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Discrete Sine Transform Based OFDMA System for Wireless Broadband Communications

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Exploiting the energy compaction property of the discrete sine transform (DST), this paper, implements the DST rather than the discrete Fourier transform (DFT) as a basis function for the OFDMA system, the proposed system is called the DST-OFDMA. The performance of the proposed DST-OFDMA system is studied and compared to the conventional DFT-OFDMA system, and the recently proposed discrete cosine transform (DCT) based OFDMA system using computer simulation. The performance study and comparison is carried based on bit error rate (BER) and peak-to-average power ratio (PAPR) metrics. Simulation results show the improvement provided by the proposed system in terms of BER performance with approximately same PAPR performance when compared to other systems. The simulation results for the proposed systems are presented to demonstrate the effectiveness of the proposed systems for broadband communications.

Introduction

Wireless digital communication is rapidly expanding, resulting in a demand for wireless systems that are reliable and have a high spectral efficiency as explained in 3GPP, and Falconer D [1, 2]. Broadband wireless communication systems must provide high-data-rate services to satisfy the increasing demands of the future wireless networks. As the bit rate increases, the problem of inter-symbol interference becomes more serious. Orthogonal frequency division multiple access (OFDMA) is an attractive technology to deal with the detrimental effects of multipath fading, but it has several inherent disadvantages such as the large peak-to-average-power ratio (PAPR) and the sensitivity to carrier frequency offsets illustrated by Hyung. G. Myung and Faisal S. Al-kamali [3-5]. The most prominent example, when the OFDMA employed in IEEE802.16e (WiMAX) as an *Air Interface for Fixed and Mobile Broadband Wireless Access Systems* [6]. In cellular applications, a big advantage of OFDMA is its robustness in the presence of multipath signal propagation which illustrated in Adachi F., and Hyung G. Myung [3, 7]. 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. There are two subcarrier mapping methods for OFDMA system. OFDMA system with block-wise subcarriers allocation is known as localized orthogonal frequency division multiple access (LOFDMA) as in Hyung. G. Myung [3, 4]. OFDMA system with regularly interleaved subcarriers allocation is also known as interleaved orthogonal frequency division multiple access (IOFDMA) as in Hyung. G. Myung [4]. In the literature, only the DFT and the DCT were proposed to implement the OFDMA system as proposed by R. Nogueroles, and Farouk A. K. AL-Fuhaidy [8, 9]. It was shown that DCT- based OFDMA (DCT-OFDMA) system provides better bit error rate (BER) performance than that of the DFT-based OFDMA (DFT-OFDMA) system. Moreover, its PAPR is approximately same to that of the DFT-OFDMA system. Up to now, the DST-based OFDMA (DST-OFDMA) system is not studied in the literature. DST uses only real arithmetic rather than the complex arithmetic used in the DFT. This reduces the signal processing complexity, and the in-phase/quadrature imbalance.

In this paper, a new OFDMA transceiver scheme based on the DST is proposed. The proposed transceiver uses a DST, rather than the DFT or the DCT, to implement the OFDMA system is characterized by its lower computation complexity in uplink transmission, mobile station, when compared to the conventional DFT which uses a combination of sinusoidal and cosinusoidal components. The proposed scheme is described and its model is derived. Then, the BER and the PAPR performances of the proposed DST-OFDMA scheme are studied and compared with the existing schemes. In contrast to the conventional DFT-OFDMA and the DCT-OFDMA systems, it is found that the DST-OFDMA provides better BER performance and an acceptable PAPR performance.

The rest of the paper is organized as follows. Section 2 defines the DST. Section 3 provides an overview about the DFT-OFDMA and the DCT-OFDMA systems. Section 3, also derives the system model of the proposed DST-OFDMA system. The PAPR problem is discussed in Section 4. Simulation results are given in section 5. Finally, Section 6 concludes the paper.

Discrete Sine Transform

In mathematics, the DST is a Fourier-related transform similar to the DFT, but using a purely real matrix. It is equivalent to the imaginary parts of a DFT of roughly twice the length, operating on real data with odd symmetry. DSTs are widely employed in solving partial differential equations by spectral methods, where the different variants of the DST correspond to slightly different odd/even boundary conditions at the two ends of the array which employed by Faisal. S. Al-kamali [10, 11]. There are several types of the DST with slightly modified definitions. In this paper, DST-I is considered. For simplicity, it is denoted by DST. The DST is given by:

$$y(k) = \sum_{n=1}^{N} x(n) \sin\left(\pi \frac{kn}{N+1}\right) \tag{1}$$

$$and\ k = 1, 2, \dots, N$$

The inverse DST (IDST) is given by:

$$x(n) = \frac{2}{N+1} \sum_{k=1}^{N} y(k) \sin\left(\pi \frac{kn}{N+1}\right) \tag{2}$$

$$and\ n = 1, 2, \dots, N$$

OFDMA Systems

This section introduces a brief explanation on the conventional DFT-OFDMA system. Then, the recently proposed DCT-OFDMA system is presented. Finally, the proposed DST-OFDMA system model is presented and compared to the DCT-OFDMA system.

The Conventional DFT-OFDMA System

The OFDMA system that is used for mobile communications was first proposed by R. Nogueroles [8]. It is based on multicarrier FDMA, where each user is assigned to a set of randomly selected sub-channels. The conventional DFT-OFDMA system model is discussed in this subsection. 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. In the DFT OFDMA 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 demapping, the equalization, the demodulation and the decoding operations are performed.

The DCT OFDMA System

The DCT-OFDMA system was recently proposed in Farouk A. K. Al-fuhaidy [9]. A block diagram of the DCT-based OFDMA system is shown in figure 1. Unlike the conventional DFT-OFDMA system, a set of trigonometric functions in the form of $\cos(2\pi m F_p t)$, where $m = 0, 1, \dots, M - 1$ and $0 < t < T$, is used to implement the DCT-OFDMA system $K=m$. F_p is the subcarriers spacing. T is the symbol period. The minimum F_p, required to satisfy the orthogonality condition, is $1/2T$. This condition is defined by Farouk A. K. AL-fuhaidy and Faisal Alkamali [9, 10]:

$$\int_0^T \sqrt{\frac{2}{T}} \cos(2\pi m F_p t) \sqrt{\frac{2}{T}} \cos(2\pi k F_p t)\ dt = \begin{cases} 1, k = m \\ 0, k \neq m \end{cases} \tag{3}$$

At the transmitter, a block of N modulated symbols for each user is mapped to corresponding subcarriers producing a block of M symbols. Then the IDCT is performed. After that a CP is added to the resulting signal. Finally, the resulting signal is transmitted through the wireless channel. After the IDCT, the signal can be expressed as follows by Farouk A. K. AL-fuhaidy [9]:

$$\overline{x_m} = \sqrt{\frac{2}{M}} \sum_{n=0}^{M-1} \overline{X_n}\, \beta_n \cos(\frac{\pi n(2m+1)}{2M}) \tag{4}$$

where $\bar{X}_n$ is the signal after subcarriers mapping, M is the length of the IDCT *(M = Q. N)*. Q is the bandwidth expansion factor of the symbol sequence. If all terminals transmit N symbols per block, the system can handle Q simultaneous transmissions without co-channel interference.

Under a frequency selective channel assumption, adding a CP of length N_c is very important. The length of the CP must be greater than the maximum excess delay of the channel to prevent the inter-block interference (IBI) as in Hyung. G. Myung, and Faisal. S. Al-kamali [4, 12]. At the receiver, the CP is removed and the received signal can be expressed as follows:

$$r = H\bar{x} + n \tag{5}$$

where $\bar{x}$ is an $M \times 1$ representing the transmitted samples, r is is an $M\times1$ containing the received samples. The matrix H is an $M\times M$ circulant matrix describing the multipath channel. Equalization is performed in the frequency domain using either minimum mean square error (MMSE), zero forcing (ZF) or regulized zero forcing (RZF). Therefore, the received signal is transformed to frequency domain using M-point DFT. Then after applying MMSE equalization, *M-point* IDFT is performed. Finally, an *M-point* DCT is applied and subcarrier demapping for the desired user is performed before the demodulation of symbols.

The main difference of the DCT OFDMA system with respect to the DFT OFDMA system is the need for an FDE at the receiver prior to the demapping process. On the other hand, the complexity of the FDE is of *O (M)* for the DCT OFDMA system and of *O (N)* for the DFT OFDMA system. If the fast implementation algorithms are taken into consideration, the fast DCT algorithm proposed by S. C. Thompson, which provides fewer computational steps than DFT. This indicates that the computational complexity of the transmitter in the DCT-based OFDMA system is lower than the computation complexity of the DFT-based OFDMA system as in S. C. Thompson [15].

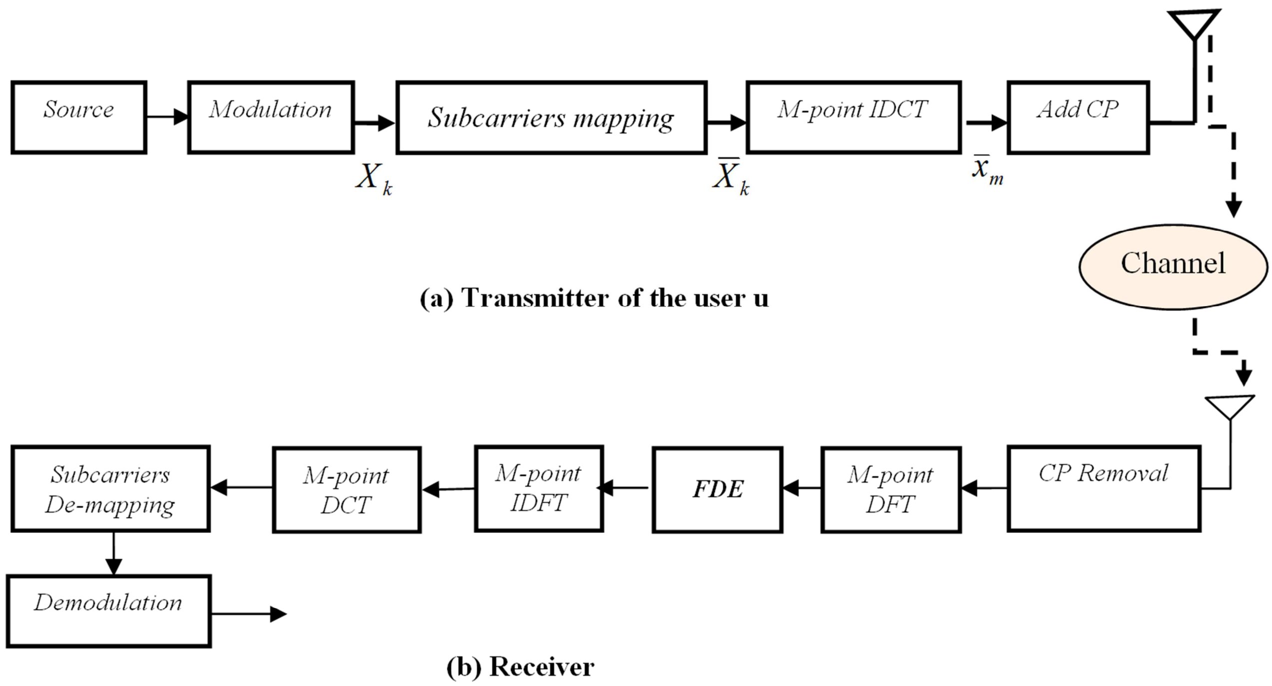

Figure 1. *A block diagram of DCT-OFDMA system [9].*

The Proposed DST OFDMA System

The proposed system by this paper, the DST-based OFDMA (DST-OFDMA) system is presented by this subsection. It is quite similar to that of the DCT-OFDMA System except replacing the IDCT with IDST at the transmitter and the DCT with DST at the receiver. Since the complex exponential functions set are not the only orthogonal basis that can be used to construct baseband multi-carrier signals. A single set of cosinusoidal or sinusoidal functions can be used as an orthogonal basis to implement the multicarrier scheme in R. Nogueroles, and Faisal. S. AL-Kamali [8, 10]. Figure 2 illustrates the transceiver block diagram of the DST-OFDMA system. At the transmitter, the input data sequence of the u^{th} user is encoded. The coded bits are mapped to multilevel symbols in one of modulation formats such as quadrature phase shift keying (QPSK), and 16-quadrature amplitude modulation (16QAM). The modulated symbols are grouped into blocks, each containing N symbols, followed by the subcarrier mapping block assigns these symbols into M ($\geq N$) subcarriers that can be transmitted, and inserts zeros into any unused subcarriers. After performing an M-point IDST, a cyclic prefix (CP) is appended at the head of IDST outputs.

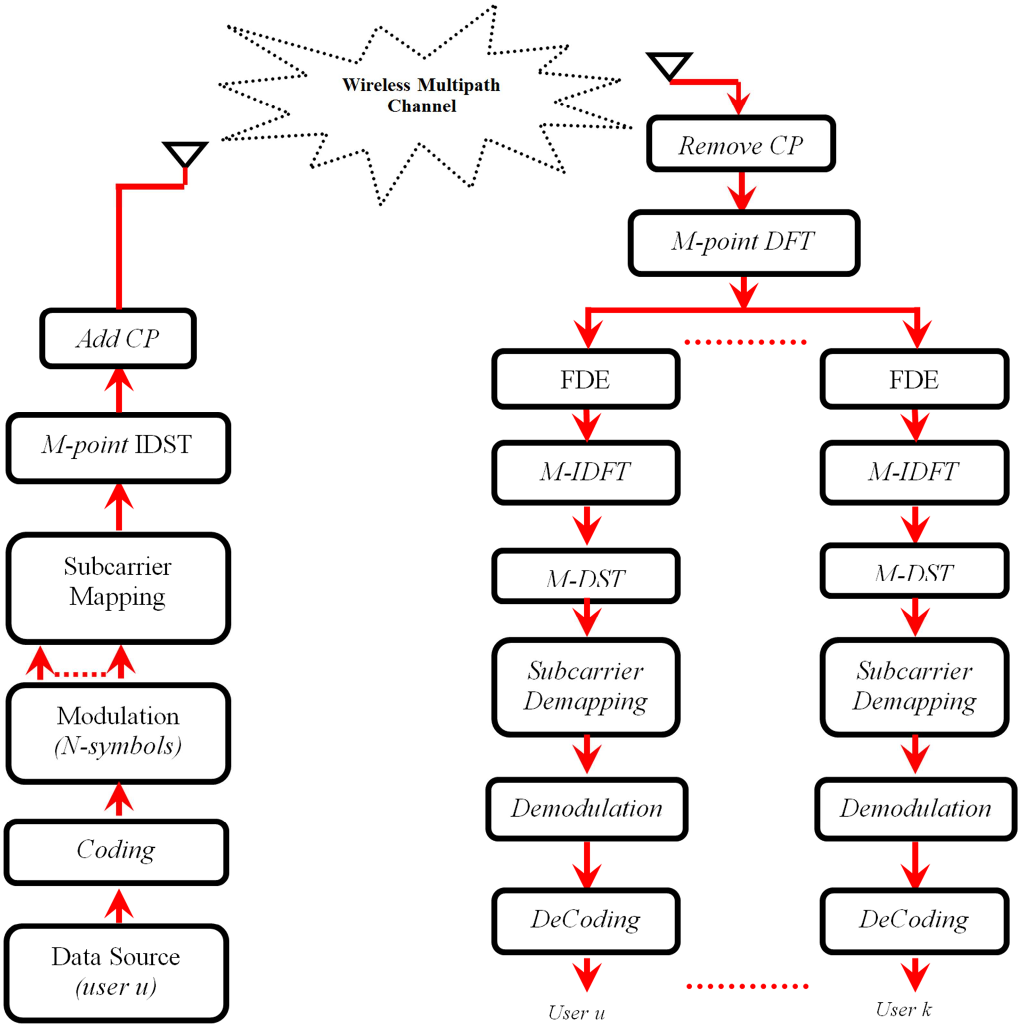

Figure 2. *A block diagram of the proposed DST-based OFDMA transceiver scheme.*

In matrix notation, the transmitted signal of the *uth* user (u = 1, 2,…., U) can be formulated as follows:

$$\tilde{x} = \prod S_M^{-1} \Gamma_u x_u \tag{6}$$

where x_u is an $N\times 1$ vector containing the modulated symbols of the u^{th} user. S_M^{-1} is the $M\times M$ IDST matrix. Γ_u is an $M\times N$ matrix describing the subcarriers mapping of the u^{th} user. $M = Q.\ N$, where Q is the maximum number of users that can transmit simultaneously. $\prod$ is an $(M+N_C)\times M$ matrix, which adds a CP of length N_C. The entries of Γ_u for both the localized and the interleaved systems are given in Eqns. (7) and (8) respectively:

$$\Gamma_u = [0_{(u-1)N\times N}; I_N; 0_{(M-uN)\times N}] \quad (7)$$

$$\Gamma_u = [0_{(u-1)\times N}; u_1^T; 0_{(Q-u)\times N}; \dots; 0_{(u-1)\times N}; u_N^T 0_{(Q-u)\times N} \quad (8)$$

where I_N and $0_{Q'\times N}$ matrices denotes the $N\times N$ identity matrix, and the $Q'\times N$ all-zero matrix, respectively. u_l $(l = 1, 2,\dots,N)$ denotes the unit column vector, of length N, with all zero entries except at l. Π can be represented as follows:

$$\Pi = [C, I_M]^T \quad (9)$$

$$C = [0_{N_C\times(M-N_C)}, I_{N_C}]^T \quad (10)$$

At the receiver side, the CP is removed from the received signal and the received signal can be written as follows:

$$r = \sum_{u=1}^{U} H_u \bar{x}_u + n \quad (11)$$

$\bar{x}_u$ is an $M\times 1$ vector representing the block of the transmitted symbols of the u^{th} user. H_u is an $M\times M$ circulant matrix describing the multipath channel between the u^{th} user and the base station. n is an $M\times 1$ vector describing the additive noise. Appling the DFT, we get,

$$R = \sum_{u=1}^{U} \Lambda_u F_M \bar{x}_u + N \quad (12)$$

where Λ_u is an $M\times M$ diagonal matrix containing the DFT of the circulant sequence of H_u. N is the DFT of n. F_M is an $M\times M$ DFT matrix. The generic M-point DFT matrix has entries $[F_M]_{p,q} = e^{-j2\pi pq/M}$, and its inverse DFT (IDFT) is $F_M^{-1} = \frac{1}{M} F_M^H$. After that, the FDE, the M-point IDFT, and the DST-OFDMA demodulation operations are performed to provide the estimate of the modulated symbols as follows:

$$\hat{x}_u = \Gamma_u^T S_M F_M^{-1} W_u R \quad (13)$$

where W_u is the $M\times M$ FDE matrix of the u^{th} user. Finally, the demodulation and the decoding processes are applied.

Peak Power Problem

The peak power problem causes the nonlinear distortion in the power amplifier and reduces power efficiency, as explained and suggesting some linear and nonlinear techniques for PAPR reduction by J. Armstrong, and Seng-Hung Wang [13, 14]. The metric used to measure the impact of this problem is the PAPR. PAPR is a commonly used measure of the range of a signal's amplitude. It is a reasonably good qualitative measure; signals with low PAPR generally require less power backoff and exhibit less performance sensitivity when amplified by a nonlinear power amplifier than do signals with high PAPR as explained in S. C. Thompson, Khalid. M. Al-sofi, and Farouk. A. Al-Fuhaidy [15, 16, 17]. An informative metric is the complementary cumulative distribution (CCDF) function of the signal amplitude measured over many samples. CCDF is the probability that the PAPR is higher than a certain PAPR value. The PAPR in dB can be expressed as in Farouk. A. Al-Fuhaidy [9]:

$$PAPR(dB) = 10\log_{10}\left(\frac{max(|x(m)|^2)}{\frac{1}{M}\sum_{m=0}^{M-1}|x(m)|^2}\right) \quad (14)$$

where $x(m)$ is the m^{th} symbol of the transmitted signal.

Simulations and Results

This section presents simulations results for the proposed system, the DST-OFDMA, and compares it to the conventional DFT-OFDMA, and the recently proposed DCT-OFDMA systems, for different subcarrier mapping techniques, the localized and the interleaved.

Simulation Parameters

A Monte Carlo simulation using Matlab environment is carried to evaluate the performance of the proposed DST-OFDMA system with different subcarriers mapping techniques. For comparison purposes, the DFT-OFDMA, and the DCT-OFDMA systems are also simulated. For the simulated DST-OFDMA system, each user occupies 64 subcarriers. The total number of subcarriers $M = 256$ and the number of users $U = 4$. In each Monte Carlo realization, all subcarriers are assigned among all users according to the subcarriers mapping technique used. QPSK and 16QAM modulation schemes are used to generate a transmitted block for each user. The channel model used for simulations is the vehicular A model used in Hyung. G. Myung, Faisal. S. Al-kamali, Farouk. A. Al-Fuhaidy, and Khalid. M. Al-sofi [3, 4, 5, 9, 16]. A convolutional code with memory length 7 and octal generator polynomials (133, 171) is chosen as the channel code. The simulation parameters which are used for simulation of the DST-OFDMA, the DCT-OFDMA, and the DFT-OFDMA are listed in Table 1.

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

Description	**Parameter**
System Bandwidth	5 MHz
Modulation	QPSK, and 16-QAM
CP	20 samples
IDFT size	256
Subcarrier Spacing	9.765625 kHz
OFDMA input Block size	64 symbols
Subcarrier Mapping	Localized and Interleaved
Channel Model	Vehicular A outdoor Channel
Noise Environment	AWGN
Channel Estimation	Perfect Channel
Equalization	MMSE

Performance Simulation and Evaluation of the Proposed System

In this subsection, the performance of the proposed system is introduced. Two different key parameters those determine the performance of the proposed system are simulated and studied, the BER and the PAPR.

BER Performance

In this subsection, the BER performance of the proposed DST-OFDMA system is presented, studied and compared to the DCT-based and DFT-based OFDMA systems using Matlab simulation results. Figures, 3 and 4 present the BER performance of the proposed system for different subcarrier mapping and different modulation techniques, QPSK and 16QAM respectively. The BER performance of the proposed system is compared to the conventional DFT-based and the recently proposed DCT-based systems. It is clear that the proposed system provides better BER performance when compared to the other systems, whenever, QPSK or 16QAM modulation is used. From figure 3, it can be seen that, at a BER=10^{-2} with QPSK and interleaved mapping, the performance gain is about 4 dB for the DST-based system, and about 1.5 dB for the DCT-based system when compared to that of the conventional DFT-based system, respectively. Moreover, the performance gain at same BER with QPSK and localized mapping is about 5 dB for the DST-based system and about 3.5 dB for the DCT-based system when compared to the conventional DFT-based system, respectively. This is attributed to the energy concentration property of the DST. From figure 4, it can be seen also that, at BER = 10^{-2} with 16QAM, the performance gain is about 3 dB for the DST-IOFDMA system, and about 3.5 dB for the DST-LOFDMA system when compared to the DCT-IOFDMA and DFT-IOFDMA systems, and DCT-LOFDMA and DFT-LOFDMA systems respectively. It is clear from figures 3 & 4 that the proposed system, the DST-OFDMA, introduces a significant BER improvement when compared to the conventional DFT-OFDMA and the DCT-OFDMA systems. This is intuitively what was expect, due to the energy concentration property of the DST. This improvement in BER is the key requirement by wireless broadband communication.

PAPR Performance

Figures 5 and 6 illustrate the CCDFs of the PAPR for DST-OFDMA, DCT-OFDMA, and DFT-OFDMA signals for the case of QPSK and 16QAM. From figures, it is shown that the DST-based and the DFT-based systems provide approximately the same CCDFs. Where, the DCT-based system produce a small increase noted for the CCDF=10^{-3} is about 0.4 dB increased. This small effect of DCT-based system can be considered of no neglectable effect on the system performance.

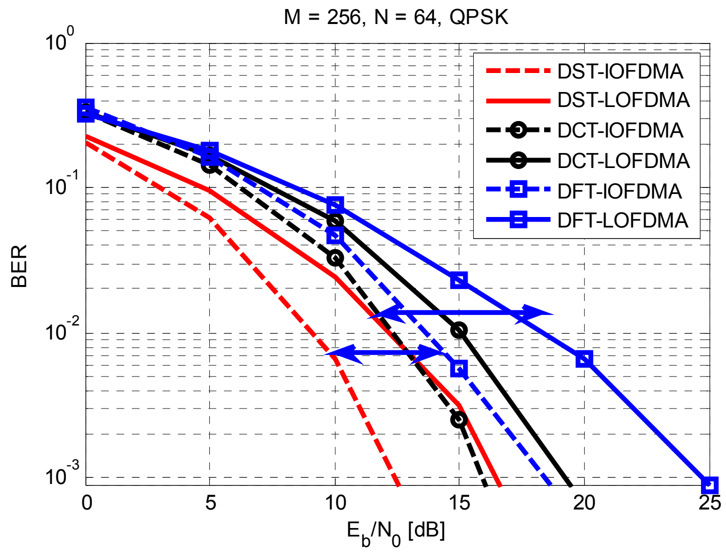

Figure 3. *BER versus* E_b/N_0 *for OFDMA systems and QPSK.*

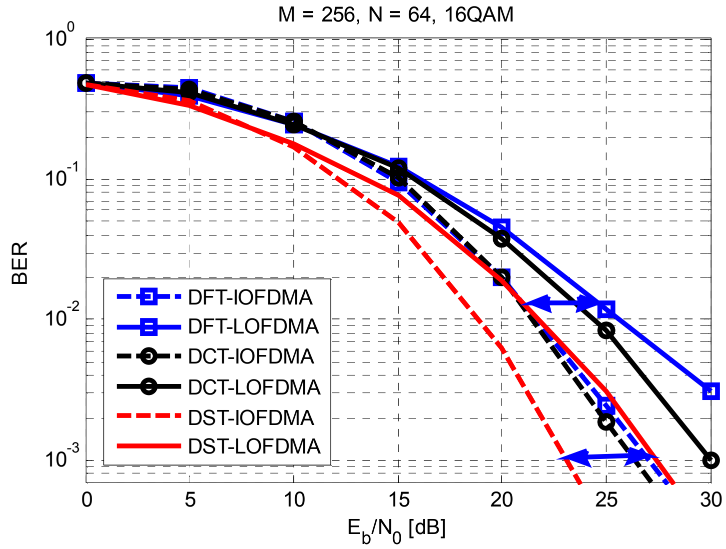

Figure 4. *BER versus* E_b/N_0 *for OFDMA systems and 16QAM.*

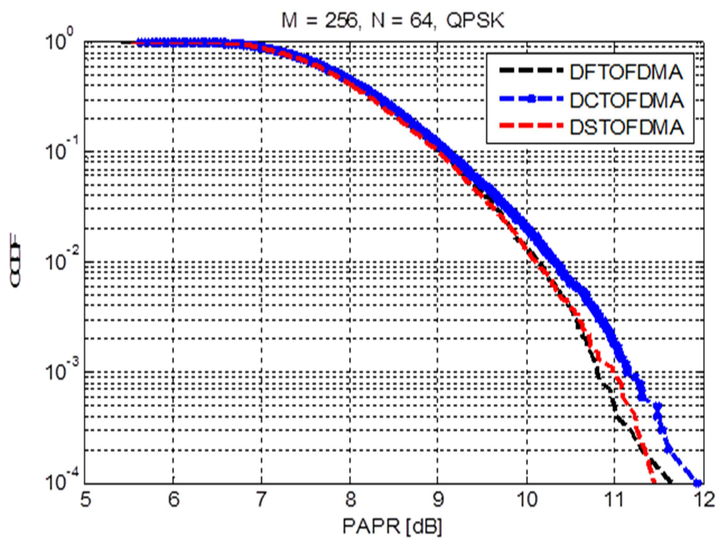

Figure 5. *CCDFs of the PAPR for OFDMA systems and QPSK.*

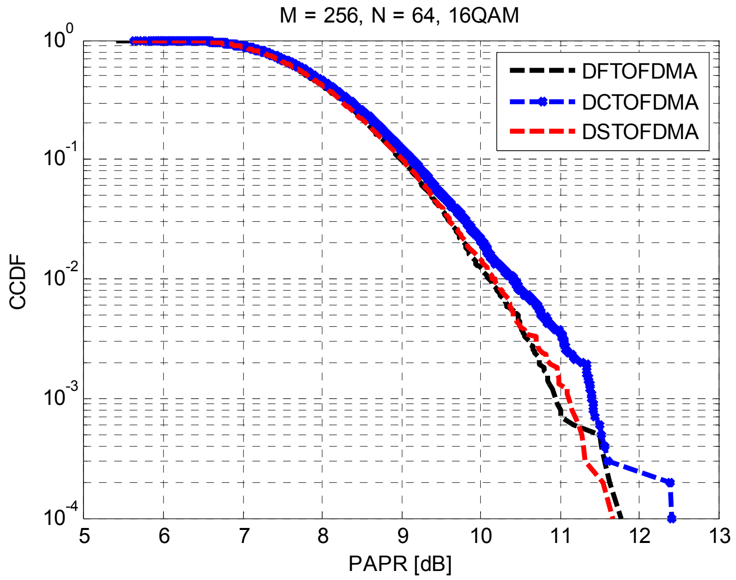

Figure 6. *CCDFs of the PAPR for OFDMA systems and 16QAM.*

Conclusions

This paper was proposed and investigated using simulation a new OFDMA system based on DST-basis function. This system was called the DST-OFDMA. The proposed system has the main advantage which is the improved BER performance, at the same PAPR performance compared to the conventional system. These are potential problems in broadband communications. It was being noticed a significant improvement in BER performance by a gain approaches 5 db. The proposed system proves its improvement with different modulation techniques, the QPSK and 16QAM. Moreover, this improvement also verified for two different subcarrier mapping techniques, the localized and the interleaved. However, the recently proposed DCT-OFDMA system provides an improvement in BER when compared to the conventional system in terms of BER with tradeoff small increase in PAPR. The proposed system, the DST-OFDMA introduces significant improvement in the BER performance compared to the DFT-OFDMA and DCT-OFDMA systems with the same PAPR of the DFT-OFDMA system. The high growth of the broadband communication requires a high increase in bandwidth and the capacity of transmission link, so, this paper focuses and provides a significant improvement in BER. ■

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