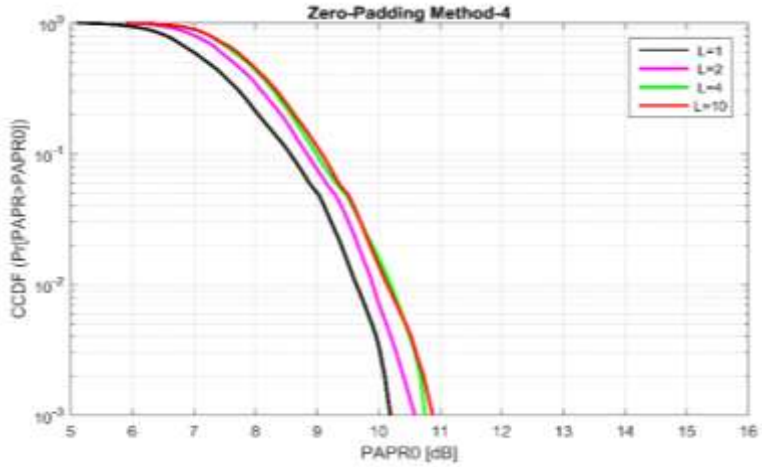

Figure 6. Zero-padding method-4 with various number of the oversampling factor

Secondly, Figure.7 depicts the PAPR performance of OFDM signal when applying zero-padding method-5, in which the (L-1) zeros are embedded between every two samples of the baseband data vector. It can be seen that the PAPR value was 10.36dB regardless number of the oversampling factor. This approach is due to the zero-padding method maintains the discrete property of the baseband signal in the time-domain, so as some peaks of the OFDM signal are

missed, and the PAPR calculations become less accurate. Accordingly, the PAPR performance when applying zero-padding method-5 has a similar approach for any number of the oversampling factor.

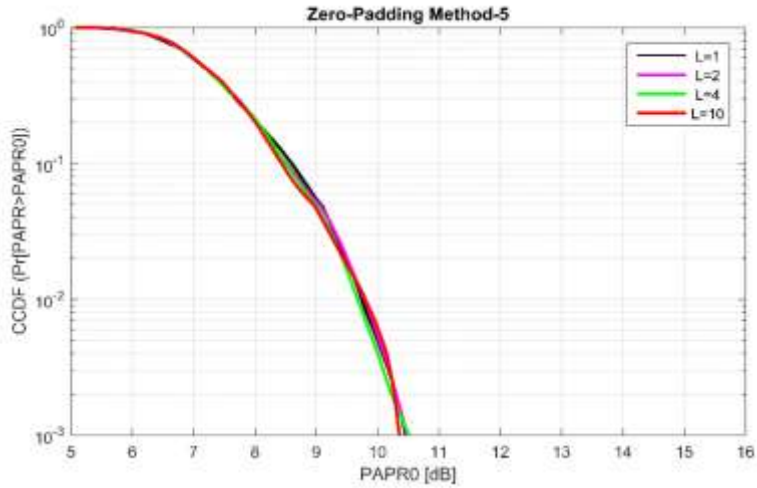

Figure 7. Zero-padding method-5 with various number of the oversampling factor

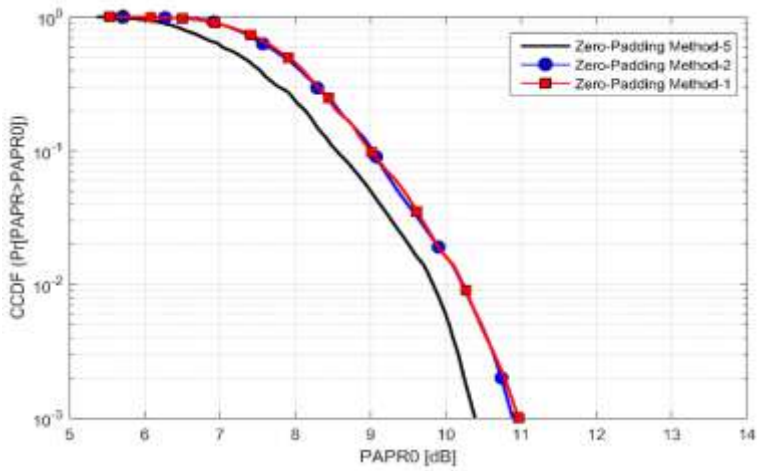

Figure 8. Comparison the Zero-padding methods-1, 2, and 5 when $L = 4$

Thirdly, the PAPR performance of zero-padding method-1 and method-2 are compared with zero-padding method-5, when $L = 4$, as shown in Figure.8. The results indicate that the methods which insert the zeros at the center or the terminal ends of the baseband data sequence appear the same PAPR performance, whereas the up-sampling method follows the discrete time PAPR

(without oversampling) approach. Similarly, Figure.9 illustrates the comparison of the zero-padding method-3, method-4, and discrete time PAPR (without zero-padding). The result mentions a similar approach of the zero-padding methods regarding of the PAPR performance.

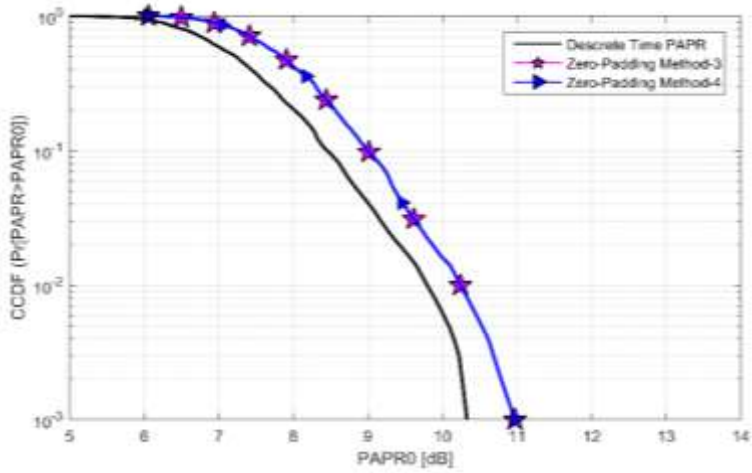

Figure 9. Comparison the Zero-padding methods-3, 4, and the discrete time PAPR when $L = 4$

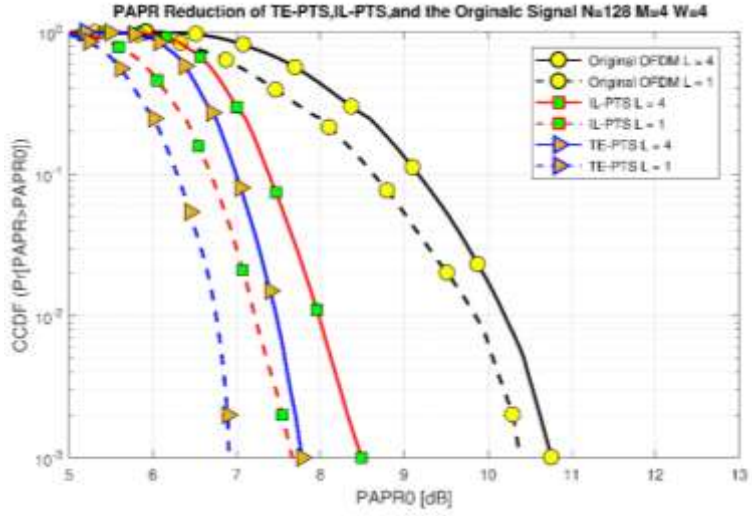

Figure 10. Comparison of the PAPR reduction performance of TE-PTS, IL-PTS, and the original OFDM signal when $L = 1$ and $L = 4$.

Lastly, Figure 10 illustrates the comparison between the oversampled signal and the non-oversampled signal for TE-PTS, IL-PTS, and the original OFDM signal in terms of the PAPR reduction performance. The comparison was conducted when N = 128, W = 4, and M = 4, whereas the zero-padding method-1 is adopted with oversampling factor L = 4. It is clear that the TE-PTS scheme is better than the IL-PTS and the original OFDM signal by 0.72dB and 3dB, respectively. Moreover, the differences between the oversampled signal and the non-oversampled signal are 0.87dB for TE-PTS, 0.83dB for IL-PTS, and 0.37dB for the original OFDM signal. The reason behind that is the oversampling operation leads to catching some peaks of the signal in the time-domain that may be missed without using the oversampling operation.

On the other hand, the PSD shape of the OFDM signal for the various zero-padding methods is simulated. Figure 11 illustrates the PSD plot of the OFDM signal when using zero-padding method-1, in which the spectral range of the OFDM signal is centered in the middle of the frequency band. As shown in Figure 12, the PSD plot of the zero-padding method-2 indicates that the spectral range of the signal is shifted from the center by 0.5MHz, and still symmetric. Moreover, as can be seen from Figure 13 and Figure 14, the spectral waveform of the signal when utilizing zero-padding methods 3, and 4 are shifted by 0.25MHz depending on the location of zeros within the baseband data sequence. In addition, the PSD simulation is conducted of the discrete OFDM signal (without oversampling) and the OFDM signal when using zero-padding method-5, as illustrated in Figure 15, and Figure 16. As is evident, the spectral range of both figures distributed as a non-symmetrically form; with the consideration that the zero-padding method-5 works to increase the signal representation because of the oversampling influence.

Figure 11. PSD of the OFDM signal when using zero-padding method-1

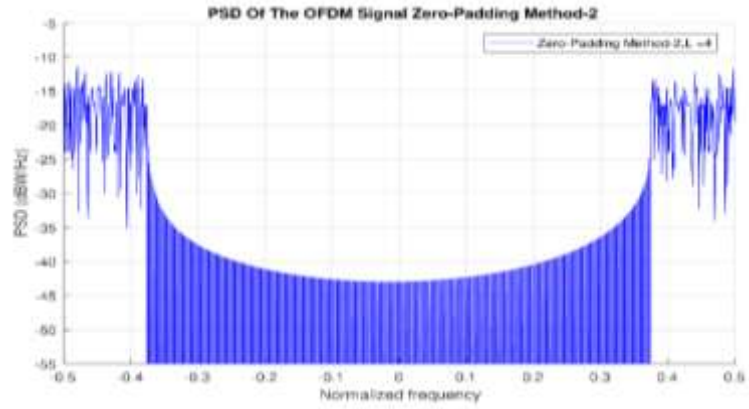

Figure 12. PSD of the OFDM signal when using zero-padding method-2

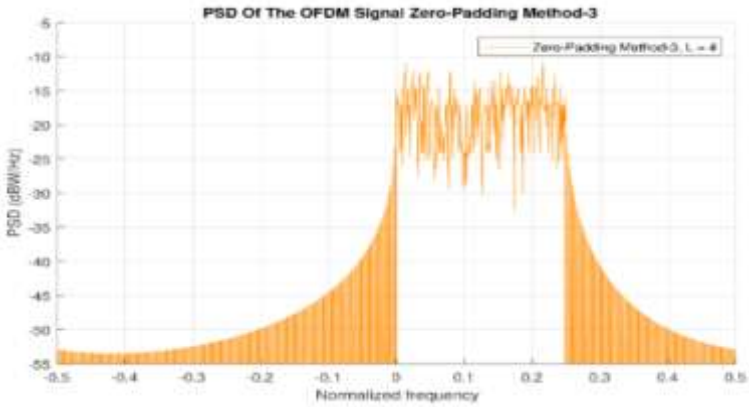

Figure 13. PSD of the OFDM signal when using zero-padding method-3

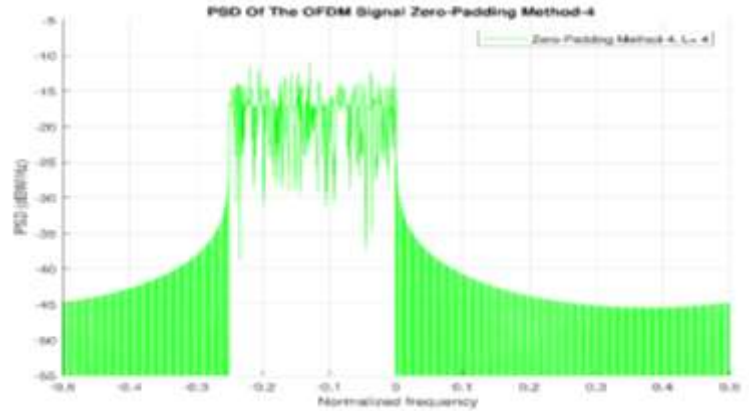

Figure 14. PSD of the OFDM signal when using zero-padding method-4

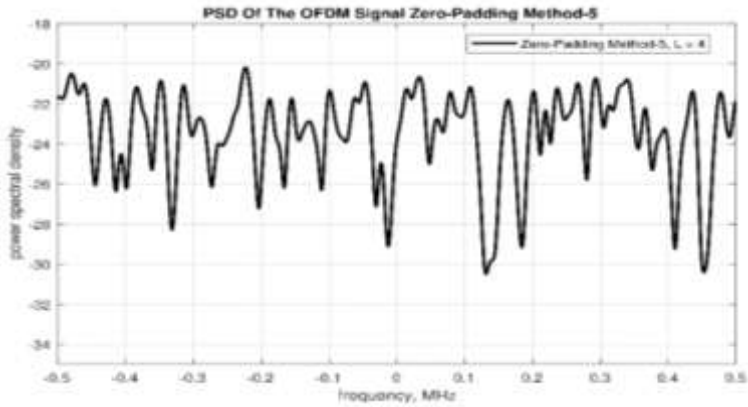

Figure 15. PSD of the OFDM signal when using zero-padding method-5

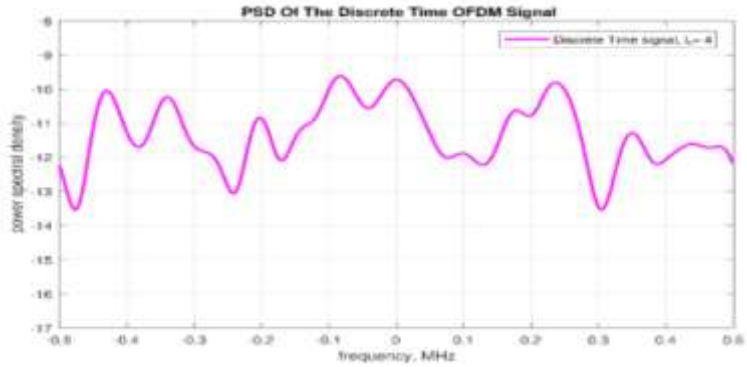

Figure 16. PSD of the discrete OFDM signal (without oversampling)

It was the main purpose of the paper to draw attention to the types of zero-padding which make up the oversampling operation of the baseband OFDM sequences in the frequency-domain and to study the effect of these methods in terms of the PAPR performance and the spectral waveform distribution. The oversampling factor of the baseband OFDM signal influences on the PAPR calculations, where increasing the oversampling factor leads to increasing the accuracy of PAPR calculations. Moreover, the results appear that the difference between the oversampled OFDM signal and non-oversampled OFDM signal is about 1dB. Besides, a comparison between TE-PTS, IL-PTS, and the original OFDM signal with and without oversampling operation is conducted. On the other hand, the PSD shape of the five types of zero-padding signals and the discrete OFDM signal are simulated when the oversampling factor is set to four. The results that obtained indicate the zero-padding method -1 localizes the spectral waveform at the middle of

the frequency band, while zero-padding methods 2, 3, and 4 lead to the frequency offsets depending on the position of zeros within the baseband data sequence. However, the up-sampling method and the original OFDM signal have the same PAPR performance, and non-symmetrical representation, because these signals have discrete property after applying the IFFT operation. Hence, some peaks of the discrete time PAPR may be missed, and thus its PAPR performance appears less than that of the continuous time PAPR. An important implication of these findings is that the zero-padding method-1 when the zeros are inserted at the center of the baseband OFDM symbol, which is the best method among the zero-padding methods. However, the main limitation of the oversampling operation is the increment of the system computational complexity, especially when the number of oversampling factor is increased.

6. Conclusion

From the research that has been conducted, it is possible to conclude that the oversampling operation of the baseband OFDM signal is useful for PAPR calculations accuracy, and spreading the spectrum of the symbols uniformly. This paper discussed five zero-padding methods for oversampling the baseband OFDM signal concerning the PAPR performance and the spectral distribution. The results refer that the zero-padding method-1 considers the best type oversampling operation because it can achieve both PAPR calculations precisely, and perfect spectral spreading. Moreover, inserting a set of zeros in the middle of the baseband OFDM signal by three times the Nyquist rate is sufficient to calculate the PAPR value precisely, and to spread the spectral range of the signal uniformly. Future work will involve the methods for reducing the complexity of the oversampling operation.

7. References

[1]. Varahram P, Ali B, Mohammady S, and Reza R., "Prototype of a Peak to Average Power Ratio Reduction Scheme in Orthogonal Frequency Division Multiplexing Systems," *KSII Transactions on Internet and Information Systems*. vol. 9, no. 6, pp. 2201-2216, 2015.

[2]. Rahmatallah Y, and Mohan S., "Peak-to-average power ratio reduction in OFDM systems: A survey and taxonomy, " *IEEE communications surveys & tutorials*. vol. 15, no. 4, pp. 1567-1592, 2013.

[3]. Jawhar Y, Shah S, Taher M, Ahmed M, Ramli K, and Abdulhasan R., "A low PAPR Performance with New Segmentation Schemes of Partial Transmit Sequence for OFDM

Systems, " *IJAAS International Journal of Advanced and Applied Sciences*, vol. 4, no. 4, pp. 14-21. 2017.

[4]. Taher M, Mandeep J, Ismail M, Samad S, and Islam M, "Reducing the power envelope fluctuation of OFDM systems using side information supported amplitude clipping approach," *International Journal of Circuit Theory and Applications*. vol. 42, no 4, pp. 425-435, 2014.

[5]. Yi W, and Leib H., "OFDM Symbol Detection Integrated with Channel Multipath Gains Estimation for Doubly-Selective Fading Channels," *Physical communication*, vol. 22, pp. 19-31, 2017.

[6]. Suyoto, Sugihartono, Iskandar, and Kurniawan, "Robust Timing Estimation for High Data Rate Mobile OFDM Systems," *International Journal on Electrical Engineering & Informatics*, vol. 9, no. 3, pp. 553-566, 2017.

[7]. Abdoli M, and Ma J., "Filtered OFDM: A new waveform for future wireless systems, " *2015 IEEE 16th International Workshop on Signal Processing Advances in Wireless Communications SPAWC*, 2015, pp. 66-70.

[8]. Liu Y, Chen X, Ai B, Zhong Z, Miao D, Zhao Z, Sun J, Twng Y, and Guan H., "Waveform Design for 5G Networks: Analysis and Comparison, " *IEEE Access*, vol. 99, pp. 1-9, 2017.

[9]. Farhan-gboroujeny B., "OFDM versus filter bank multicarrier," *IEEE signal processing magazine*, vol. 28, pp. 92-112, 2011.

[10]. Sundararajan M, Govindaswamy U., "Multicarrier Spread Spectrum Modulation Schemes and Efficient FFT Algorithms for Cognitive Radio Systems," *Electronics*, vol. 3, no. 3, pp. 419-443, 2014.

[11]. Wu X, Wang J, Mao Z, Zhang J., "Conjugate interleaved partitioning PTS scheme for PAPR reduction of OFDM signals," *Circuits, Systems and Signal Processing*, vol. 29, no. 3, pp. 499-51, 2011.

[12]. Jawhar Y, Shah S, Taher M, Ahmed M, and Ramli K., "An Enhanced Partial Transmit Sequence Segmentation Schemes to Reduce the PAPR in OFDM Systems," *International Journal of Advanced Computer Science and Applications (IJACSA)*. vol. 7, no. 12, pp. 66-75, 2016.

[13]. Tellambura C., "Computation of the continuous-time PAR of an OFDM signal with BPSK subcarriers," *IEEE Communications Letters*, vol. 5, no. 5, pp. 185-187, 2001.

[14]. Woo Y., "Analysis of Oversampling Effect on Selected Mapping Scheme Using CORR Metric," *IEICE Transactions on Communications*, vol. 99, no. 2, pp. 364-369, 2016.

[15]. Shi Q. and Y. Karasawa., "Frequency-domain oversampling for OFDM systems: exploiting inter-carrier interference and multipath diversity," *9th IEEE International Symposium on Communications and Information Technology ISCIT 2009*, 2009, pp. 1097-1101.

[16]. Muquet B, Zhengdao W, Giannakis G, Courville M, and Duhamel P., "Cyclic prefixing or zero padding for wireless multicarrier transmissions," *IEEE Transactions on Communications*, vol. 50, no. 12, pp. 2136-2148, 2002.

[17]. Jawhar Y, Abdulhasan R, Ramli K, "Influencing Parameters in Peak to Average Power Ratio Performance on Orthogonal Frequency-Division Multiplexing System," *ARPN Journal of Engineering and Applied Sciences*, vol. 11, no. 6, pp. 4322-4332, 2016.

[18]. Kim K, "On the Shift Value Set of Cyclic Shifted Sequences for PAPR Reduction in OFDM Systems," *IEEE Transactions on Broadcasting*, vol. 62, no. 2, pp. 496-500, 2016.

[19]. Sudha V. and Kumar D, "Peak-to-Average Power Ratio Reduction of OFDM Signals by Applying Low Complexity SLM and Clipping Hybrid Scheme," *International Journal on Electrical Engineering and Informatics*, vol. 6, no. 2, pp. 394-403, 2014.

[20]. Mhatre K, and Khot U, "Efficient Selective Mapping PAPR Reduction Technique," *International Conference on Advanced Computing Technologies and Applications ICACTA*, vol. 45, 2015, pp. 620-627.

[21]. Lee K, Cho Y, Woo J, No J, Shin D, "Low-complexity PTS schemes using OFDM signal rotation and pre-exclusion of phase rotating vectors," *IET Communications*, vol. 10, no. 5, pp. 540-547, 2016.

[22]. Elshirkasi A, Siddiqi M, and Habaebi M, "Generalized Discrete Fourier Transform Based Improvement of Partial Transmit Sequence Scheme to Reduce PAPR in OFDM Systems," *Journal of Theoretical & Applied Information Technology*, vol. 76 no. 1, pp.76-81, 2015.

[23]. Hussain M., "Low Complexity Partial SLM Technique for PAPR Reduction in OFDM Transmitters," *International Journal on Electrical Engineering and Informatics*, vol. 5, no. 1, pp. 1-11, 2013.

[24]. Manton H, "An OFDM interpretation of zero padded block transmissions," *Systems & Control Letters*, vol. 47, no 5, pp. 393-399, 2002.

[25]. Jawhar Y, Abdulhasan R, and Ramli K., "A New Hybrid Sub-Block Partition Scheme of PTS Technique for Reduction PAPR Performance in OFDM System," *ARPN Journal of Engineering and Applied Sciences*, vol. 11, no 6, pp. 3904-3910, 2016.

[26]. Taher. M, Singh J, Ismail M, Samad S, Islam M and Mahdi H., "Post-IFFT-Modified Selected Mapping to Reduce the PAPR of an OFDM System," *Circuits, Systems, and Signal Processing*, vol. 34, pp. 535-555, 2015.

[27]. Han S, and Lee J., "An overview of peak-to-average power ratio reduction techniques for multicarrier transmission," *IEEE Wireless Communications*, vol.12, pp. 56-65. 2005.

[28]. Varahram P, and Ali B., "A low complexity partial transmit sequence for peak to average power ratio reduction in OFDM systems," *Radioengineering*. vol. 20, pp. 677-682, 2011.

[29]. Ibraheem Z, Rahman M, Yaakob N, Razalli M, Dawood S, and Ahmed K., "Performance Comparison of Partitioning PTS Based PAPR Reduction of OFDM Systems Under Different Modulations Techniques," *Journal of Theoretical and Applied Information Technology*, vol. 66, 775-781, 2014.

[30]. Jiang T, Xiang W, Richardson C, Guo, J, and Zhu G., "PAPR reduction of OFDM signals using partial transmit sequences with low computational complexity," *IEEE Transactions on Broadcasting*, vol. 53, pp. 719-724, 2007.

[31]. Al-Jawhar Y, Ramli K, Mustafa S. Abdulhasan R, Farhood H, and Alwan M., "A New Partitioning Scheme for PTS Technique to Improve the PAPR Performance in OFDM Systems," *International Journal of Engineering and Technology Innovation*, vol. 8, no 3, pp. 217-227, 2018.

Yasir Amer Jawhar received his bachelor's degree from the department of Electrical Engineering, College of Engineering at University of AL-Mustansiriya Baghdad, Iraq in 1998. He received his M.S. degree from Faculty of Electrical and Electronic Engineering, University Tun Hussein Onn Malaysia in 2015. He is currently working toward his Ph.D. degree at Faculty of Electrical and Electronic Engineering, University Tun Hussein Onn Malaysia. His research interests mainly focus on signal processing in communication, OFDM, PAPR reduction in Multicarrier system, 5G waveform design, and wireless network.

Khairun Nidzam Ramli is a Senior Lecturer of Faculty of Electrical and Electronic Engineering at Universiti Tun Hussein Onn Malaysia (UTHM), Johor, Malaysia. He obtained his BEng in Electronic Engineering from the University of Manchester Institute of Science and Technology (UMIST), United Kingdom, in 1997, and the MEng at the Universiti Kebangsaan Malaysia (UKM), Malaysia, in 2004. He worked within the antennas and applied electromagnetic research group at University of Bradford, United Kingdom since 2007, on a number of projects, concentrating on antenna design and computational electromagnetics. Later, he obtained his PhD for research in electromagnetic analysis using hybrid computational techniques from the University of Bradford in 2011. His typical academic interests include wireless technologies, antennas, electromagnetics, and engineering computing. He is a member of the IEEE.

Montadar Abas Taher received the B.Sc degree in Electronics and Communications Engineering from Al-Nahrain University, Iraq, in 2000. He received the M.Sc degree in Satellite Engineering from Al-Nahrain University, Iraq, in 2003, and the PhD degree in 2015. He is a lecturer in University of Diyala, Iraq (2010). Currently is the Head of Department of Communications Engineering (University of Diyala). He is a reviewer for some international journals. His main research interests are OFDM, CDMA, MC-CDMA, PAPR reduction in Multicarrier system, and DSP for telecommunication.

Nor Shahida Mohd Shah received her B.Eng. from Tokyo Institute of Technology, Master with Distinction from University of Malaya, and PhD from Osaka University in year 2000, 2003, and 2012, respectively. In 2004, she joined University Tun Hussein Onn Malaysia until now. Her research interests include optical fiber devices, optical communication, nonlinear optics, optical signal processing, antenna and propagation, and wireless communication.

Lukman Audah was born in Kuala Lumpur, Malaysia. He received Bachelor of Engineering (Telecommunications) from Universiti Teknologi Malaysia in 2005. He then received his MSc. in Communication Networks and Software from University of Surrey, United Kingdom. He also received PhD in Electronic Engineering from University of Surrey. He is currently a lecturer in the Communication Engineering Department, Universiti Tun Hussein Onn Malaysia. His research interests are wireless and mobile communications, Internet traffic engineering, network system management, data security and satellite communications.

Mustafa Sami Ahmed received the Bachelor Degree in computer communication engineering from AL-Rafidain University College in 2011, and the M.Sc. Electrical engineering in the field of communication engineering by University Tun Hussein Onn Malaysia in 2015. Now, he is currently working toward his Ph.D. degree at the same University of master degree. His research interests are in the area of digital signal processing and wireless communication.