Enhancing the Performance of OFDM Systems-Based PAPR Reduction

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***Abstract*—**In this work a comparison has been made among different proposed algorithms in order to improve the performance of a power consumption wireless network. They are used to combat one of the Orthogonal Frequency Division Multiplexing (OFDM) technique drawbacks, which are considered as a key technique in enhancing the new era of wireless systems' quality of service (QoS).

Therefore, three different propositions have been investigated and covered by this work and classified as; linear coding based, wavelet transformation based, PWM based. Furthermore, a MATLAB program has been run to check their performance and covers two different criteria; the curves of CCDF and the SER curves. This is in order to reduce the Peak-to-Average Power Ratio (PAPR) effect.

***Keywords*—**OFDM, PAPR, Linear Coding, Wavelet, PWM.

I. Introduction

In this work, a wireless sensor and actuator network (WSAN) has been built in order to monitor the energy consumption and to give a management solutions for this purpose. Thus, this will support the transitions to environmentally friendly building sectors to be able to manage and control their energy consumption. Therefore, a solution of energy consumption model is built; Energy Consumption Efficiency Management (ECEM) [1].

Furthermore, those energy signals will be multiplexed and sent through a wireless network-based on Orthogonal Frequency Division Multiplex (OFDM) technique. The OFDM technique is chosen due to its powerfulness in enhancing the wireless systems Quality of Services (QoS). It is found in the literature, that it can enhance the performance and can support the reliability of the new generations' wireless systems [2].

In [2-6], the researchers were turned their interest toward using and proposing the OFDM technique in order to support the huge demand of the high data-rate (+100Mbps) in the downlink of the new era wireless systems. Then, the capacity of such systems will be restrained and relieved. This is due to the consideration of being a multicarrier technique and the ease of generation making use of the fast Fourier transformation (FFT) and its inverse. Therefore, not only the inter-symbol-interference channel impairment is combatted but also the frequency selective drawback; which is attained by imposing the cyclic prefixes (CP) before the transmission. This is in addition the use of FFT will give the highest spectral efficiency, because it is flexible for the impulse noise and multipath impairments. The CP will increase the delay spread of the channel which will combat the channel drawbacks.

One of the major drawbacks is arises due to the coherence addition process in order to complete the FFT transformation; namely peak-to-average power ratio (PAPR). This will lead to the envelope fluctuation instability and to limit the usage of the nonlinear devices in such systems. Therefore and in order to reduce the effect of this drawback, the dynamic range of such devices should be improved. As a consequence, the system complexity will be increased due to the behaviour of the complex Gaussian process instead of the Raleigh power distribution. Therefore, many different techniques that have been found in the literature and divided into either distortion or distortion less techniques [7,8].

This work will give a comparison between our previously published work that could be found in [9,10] with the founded work in the literature. Moreover, it shows the performance improvement by overcoming the complexity found in the literature. PAPR could be defined in the literature as:

PAPR=

$$\left[\left[10\log_{10}\left\{\frac{P_{peak}}{P_{avg}}\right\}=10\log\left\{\frac{\left|\frac{1}{\sqrt{N}}\sum_{n=0}^{N-1}X_n e^{j2\pi f_0 n t}\right|^2}{\frac{1}{NT}\int_0^{NT}\left|\frac{1}{\sqrt{N}}\sum_{n=0}^{N-1}X_n e^{j2\pi f_0 n t}\right|^2 dt=\frac{1}{T}\int_0^{T}\left(\sum_{v=0}^{N-1}c_v^2\right)dt}\right\}\right]\right] \quad (1)$$

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where, P_{peak} is the maximum power of an OFDM symbol, P_{avg} is the average power, X_n is the modulated data of the n-th OFDM symbol, T is the period of the OFDM symbol, c_v is the magnitude of the modulated data, and the nominal subcarrier frequency is denoted by f_0. In (1), X_n plays a vital role in order to determine the value of the average power that is found in the OFDM signal. Thus, finding P_{avg} will help in controlling the dynamic range of the nonlinear devices. This value will be related to the size of the IFFT, N, and depending on the used modulation technique [2]. This value will equal to N when using the binary phase shift keying and then the found PAPR equals to $\log_{10}\left(P_{avg}\right)^{10}$.

These results were the start of our published work in [9]. The second proposition that will be involved with the comparison in the work in [11], which is based on replacing the FFT with the wavelet packet transform (WPT). This is clearly based on the definition that the wavelet packets are considered as a general form of the FFT. Therefore and in order to change the fundamental principle of the FFT, both of its even parts and odd ones are replaced. Moreover and to impose the WPT instead of FFT, special filters should be used, such as the Quadrature Mirror Filters (QMF), to localize the basis in both time and frequency domains. These filters should be defined in a suitable length L in order to define the sequence of wavlet packets; basis function in another meaning. These packets should satisfy the orthogonality issues to be used in calculating the discrete version [2,12,13]. Finally, a new proposition based on using the pulse width modulation (PWM) process has been imposed. This proposition is trying to work over the envelope fluctuation and to keep it within the nonlinear devices dynamic range. Due to its representation, it is considered as base for controlling the power electronics [14]. Furthermore, this representation could be attained either using the direct digital generation or the uniformly sampled PWM, which is chosen to be used in this work with a triangle carrier signal in order to reduce the dominant higher frequency [14,15]. Figure 1 depicts the generation of the PWM with the triangle carrier.

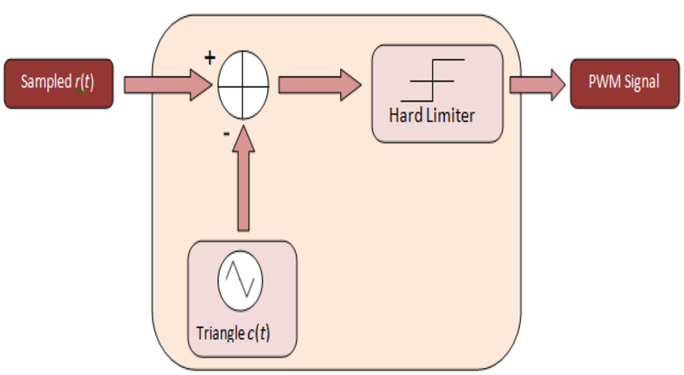

Figure 1. PWM generation block based on the uniformly sampled technique

In this work, the performance of the previously proposed techniques for combatting the PAPR effect will be checked. Two main criteria are involved in this comparison; reducing the PAPR ratio problem and defining the meaning of BER.

As mentioned previously, the PAPR combating will be compared based on the previous mentioned three categories. Moreover, it is known that the BER will be defined by defining the relationship bet error probabilities with the signal to interference ratio (SINR) as found in (2) [16].

$$BER_{SINR} = BER_{WGN}\left[-\lambda ln\left(\frac{\sum_{q=1}^{Q}\sum_{n=1}^{N} e^{\left(-\frac{\left(E\left(|s_o|^2\right)/E\left(|s_1|^2\right)\right)}{\lambda}\right)}}{NQ}\right)\right] \quad (2)$$

where s_0 is the useful information, s_1 is the interference signals, n is the n-th subcarrier; $n \in [1, N]$, λ is a unique parameter based on the system level simulation, Q is the set of symbols that will be transmitted through certain number of antennas.

The rest organization of this work is as follows: the introduced structure of the OFDM system – based our work models are defined in Section 2, the numerical and simulation results are presented in Section 3, while the last section summarizes the conclusion.

II. The ECEM work based OFDM systems

The WSAN that is used in the ECEM project consist of large number of small sensor nodes distributed over the 800th floor of the engineering faculty buildings in Philadelphia University. The goal behind this network is about a collaborative monitoring of the electrical active power loads such as appliances and aggregate devices. Moreover, environmental parameters such as temperature, humidity, light intensity, .. etc can be monitored in order to enhance obtaining the desired efficient power consumption plan. In such applications, novel and advanced communication techniques and distributed monitoring and control algorithms are needed, in order to establish robust and optimized system operation with minimal usage of resources. To achieve these goals, WSANs are faced with numerous research challenges and development of new algorithms and techniques that support data-driven self-configuration and self-optimization. This introduces the concept of SWSANs, encompassing the WSAN application framework in which a large amount of acquired data is used within an intelligent distributed data processing and control subsystem that ensures the desired overall system behavior [2].

In order to manage the gathered data for the analysis stage, the OFDM technique has been imposed to reduce the system complexity and to well manage the huge transmitted data. Generally, Figure 2 depicts the use of the OFDM transmitter with the ECEM system. As an input stage, there are n-wireless sensors (WS) that collect energy consumption signals and sent to the administrator through an OFDM stage. Inside the OFDM stage, there are four different parts starting from the serial to parallel block and ending with guard interval block that uses the cyclic prefix in order to overcome the channel effect [1,2]. After that, the proposition stage which includes the three different proposed techniques.

After that, the performance enhancement will be checked using two different main factors; the CCDF and the BER. This work is divided into three main parts; starting with the direct impact of the FFT size over the calculation of the PAPR value, which leads to the proposition of linear coding part; the work based on the WT; and the PWM based work [2].

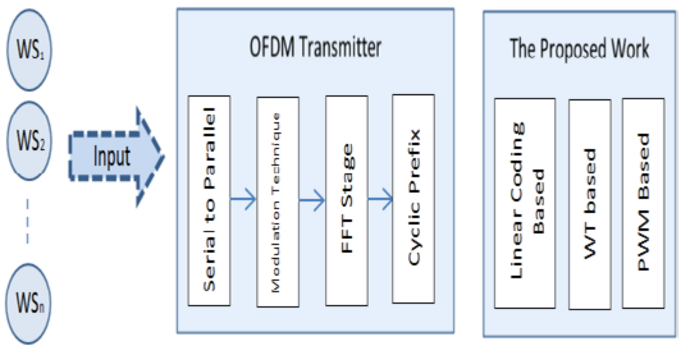

Figure 2. The proposed ECEM transmitter based OFDM structure

The work found in [9,10] describes the projection process of the relationship between N and the PAPR that leads to the proposition of the linear coding. Figure [3] explains the process that has been made to overcome the PAPR effect based on the spreading process. Therefore, the affected OFDM symbol will be spread based on the used coding rate of the linear coding involved.

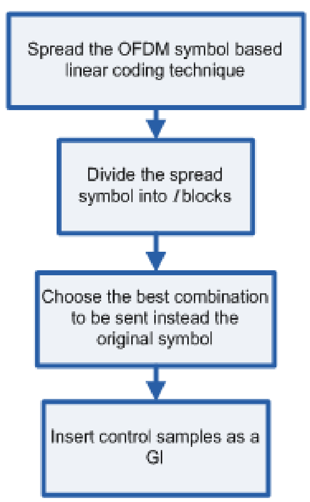

Figure 3. The flowchart of the proposed algorithm in [9,10]

In the first proposition, the spreading process will be attained by making use of the linear coding techniques; such as convolutional techniques, turbo encoding techniques and the low density parity check encoding techniques. Therefore, the spreading will be defined in terms of the coding rate. In the work [9,10], the coding rate, I, means that the affected OFDM symbol with symbol period T will be spread to be a symbol with period of $I\times T$. After the spreading stage, the new symbol will be divided into I blocks, each of them has its sub PAPR value. The next stage is about finding the block with the lowest PAPR to be sent instead of the original one. This will give a computational complexity of the first order and based on N. the complexity equation is driven in [9].

The second proposed work that is based on the WT is depicted in Figure 4 and found in [11,18]. The proposed work procedure is summarized as follows:

1. Reading and de-noising the OFDM symbol,
2. Distinguish both of large and small wavelet coefficient values by making use of a soft thresholding block [19].
3. Adaptive thresholding process is imposed in order to allocate the peaks and then be classified according to it surrounded samples and saved with their locations.
4. The located peaks will be projected on the conventional OFDM signal by making use of an average filter.

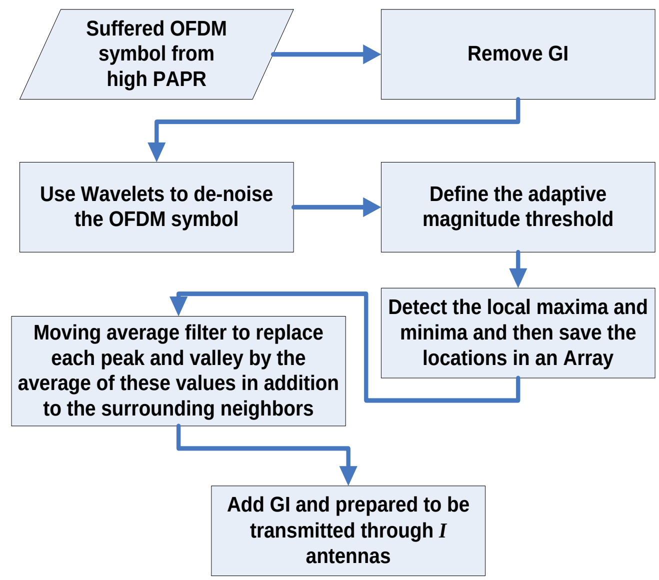

Figure 4. The flowchart of the proposed algorithm that is based on WT

For the third proposed work, the QoS has been taken into consideration based on condensing the system complexity for reducing the inter symbol interference (ISI). For this purpose, the PWM has been imposed after the OFDM transmitting stage. Furthermore, the maximum efficiency has been investigated based on the achieved CCDF curves. This proposition is clearly shown in Figure 5 [2,20].

The third proposition stages are described in the following procedure as [2, 20]:

1. Inserting a zero sample for distinguishing purposes to the start point.
2. Oversample the OFDM symbol.
3. Making use of the proposed criteria in (3) to determine the new OFDM symbols' envelope

$$\dot{x}(i) = \begin{cases} \dot{x}(i) = \dot{x}(1,(i-1)) & ,\text{then } \dot{x}(i) = 0 \\ \dot{x}(i) < \dot{x}(2,(i-1)) & ,\text{then } \dot{x}(i) = -\text{slope} \\ \dot{x}(i) > \dot{x}(3,(i-1)) & ,\text{then } \dot{x}(i) = +\text{slope} \end{cases} \quad (3)$$

where $\dot{x}(i)$ is the processed OFDM i-th sample and $i\in[1,M]$, M is the total number of samples in the oversampled OFDM symbol.

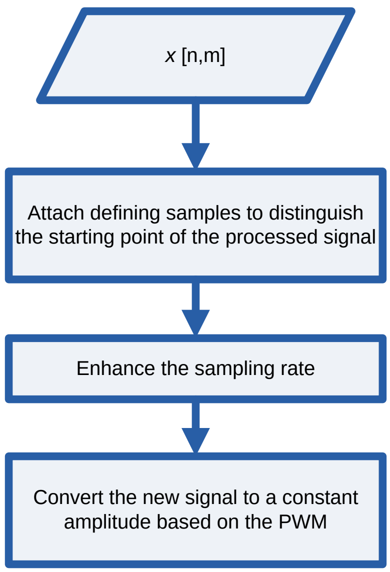

Figure 5. The PWM conversion procedure flowchart

The next section describes the effect of the proposed work on the OFDM system's QoS. For the purpose, a MATLAB simulation has been fulfilled to compare both of the BER and CCDF curves with the literature [2, 9, 20].

III. Simulation Results and Discussion

A MATLAB simulation has been performed in order to compare the three proposed work performances. The simulation specifications are as follows:

- Two types of the input data;
  - A random theoretically generated test data,
  - Practical signals that have been extracted from the ECEM project network.
- OFDM transceiver with the following blocks;
  - Convolutional encoder as a spreading process,
  - 16QAM mapper technique,
  - A 256 FFT point

The novelty of this work comes from the proposition of three different works that dealt with overcoming the effect of PAPR. Therefore and to check the system performance, a MATLAB simulation has been conducted in order to simulate both of the BER and CCDF curves for the processed OFDM signal [2].

Table 1 depicts the simulation results for the first proposed work and compares the results of the theoretically generated input data with the ECEM ones. From the depicted results, the QoS has been improved, while the probability of the PAPR values that will exceed the 20dB is reduced to the range of 18% to 25% for different spreading rate (convolutional encoding rate) [2]. For the ECEM input data, the CCDF curves have been improved to fall in the range of 11% to 33%. As a result, the link between the PAPR and the spreading rate found in [9] gives promising results in order to overcome this deficiency. Secondly, as it has been concluded from the published work in [11], the use of discrete wavelet transform (DWT) is clearly described in Table 2 as shown below. It is compared with both of the conventional OFDM and the proposed work that is found in the literature such conventional clipping technique, partial transmit sequence (PTS) and selective mapping (SLM).

Table 1. A convolutional encoder based proposed work

Input data	Modulation Technique	Coding Rate	PAPR without coding	PAPR-based convolutional encoder	
				Spreading Rate	
				2	3
Theoretical Data	QPSK	0.5	10.39	2.2	1.7
		0.33	11.25	2.3	1.82
	16 QAM	0.5	8.31	1.61	1.25
		0.33	11.61	2.15	1.9
ECEM project data	QPSK	0.5	14.3	3.1	2.7
		0.33	13.9	4.6	4.1
	16 QAM	0.5	12.6	2.2	1.3
		0.33	11.5	2.14	1.9

Table 2. A DWT based proposed work

I/P Data	Modulation technique	PAPR without coding (dB)	Previous work (dB)			PAPR based DWT (dB)	Improvement percentage (%)
			Clipping tech.	PTS	SLM		
Theoretical	16 QAM	10.3	8.12	6.3	5.9	1.2	11%-41%
ECEM project	16 QAM	11.5	8.5	7.8	5.2	2.1	11%-41%

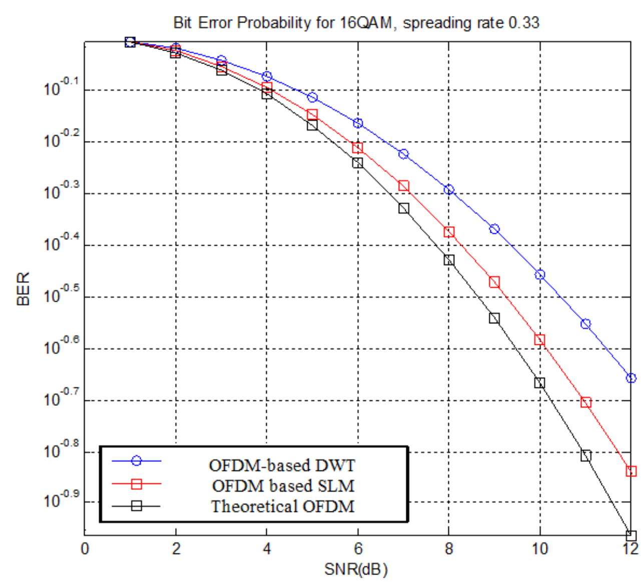

Figure 6. OFDM work based DWT BER comparison with SLM BER curves.

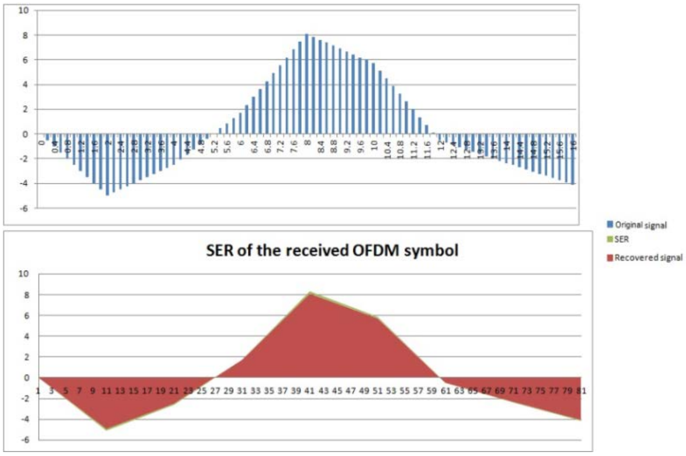

Figure 7. PWM based work SER values

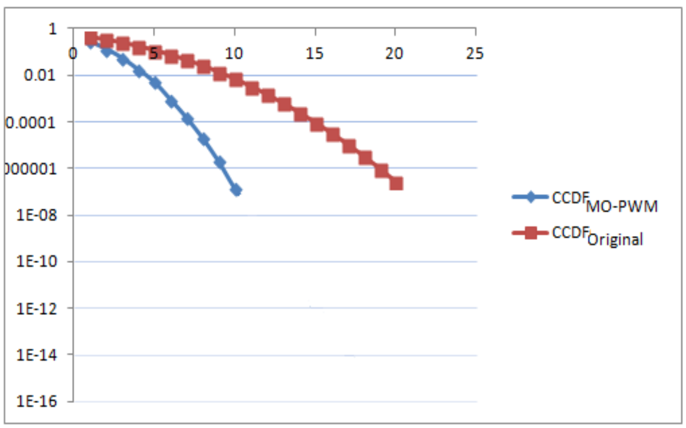

Figure 8. PWM based work CCDF curves

The two different input data have been investigated in order to check the second proposed work performance. This comparison is shown in Table 2; three different proposed work in the literature are summarized in our previously published work [9-11], and the work based on the DWT. There is up to 80% improvement over the conventional OFDM work; the PAPR values have been reduced to 1.2 dB from 10.3 dB. Furthermore, the DWT based work shows the powerfulness over the proposed work in the literature such as the clipping technique, the SLM technique and the PTS technique. It gives up to 85% further reduction percentage.

Figure 6 depicts the QoS enhancement based on the BER values. As an example, this enhancement has been investigated at the threshold of 12 dB. The DWT based work shows a little enhancement for the BER to reach the $10^{-0.67}$ from $10^{-0.85}$. This slight enhancement is due to the nature of theoretically generated data.

After the DWT based work, the PWM based work has been proposed. In this proposition, the QoS has been expected to be the best. This is due to that the PWM fixes the envelope to a certain predetermined constant levels, which will be attained at the increases of complexity point of view. Figures 7 and 8 respectively depict both of the CCDF and the sample error rate (SER) curves. It is has been clearly shown that SER results of the proposed work which is equal to 39.67×10^{-4}. It can be considered as a promising achieved value for QoS enhancement. Furthermore, another enhancement has been shown in Figure 8 that the CCDF has been reduced from 10^{-4} to be around 10^{-13} at the threshold of 20 dB [2].

IV. Conclusion

Three propositions to enhance the OFDM systems have been discussed in this work. In order to check those proposition; a practical OFDM system has been built based on the ECEM project network. Thus, two types of data has been check through this work; theoretically generated and practically extracted data were involved. The OFDM QoS has been investigated based on either combatting the PAPR values of the error ratios. From this comparison, the third proposal that is based on the PWM gives the best enhancement over the previous two, where the CCDF values reduced to almost 0 and this is true also for the error ratio. As a comparison, the first proposal gives an extra 25% reduction ratio over the literature work, while the second proposal increases tis ratio to reach around 40%.

The QoS of the proposed work will be checked in the future work in terms of the projection of the achieved PAPR reduction values on both of the complexity issues and the cost factors.

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