DFT-Based OFDMA System with Phase Modulation for Broadband Communication

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Abstract: This paper proposes, a DFT-based OFDMA with phase modulation (DFT-OFDMA-PM) system. One main advantage of the phase modulated system is the constant envelope (CE) resulted signal, i.e, *0 dB PAPR*, the second advantage is the ability to improve the diversity of multipath channels. These advantages have been exploited in the proposed system of this paper. The performance of the proposed system in terms of the bit error rate (BER) is studied and investigated and compared to the previously proposed DCT-OFDMA-PM system and the conventional OFDMA system without PM via computer simulation. The key parameter that affects the performance of the PM systems, the modulation index, is also studied and the optimum value is selected using exhaustive simulation scenarios. Moreover, the PAPR is also simulated for the proposed system and compared to the conventional system. Simulation results show the significant improvement of the proposed system in terms of PAPR and BER when compared to the conventional system. The simulation results for the proposed system show the effectiveness of the proposed system for wireless broadband communications.

Keywords: DFT, DCT, OFDMA, PAPR, Phase Modulation

1. Introduction

Wireless digital communication is rapidly expanding, resulting in a demand for wireless systems that are reliable and have a high spectral efficiency [1]. Orthogonal frequency division multiple access (OFDMA) is an attractive technology to deal with the detrimental effects of multipath fading, but it faces several inherent disadvantages such as the high peak-to-average-power ratio (PAPR) and the sensitivity to carrier frequency offsets [2, 3]. In cellular applications, a big advantage of OFDMA is its robustness in the presence of multipath signal propagation [4]. The immunity to multipath derives from the fact that an OFDMA system transmits information on M orthogonal frequency carriers, each operating at $1/M$ times the bit rate of the information signal. On the other hand, the OFDMA waveform exhibits very pronounced envelope fluctuations resulting in a PAPR. Signals with a high PAPR require highly linear power amplifiers to avoid excessive intermodulation distortion. To

achieve this linearity, the amplifiers have to operate with a large backoff from their peak power. The result is low power efficiency (measured by the ratio of transmitted power to dc power dissipated), which places a significant burden on portable wireless terminals [5]. Several PAPR reductions techniques for multicarrier transmissions are surveyed by S. H. Han [6]. These techniques can be classified into two groups, the first one which is called distortion reduction techniques, such as, windowing and clipping [7]. The second one called non distortion reduction techniques, which can be classified into two different types. Which are either based on multiple signal representations, such as, the partial transmit sequence (PTS) technique, the selective mapping (SLM) technique, and the interleaving technique, or technique based on signal transformation such as phase modulation (PM) [5, 6, 8-12]. The PM based systems have several advantages. The resulted signal by the PM-based system has a constant envelope (i.e. 0 dB PAPR) which allows the PA to operate near the saturation region, thus maximizing the power efficiency. Therefore, these systems have a larger coverage

area since more signal power is radiated into the channel. The goal of this paper is to propose a DFT-based OFDMA with PM and comparing its performance with the recently proposed DCT-based OFDMA (DCT-OFDMA-PM) system by F. AL-Fuhaidy [5]. Although, the key parameter affecting the PM-based system, the modulation index, is also studied and the optimum value is chosen using simulation which verified the mathematical indication. PM-based systems also have the ability to improve the diversity of multipath channels which is studied and verified using simulation of bit error rate (BER).

The reminder of this paper is organized as follows. Section 2 presents an overview on the conventional OFDMA system. Then, the proposed DFT-OFDMA-PM system model is derived and introduced in Section 3, the recently proposed DCT-OFDMA-PM system is also presented and a comparison study between the DFT-OFDMA-PM and the DCT-OFDMA-PM systems is discussed in case of the type of orthogonal subcarriers used by each system. Simulation results for the proposed system DFT-OFDMA-PM in terms of bit error rate (BER), modulation index, *h*, and the PAPR, are presented, discussed, and compared with the DCT-

OFDMA-PM and the conventional OFDMA systems by Section 4. Finally, Section 5 concludes the paper.

2. The Traditional OFDMA System

The OFDMA system that is used for mobile communications was first proposed by R. Nogueroles [13]. Figure 1 presents a block diagram for the conventional DFT-based OFDMA system. It is based on multicarrier FDMA, where each user is assigned to a set of randomly selected sub-channels. There are *U* uplink users communicating with a base station through independent multipath fading channels. A total of *M* subcarriers are assumed and each user is assigned *N* subcarriers. At the transmitter, the encoded signals are modulated and then the subcarriers are mapped in the frequency domain. After that, the IDFT is performed, and a cyclic prefix (CP) is added to the resulting signal. Finally, the resulting signal is transmitted through the wireless channel. At the receiver, the CP is removed and the DFT is then applied. Finally, the subcarrier remapping, the equalization, the demodulation and the decoding operations are performed.
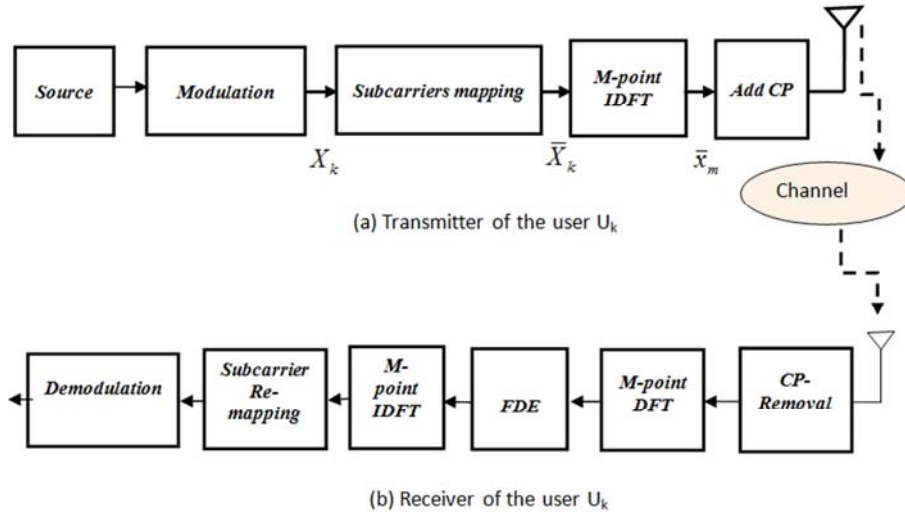

Figure 1. A block diagram for the DFT OFDMA system over frequency selective fading channel.

3. The OFDMA Proposed Systems

This section firstly presents the proposed DFT-based OFDMA system with phase modulation along with its mathematical model. Then, a brief literature on the recently proposed DCT-based OFDMA system with phase modulation is introduced in order to illustrate the similarity and differences to the proposed system.

3.1. The Proposed DFT-OFDMA-PM System

This section introduces the proposed system named DFT-OFDMA-PM, which refers to Discrete Fourier Transform-based Orthogonal Frequency Division Multiple Access with Phase Modulation. The proposed system is suggested as a new transceiver scheme for the OFDMA system. The block diagram which illustrates the proposed system is shown in

Figure 2. Now, an illustration of the proposed system mathematical model is presented.

During each block interval, *T-seconds*, an *M-point IDFT* calculates a block of time samples *x (n)*. Next step, a high PAPR DFT-OFDMA sequence, *x (n)*, is passed through a phase modulator to obtain a 0 dB PAPR sequence *s (n)=exp (j C x (n))*, where *C* is a scaling constant. Then N_g samples of CP are added to *s (n)*. The continuous-time DFT-OFDMA-PM signal, *s (t)*, is then generated at the output of the digital-to-analog (D/ A) converter. This baseband signal can be expressed as follows [5, 9, 13]:

$$S(t) = Ae^{j\emptyset(t)} = Ae^{j[2\pi h.m(t)+\theta]}, T_g \leq t < T \qquad (1)$$

where *A* is the signal amplitude, *h* is the modulation index, θ is an arbitrary phase offset used to achieve phase continuous modulation [5, 13]. T_g is the guard period, *T* is the block

period, and $m(t)$ is a real-valued DFT-OFDMA signal and given as:

$$m(t) = C_N \sum_{k=1}^{M} X_k q_k(t) \qquad (2)$$

where C_N is the normalization constant used to normalize the variance of the message signal ($\sigma_x^2 = 1$) after subcarrier

mapping and consequently the variance of the phase signal, $\sigma_\phi^2 = (2\pi h)^2$. This requirement is achieved by setting C_N as follows:

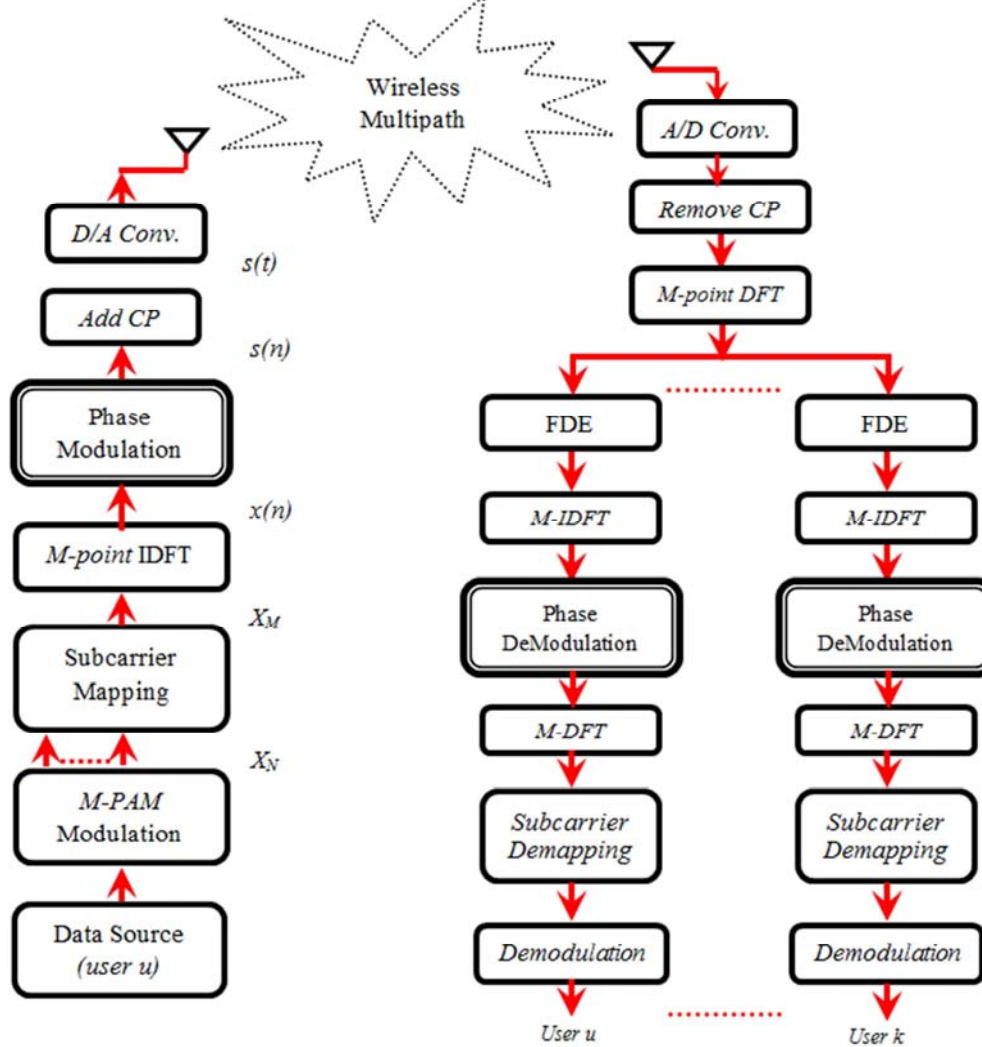$$C_N = \sqrt{\frac{2}{M\sigma_x^2}} \qquad (3)$$

Figure 2. A block diagram for the proposed DFT-OFDMA-PM Transceiver system.

X_k is the resulted sequence after subcarrier mapping and $q_k(t)$ are the orthogonal subcarriers which are also must be real-valued for phase modulation [5, 13],

$$q_k(t) = \cos\left(\frac{\pi kt}{T}\right) + \sin\left(\frac{2\pi kt}{T}\right), 0 \leq t < T, 1 \leq k < M \quad (4)$$

From Eqs.(1) and (2), the phase signal, $\phi(t)$, can be written as follows:

$$\phi(t) = \theta + 2\pi h C_N \sum_{k=1}^{M} X_k q_k(t) \qquad (5)$$

The received signal is.

$$r(t) = \int_0^{\tau_{max}} h(\tau, t)s(t - \tau)d\tau + z(t) = \int_0^{\tau_{max}} h(\tau)s(t - \tau)d\tau + z(t) \qquad (6)$$

where $h(\tau, t)$ is the channel impulse response (CIR), τ_{max} is the channel's maximum propagation delay, and $z(t)$ is the additive white Gaussian noise. The channel is assumed to be static over the block interval, and therefore, $h(\tau, t) = h(\tau)$.

The addition of the CP makes the linear convolution with

the CIR equivalent to a circular convolution. Thus, by choosing $N_g \geq L$ (L is the length of the CIR), the received samples, $r(n)$ are represented equivalently by a linear (*) or a circular ( ) convolution,

$$r_n = s_n * h_n + z_n = (s_n * h_n)_{Cir} + z_n = IDFT\{S_k H_{k\}+z_n} \qquad (7)$$

where $\{S_k, H_k\}$ are the DFTs of $\{s_n, h_n\}$ respectively. Then, after the A/ D converter, the CP samples are discarded and the remaining samples are equalized by frequency domain equalization (FDE). The FDE can perfectly invert the effect of the channel. Its advantage is the relatively low complexity, and the disadvantage is the requirement of a CP overhead. The block of FDE includes three blocks, DFT, FDE, and IDFT respectively and is shown in Figure 2. The FDE output is:

$$\hat{s}_n = IDFT\{R_k C_k\} = (r_n * c_n)_{Cir} \qquad (8)$$

where R_k is the DFT of the received signal r_n and C_k represents the equalizer correction term, which is computed according to the type of the equalizer. For MMSE equalizer the correction term is computed as follows [15-18]:

$$C_k = \frac{H_k^*}{|H_k|^2 + (SNR^{-1})} \qquad (9)$$

where *SNR* is the signal-to-noise ratio. After that, the time domain signal is applied to the phase demodulator as shown in Figure 3.

The phase demodulator includes three operations, a finite impulse response (FIR) filter which is used to improve the phase demodulator performance, the *arg (.)* is used to extract the phase of the signal. Finally, the phase unwrapper is used to reduce the effect of phase ambiguities and makes the receiver insensitive to phase offsets caused by the channel and the memory term.
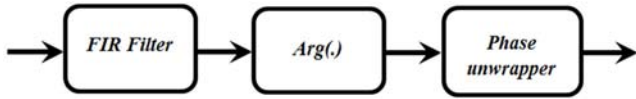

Figure 3. *Phase demodulator.*

3.2. The DCT-OFDMA-PM System

This section presents the main difference of the recently proposed system, the DCT-OFDMA-PM, introduced by F. Al-fuhaidy to our proposed DFT-OFDMA-PM system [5]. By R eferring to the block diagram of the DCT-OFDMA-PM, it sh ows high similarity to our proposed system shown in Figure 2, except the uses of IDCT at the transmitter and the DCT at t he receiver, which is a single sinusoidal as presented in Eq.(1 0) rather than a combination of sinusoidal and cosinusoidal f unctions of our proposed system shown by above subsection in Eq.(4).

$$q_k(t) = \cos\left(\frac{\pi k t}{T}\right), 0 \le t < T, 1 \le k < M \qquad (10)$$

Moreover, the performance is analyzed and compared by this paper for the two systems using simulation which illustra tes the improvement introduced by the proposed system.

4. Simulations and Results

This section presents and discusses simulation results for the proposed system, the DFT-OFDMA-PM, and compares it to the DCT-OFDMA-PM system for different subcarrier techniques, localized and interleaved mapping. Moreover, the modulation index, *h,* is studied and the optimum value is chosen using simulation. We note that the abbreviations DFT-LOFDMA-PM and DFT-IOFDMA-PM refer to localized and interleaved subcarrier mapping respectively. Similarly, DCT-LOFDMA-PM and DCT-IOFDMA-PM for DCT-based system localized and interleaved subcarrier mapping respectively.

4.1. Simulation Parameters

Since that the DFT-OFDMA-PM system was not introduced by F. Al-fuhaidy or other previous researches, it will be introduced by this paper [5]. Although, and for comparison purpose, the DCT-OFDMA-PM which is recently proposed by F. Al-fuhaidy is also simulated [5]. A Monte Carlo simulation with 10^4 iterations for each scenario is used to evaluate the performance of different systems.

For simulation of the DFT-OFDMA-PM, and the DCT-OFDMA-PM systems, simulation parameters are chosen similarly to parameters used by different previous researches that simulate the Constant-Envelope-OFDM with some additional special parameters used for OFDMA as shown in Table 1 [5, 9, 13, 16].

Table 1. *Simulation parameters for DFT-OFDMA-PM, and DCT-OFDMA-PM systems.*

	Description	Parameters
Transmitter	Block size for each user 'N'	64
	Modulation	4-PAM
	Number of users 'Q'	4
	Modulation index 'h'	0.0/ 2π, to 2.0/ 2π, step by 0.2
	Oversampling 'J'	8
	DCT 'N_{DCT}' and DFT size, 'N_{DFT}'	$N*Q*J=2048$
	Block period 'T'	128 μs
	Subcarrier mapping	Localized and Interleaved
Channel	Channel model	Vehicular A outdoor channel
	Noise environment	AWGN
Receiver	Channel estimation	Perfect channel
	Equalization	MMSE

4.2. Performance of the Proposed DFT- OFDMA-PM System

This subsection presents simulation results for the proposed system, the DFT-OFDMA-PM. The performance of the proposed system is discussed and analyzed in terms of the BER, the modulation index, and the PAPR, and compared to the DCT-OFDMA-PM system and the traditional system.

4.2.1. The Selection of the Optimum Modulation Index

A well-known problem in phase modulation scheme is the nonlinearity for the spectrum transformation of the phase modulated signal. However, by proper choice of the modulation index h, this problem is elevated. An investigation of the effect of the modulation index, h, on the BER performance is carried via simulation results analysis of the proposed system for different values of, h. Moreover, and in order to verify this analysis, this study extended by involving the DCT-OFDMA-PM system simulation results. Actually, it is noted that the performance of the proposed system is degraded for some values of h. Figures 4, 5, 6, and 7 show different curves for the BER versus E_b/N_0 of the proposed DFT-OFDMA-PM and the DCT-OFDMA-PM systems with different values, $0.2/2\pi$, $1.0/2\pi$, and $1.4/2\pi$, of modulation index, h.
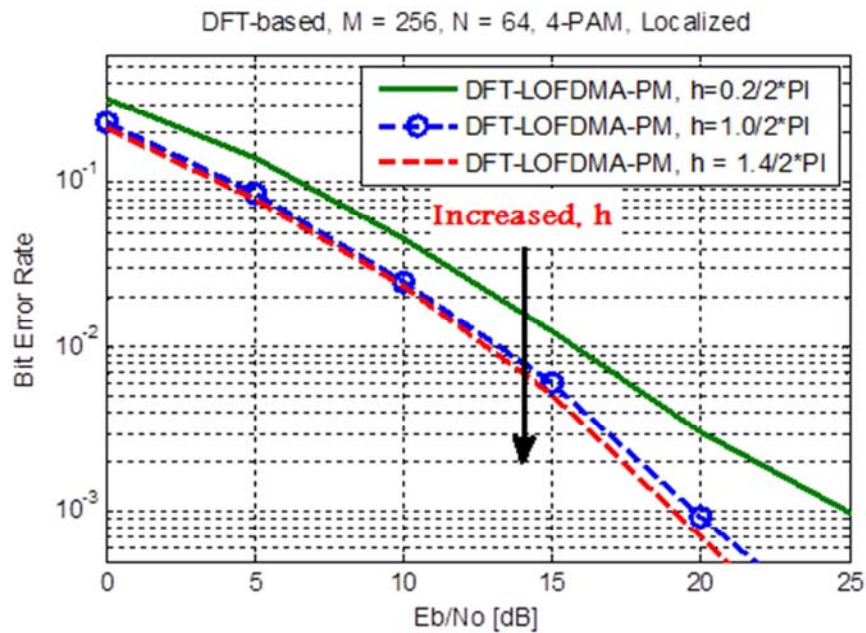

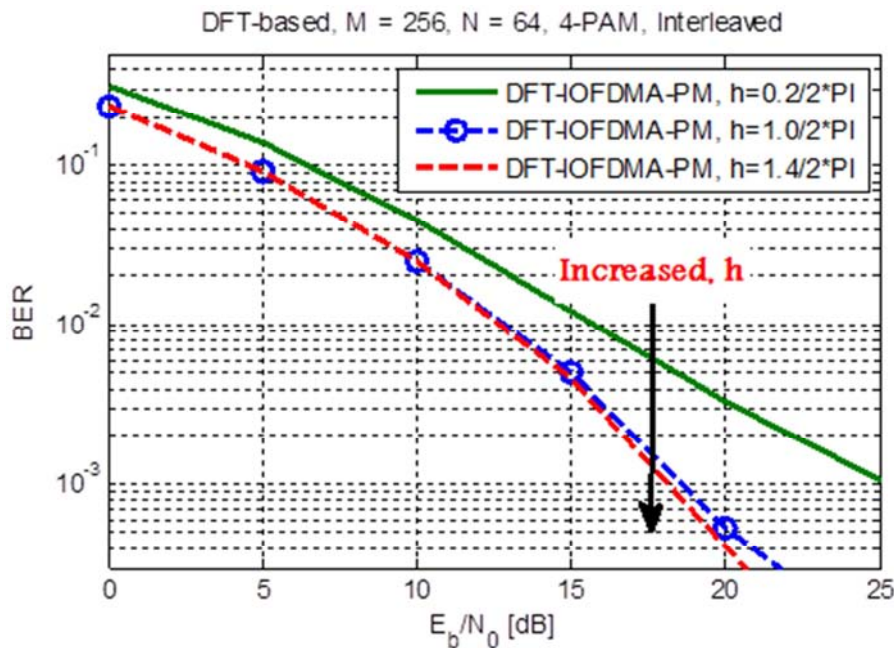**Figure 4.** BER vs. E_b/N_0 for DFT-LOFDMA-PM and different modulation index, h.

Figure 5. BER vs. E_b/N_0 for DFT-IOFDMA-PM and different modulation index, h.
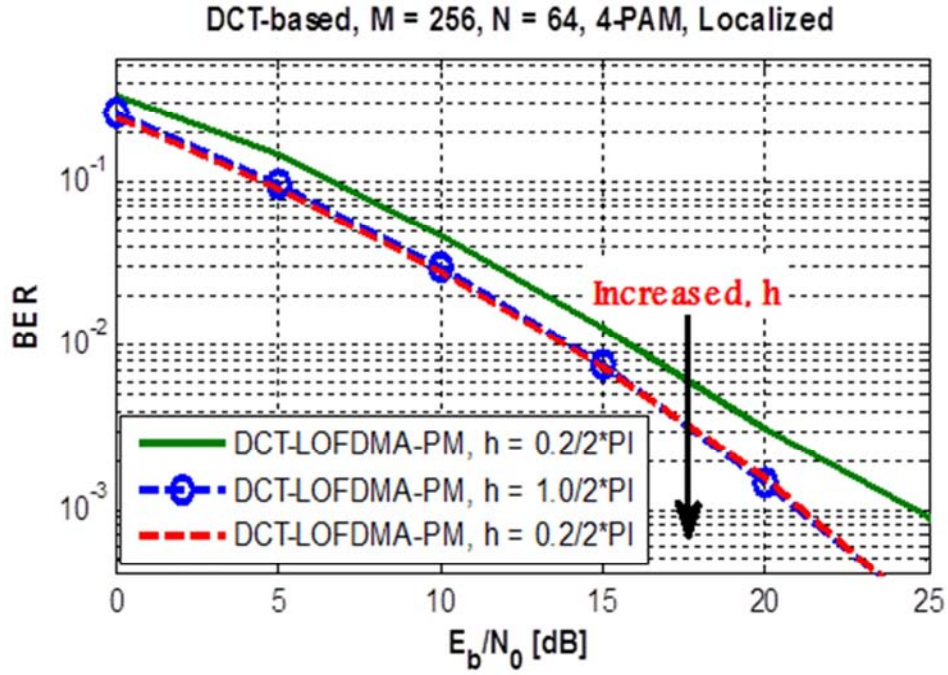
Figure 6. *BER vs. E_b/N_0 for DCT-LOFDMA-PM and different modulation index, h.*
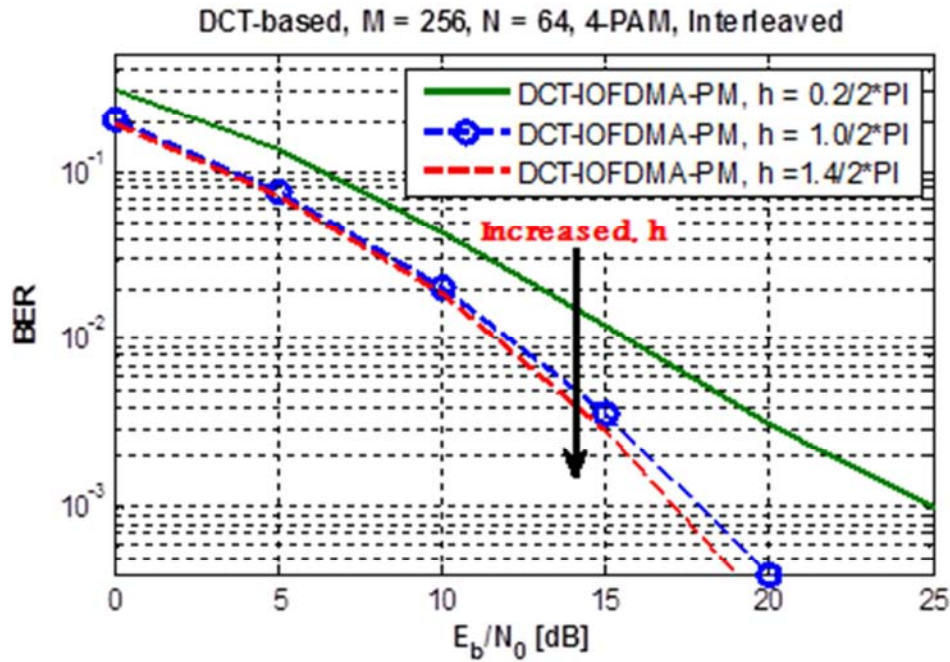

Figure 7. *BER vs. E_b/N_0 for DCT-IOFDMA-PM and different modulation index, h.*

It is clear from the above figures that BER performance is decreased as *h* increased. Also, it is noticed that for *h* greater than $1/2\pi$, the BER may has a small improvement at E_b/N_0 equal or greater than *20 dB* while, the E_b/N_0 is the dominant.

In this paper, the optimum value of *h* is selected to be equal to $1.0/2\pi$. This selection takes in consideration that the modulation index controls the system performance bandwidth metric. A useful bandwidth expression for the continuous PM signal is the root-mean-square (RMS) bandwidth [9, 13]:

$$BW = \max(2\pi h, 1)\, W \qquad (11)$$

As shown in Eq. (11), the signal bandwidth grows with $2\pi h$, which in turn reduces the bandwidth efficiency. Exhaustive simulation scenarios for the BER against E_b/N_0 and for wide range values of *h* are carried and presented by the following figures. Figures 8 and 9 demonstrate variations of the BER for different signal to noise ratio and different modulation index. A clear indication about modulation index is shown. The BER decreases as modulation index increased from *0.0/ 2π, up to 1.0/ 2π step by 0.2*, after that the BER

either has small decrease with localized subcarrier mapping or it increases with interleaved subcarrier mapping. Thus, the

modulation index, $h = 1.0/ 2\pi$, can be selected as an optimum value for good BER and saved system bandwidth.
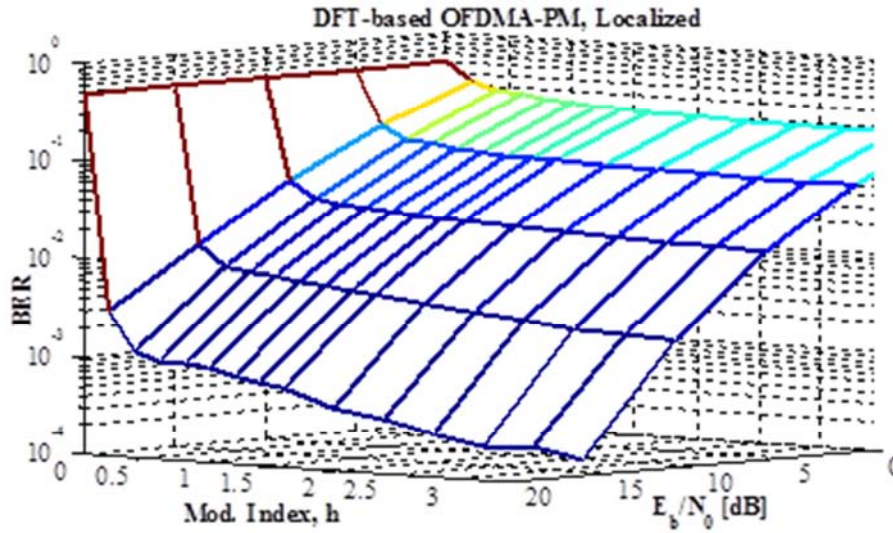

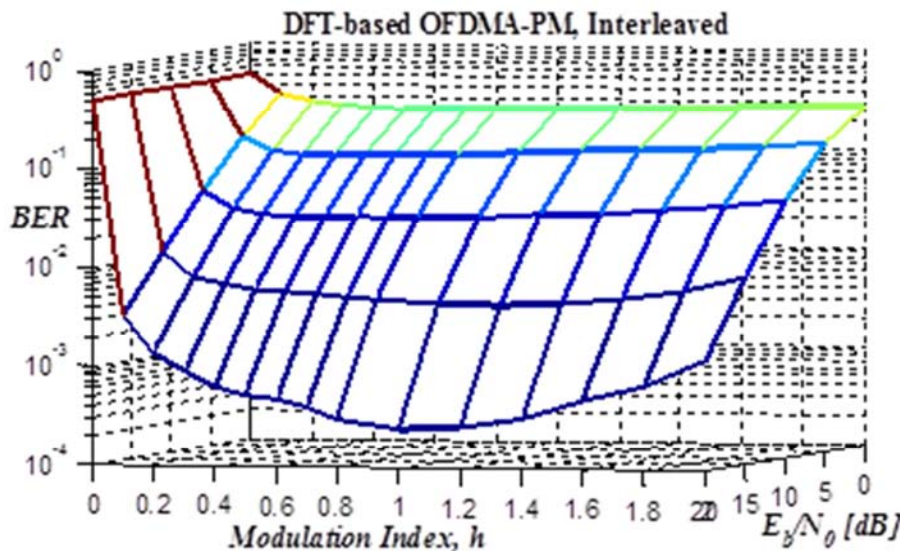*Figure 8.* Variation of the BER with modulation index, h, and E_b/ N_0 for the proposed DFT-LOFDMA-PM.

Figure 9. Variation of the BER with modulation index, h, and E_b/ N_0 for the proposed DFT-IOFDMA-PM.

4.2.2. BER Improved Performance Introduced by the Proposed System in Term of BER

In this subsection, the BER performance of the proposed system, the DFT-OFDMA-PM, is compared to the BER performance of the DCT-OFDMA-PM and the conventional DFT-based and DCT-based OFDMA systems. The modulation index, *h,* is selected to be equal to the optimum value, *1.0/ 2π* Fig.10 and 11 illustrates the BER performance of the proposed system, the DFT-OFDMA-PM when compared to the DCT-OFDMA-PM system, and to the DFT-based and the DCT-based systems without PM, for different subcarrier mapping, localized and interleaved respectively. It is also clear from figures that the DFT-OFDMA-PM has small improvement in BER when compared to DCT-OFDMA-PM in case of localized subcarrier mapping and vice versa in case of interleaved subcarrier mapping. At this

point, we shall note that the localized subcarrier mapping is the preferred choice in broadband communication system. This is due to many problems associated with interleaved subcarrier mapping such as carrier frequency offset. By looking to the improvement introduced by the proposed DST-OFDMA-PM system when compared to the conventional systems. The proposed DST-LOFDMA-PM provides about *4.5 dB* and *3 dB* E_b/ N_0 enhancement at *BER = 10^{-2}* when compared to DFT-based and DCT-based systems without PM respectively. Approximately, similar improvement achieved by the DFT-IOFDMA system compared to the conventional systems without PM.

We note that the improvement introduced by the proposed system is due to the ability of the phase modulation to exploit the diversity of multipath channels.

4.2.3 The PAPR Performance

This section presents simulation results for the proposed system in term of PAPR when compared to the conventional system. Figures 12 and 13 present the PAPR for the DFT-OFDMA-PM and the traditional OFDMA system, with localized and interleaved mapping respectively. It is clear from figures, that the proposed system provides the better PAPR, 0 dB, while the conventional system posed from a very high PAPR. Intuitively, this is due to that the proposed system transmit a constant envelop fluctuated signal, along with the information signal is phase modulated. This improvement clears the effect of the PAPR problem in the proposed system which was considered as a main challenge in 4G mobile generation.

This improvement in case of constant envelop transmitted signal, neglect the effect of the power amplifier of the transmitted device, the mobile terminal. And lower the cost by using nonlinear power amplifier device with the mobile terminal, uplink transmission. We note that this challenge is not considered by the downlink transmission, the base station.
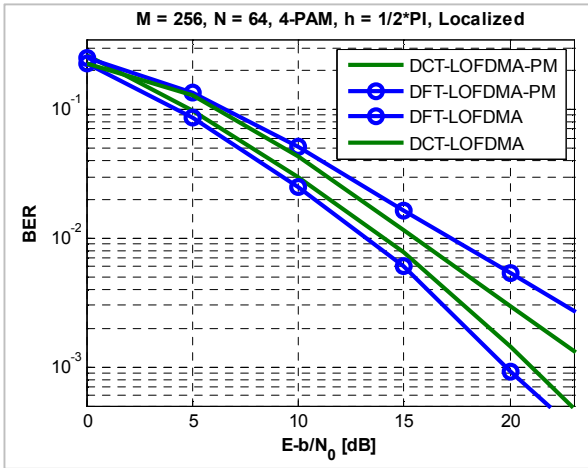

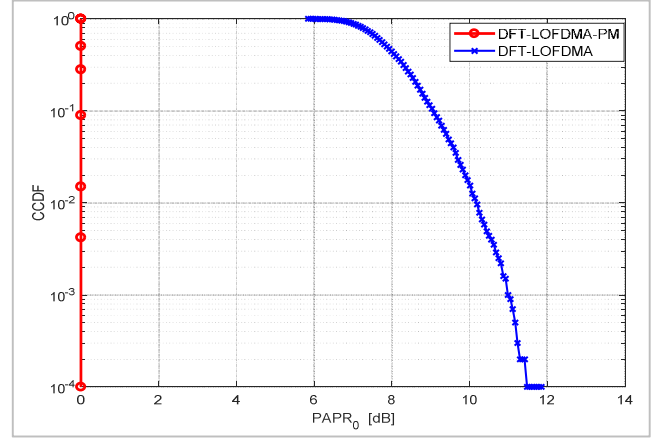
Figure 12. *CCDF vs.PAPR for the DFT-LOFDMA-PM and the conventional OFDMA system.*

5. Conclusions

This paper was proposed and investigated using simulation a new transceiver scheme for the OFDMA system by adding phase modulation to the resulted signal before transmission. This system was called DFT-OFDMA-PM. The proposed system has different advantages such as reduced PAPR and improved BER performance, which are the common problems in the broadband communications. The proposed DFT-OFDMA-PM system provides a constant envelope signal, i.e., 0dB PAPR, due to constant amplitude output signal since the transmitted signal is phase modulated. This is the main advantage of the proposed system which play as a main challenge in broadband communication either in 3G or 4G mobile communication. Moreover, the proposed system improved the BER performance. As shown by simulation results, the proposed system provide a significant enhancement in BER when compared to the conventional systems and the recently proposed DCT-OFDMA-PM system which is desired in broadband communications. Finally, since, the proposed system add a PM block to the conventional system which affected by the modulation index so, the effect of the modulation index was also studied by executing exhaustive simulation scenarios and studying its effect on performance, and the optimum value was selected. Simulation results show the effectiveness of the proposed system in broadband communications.

Figure 10. *BER vs. E_b/N_0 for DFT-LOFDMA-PM and different systems.*

Figure 11. *BER vs. E_b/N_0 for DFT-IOFDMA-PM and different systems.*

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Biography

Farouk Abduh Kamil Al-Fuhaidy. He received the B. S. E. E. Computer Engineering and M. S. E. E. in Computer Engineering respectively and Ph. D. in Communication Engineering from the Military Technical College, Cairo, Egypt in 2007, 2009 and 2013 respectively. He joined the teaching staff of the Department of Electrical Engineering, Faculty of Engineering and Architecture, Ibb University, Yemen, in 2014. His research interests and activities are in the areas of CDMA, OFDMA, SC-FDMA Systems, Wireless Sensor Networks and adhoc Networks Routing Protocols, Embedded Systems, IOT, broadband communications, and advanced signal and image processing Techniques.

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