A Novel Radon-Wavelet-Based Multi-Carrier Code Division Multiple Access Transceiver Design and Simulation under Different Channel Conditions

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Abstract: *Wireless digital communication networks are rapidly expanding resulting in a demand for reliable and high spectral efficiency systems. Multi-Carrier Code Division Multiple Access (MC-CDMA) has emerged recently as a promising candidate for the next generation broad-band mobile networks. Also it was found recently that Radon-discrete wavelet transform (DWT) based Orthogonal Frequency Division Multiplexing (OFDM) is capable of reducing the Inter Symbol Interference (ISI) and the Inter Carrier Interference (ICI), which are caused by the loss of orthogonality between the carriers. Radon-DWT-OFDM can also support much higher spectrum efficiency than Fast Fourier Transform-based OFDM (FFT-OFDM). In this paper a novel Radon-DWT-MC-CDMA transceiver design will be presented based on the Radon-DWT-OFDM that is used as a basic building block in the design of MC-CDMA transceiver to increase the orthogonality against the multi-path frequency selective fading channels. Simulation results are provided to demonstrate the significant gains in performance and simplicity due to the proposed technique. The Bit Error Rate (BER) performance of the proposed Radon-DWT-MC-CDMA scheme was compared with that of FFT based MC-CDMA, Radon based MC-CDMA, and Discrete Multiwavelet Transform (DMWT) based CDMA and tested in AWGN, Flat fading and Selective fading channels. The simulation results showed that proposed system outperforms the other systems.*

Keywords: *Finite radon transform, DWT, radon-wavelet based OFDM, multiwavelet based MC-CDMA, radon based MC-CDMA, FFT based MC-CDMA.*

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1. Introduction

Multi-path fading channels have a severe effect on the performance of wireless communication systems even those systems that exhibits efficient bandwidth, like OFDM and MC-CDMA [13], there is always a need for developments in the realization of these systems as well as efficient channel estimation and equalization methods to enable these systems to reach their maximum performance [2].

CDMA has been a strong candidate to support multimedia mobile services because it has the ability to cope with the asynchronous nature of the multimedia traffic and it can provide higher capacity as opposed to the conventional access schemes [17, 25]. The main problem in the design of a communications system over a wireless link is to deal with multi-path fading, which causes a significant degradation in terms of both the reliability of the link and the data rate [22].

Recently, a number of MC-CDMA systems have been proposed as an alternative to the classical single-carrier CDMA systems [4, 5, 12, 26, 27]. The principle of CDMA was combined with OFDM which allows one to use the available spectrum in an efficient way and retain the many advantages of a CDMA system [2]. This combination of OFDM-CDMA or Multi-Carrier CDMA was first proposed in [29]. It is a useful technique for 4G systems where variable data rates as well as reliable communication systems are needed. Combining OFDM with CDMA has one major advantage; it can lower the symbol rate in each subcarrier compared to OFDM so that longer symbol duration makes it easier to synchronize. MC-CDMA not only mitigates the ISI but also exploits the multipath [6]. In [3] the same idea was proposed and the performance of Maximum Likelihood Detection for MC-CDMA systems was analyzed.

In [21], the conventional Fourier based complex exponential carriers of the OFDM system was replaced with some orthonormal wavelets in order to reduce the level of interference. The wavelets are derived from multistage tree-structured Haar and Daubechies orthonormal quadrature mirror filter bank. Comparing with the conventional OFDM, it was found that the Haar and Daubechies-based orthonormal wavelets are capable of reducing the power of ISI and ICI.

The FFT-OFDM has currently drawn most of attention in the area of wireless communication. To combat ISI and ICI, cyclic prefix is inserted between FFT-OFDM symbols which take around 25 percent of bandwidth. To improve bandwidth efficiency and reduce ISI and ICI, DWT-OFDM was proposed. In [31] FFT-OFDM and DWT-OFDM were studied at different transmission scenarios. In [9] a Discrete

Multiwavelet OFDM system was proposed and studied under different channel conditions and in [10] a novel Radon multi-carrier direct sequence system was proposed and simulated in different scenarios. In [14] ICI and its effects on performance of OFDM systems were studied and in [15] BER of OFDM in Rayleigh fading environments with selective diversity is discussed.

DWT-based MC-CDMA has recently gained popularity in literature due to very high spectral containment properties of wavelet filters [16, 19, 20, 28, 30, 32]. Wavelet-based MC-CDMA can better combat narrowband interferences and more robust to ICI than traditional FFT filters. Moreover, since the classic notion of a guard band does not apply for DWT-MC-CDMA; data rates can be enhanced over those of FFT implementations.

In this paper FFT-OFDM is replaced by Radon-DWT-OFDM in order to further reduce the level of interference and increase spectral efficiency. We provide the performance comparisons of FFT-MC-CDMA, Radon-MC-CDMA, DMWT-MC-CDMA, and Radon-DWT-MC-CDMA on three different channel models: AWGN, flat fading and selective fading. Simulation results show that proposed design achieves much lower bit error rates, increases Signal to Noise power Ratio (SNR), and can be used as an alternative to the conventional MC-CDMA.

2. MC-CDMA System

The MC-CDMA transmitter spreads the original data stream over different subcarriers using a given spreading code in the frequency domain [3, 29]. Figures 1 and 2 show the MC-CDMA transmitter of the k_{th} user for BPSK scheme and the power spectrum of the transmitted signal respectively [5], where $d_k(t)$ is the data bits for k_{th} user, G_{MC} denotes the processing gain, N_C is the number of subcarriers and $c_k(t)=[c_k^1 c_k^2 \cdots c_k^{G_{MC}}]$ is the spreading Pseudo-random Noise (PN) sequence of the k_{th} user. It is assumed that N_C=G_{MC} as in [29], however N_C do not have to be equal to G_{MC} as in [5].

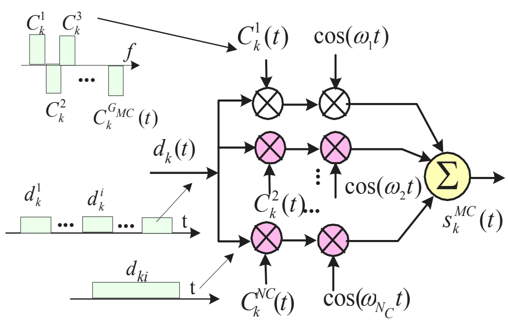

Figure 1. MC-CDMA transmitter system model.

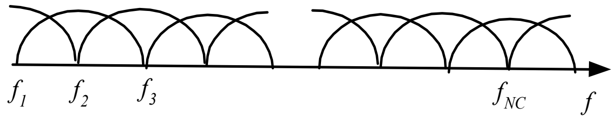

Figure 2. Power spectrum representation of the transmitted signal.

In MC-CDMA systems, the original data stream from a user is spread with the user's specific spreading code in the frequency domain. In other words, a fraction of the symbol corresponding to a chip of the spreading code is transmitted through a different subcarrier. The narrowband subcarriers are generated using BPSK modulated signals, each at different frequencies, which at baseband are multiples of a harmonic frequency $1/T_S$. That is:

$$\Delta f = f_i - f_{i-1} = 1/T_S \tag{1}$$

Where, T_S is the symbol duration of data stream. The subcarrier frequencies are orthogonal to each other at baseband. The transmitted signal of the k_{th} user is given by:

$$S_k^{MC}(t) = d_k(t)\sum_{i=1}^{N_C} c_k^i \cos\omega_i t \tag{2}$$

And the total bandwidth required for transmission is $(N_C+1)G_{MC}/N_C T_S$. Figure 3 shows the receiver of MC-CDMA systems [5]. The received signal $r(t)$ for all K users is given as:

$$r(t) = \sum_{k=1}^{K} d_k(t)\sum_{i=1}^{N_C} h(i)c_k^i \cos\omega_i t + n(t) \tag{3}$$

Where *n(t)* is the Additive White Gaussian Noise (AWGN) and *h(i)* is the complex signal channel coefficient of the i_{th} subcarrier. The received signal is demodulated with corresponding subcarrier followed by lowpass filtering to generate the baseband signal.

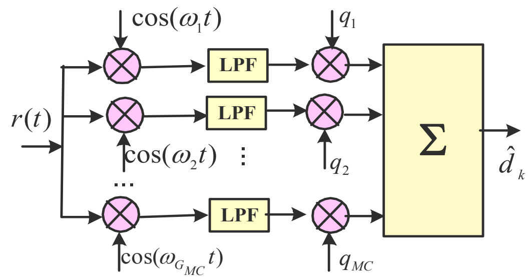

Figure 3. MC-CDMA receiver system model.

The baseband signal is weighted by coefficients $\{q_i, i=1,2,...,G_{MC}\}$, then all baseband signals are combined together. From Figure 3 it can be seen that the received signal is combined in the frequency domain therefore the receiver can always employ all the received signal energy scattered in the frequency domain. This is the advantage of MC-

CDMA [3, 29]. Different combining techniques to enhance the system performance can be used, which correspond to different choices of $\{q_i, i = 1,2,...,G_{MC}\}$. Typical combining techniques include maximum ratio combining, equal gain combining [29] and minimum mean square error combining [3]. The drawback of this system is that, it does not consider the multipath and fading effects.

3. The Radon-Wavelet Based OFDM Transceiver

Due to good orthogonality of both DWT and Finite Radon Transform (FRAT) which reduces ISI and ICI, in Radon-DWT-OFDM system there is no need of using Cyclic Prefix (CP) [11]. The block diagram of the Radon-wavelet based OFDM system is depicted in Figure 4 and the Inverse Discrete Wavelet Transform (IDWT) modulator and DWT demodulator are shown in Figure 5.

The processes of Serial to Parallel (S/P) converter, signal demapper, insertion of training sequence, and zero padding operation are the same as in the FFT-OFDM. After that the IDWT is applied to the signal. The main and important difference between FFT based OFDM and DWT based OFDM is that in DWT based OFDM cyclic prefix is not added to OFDM symbols. Therefore the data rates in DWT based OFDM is higher than those of the FFT based OFDM. At the receiver, the zeros padded at the transmitter are removed, and the other operations of channel estimation, channel compensation, signal demapping and Parallel to Serial (P/S) conversion are performed in the same manner as in FFT based OFDM.

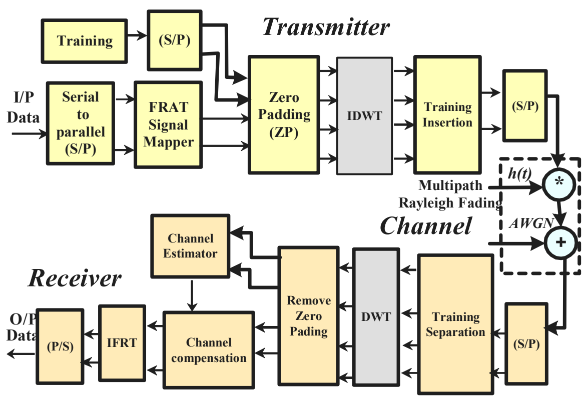

Figure 4. Block diagram of FRAT-DWT based OFDM system.

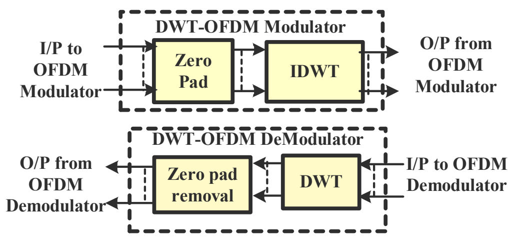

Figure 5. DWT-OFDM modulation- demodulation.

In conventional OFDM system, the length of input data frame is 60 symbols, and after (S/P) conversion and QAM mapping the length becomes 30 symbols. Zero padding operation makes the length 64 symbols which are the input to IFFT (sub-carrier modulation). After adding CP (usually 40% of the length of the frame), the frame length becomes 90 symbols. Since OFDM operations applied to training symbols are the same as those applied to transmitted data (except the mapping operation), the length of training symbols is also 90 symbols. The training and data frames are transmitted as one frame starting with training, so the length of transmitted frame is 180 symbols [24].

In Radon-DWT OFDM system, the length of the input data frame must be ($p \times p$), where p is a prime number [1]. The closest number to 60 is (7×7) which makes the frame length 49 symbols. This is because the input of FRAT must be a two dimensional matrix with size ($p \times p$).

The procedure steps of using the Radon based OFDM mapping implemented in this design is as follows [7, 8]:

- *Step 1*: Suppose $d(k)$ is the serial data stream to be transmitted using OFDM modulation scheme. Converting $d(k)$ from serial form to parallel form will construct a one dimensional vector containing the data symbols to be transmitted:

$$d(k) = (d_0 \; d_1 \; d_2 \; ...... \; d_n)^T \tag{4}$$

Where, k and n are the time index and the vector length respectively.

- *Step 2*: Convert the data packet represented by the vector *d(k)* from one-dimensional vector to a $p \times p$ two dimensional matrix *D(k)*, where p should be a prime number according to the matrix resize operation.
- *Step 3*: Take the 2-D FFT of the matrix *D(k)* to obtain the matrix, $F(r,s)$. For simplicity it will be labeled by F.

$$F(r,s) = \sum_{m=0}^{p-1}\sum_{n=0}^{p-1} D(m,n) e^{-j(2\pi/p)rm} e^{-j(2\pi/p)ns} \tag{5}$$

- *Step 4*: Redistribute the elements of the matrix F according to the optimum ordering algorithm given in [18]. So, the dimensions of the resultant matrix will be $p \times (p+1)$ and will be denoted by the symbol $\mathcal{F}_{opt}$. The two matrixes for FRAT window=7 are given by:

$$\mathcal{F} = \begin{bmatrix} f_1 & f_8 & f_{15} & f_{22} & f_{29} & f_{36} & f_{43} \\ f_2 & f_9 & f_{16} & f_{23} & f_{30} & f_{37} & f_{44} \\ f_3 & f_{10} & f_{17} & f_{24} & f_{31} & f_{38} & f_{45} \\ f_4 & f_{11} & f_{18} & f_{25} & f_{32} & f_{39} & f_{46} \\ f_5 & f_{12} & f_{19} & f_{26} & f_{33} & f_{40} & f_{47} \\ f_6 & f_{13} & f_{20} & f_{27} & f_{34} & f_{41} & f_{48} \\ f_7 & f_{14} & f_{21} & f_{28} & f_{35} & f_{42} & f_{49} \end{bmatrix} \tag{6}$$

$$\mathcal{F}_{opt} = \begin{bmatrix} f_1 & f_1 & f_1 & f_1 & f_1 & f_1 & f_1 & f_1 \\ f_2 & f_{10} & f_9 & f_{16} & f_8 & f_{21} & f_{14} & f_{13} \\ f_3 & f_{19} & f_{17} & f_{31} & f_{15} & f_{34} & f_{20} & f_{18} \\ f_4 & f_{28} & f_{25} & f_{46} & f_{22} & f_{47} & f_{26} & f_{23} \\ f_5 & f_{30} & f_{33} & f_{12} & f_{29} & f_{11} & f_{32} & f_{35} \\ f_6 & f_{39} & f_{41} & f_{27} & f_{36} & f_{24} & f_{38} & f_{40} \\ f_7 & f_{48} & f_{49} & f_{42} & f_{43} & f_{37} & f_{44} & f_{45} \end{bmatrix} \quad (7)$$

- *Step 5*: Take the 1D-IFFT for each column of the matrix $\mathcal{F}_{opt}$ to obtain the matrix of Radon coefficients R:

$$R = \frac{1}{p}\sum_{k=0}^{N-1} F_{opt}\, e^{\frac{j2\pi kn}{p}} \quad (8)$$

- *Step 6*: Construct the complex matrix $\overline{R}$ from the real matrix R such that its dimensions will be $p\times(p+1)/2$ according to:

$$\overline{r_{l,m}} = r_{i,j} + j \quad r_{i,j+1}\ , 0 \le i \le p, 0 \le j \le p \quad (9)$$

Where, $\overline{r_{l,m}}$ refers to the elements of the matrix $\overline{R}$, while $r_{i,j}$ refers to the elements of the matrix R. matrixes R and $\overline{R}$ are given by:

$$\mathcal{R} = \begin{bmatrix} r_{1,1} & r_{1,2} & r_{1,3} & \cdots\cdots & r_{1,p+1} \\ r_{2,1} & r_{2,2} & r_{2,3} & \cdots\cdots & r_{2,p+1} \\ \vdots & \vdots & \vdots & \cdots\cdots & \vdots \\ \vdots & \vdots & \vdots & \cdots\cdots & \vdots \\ r_{p-1,1} & r_{p-1,2} & & \cdots\cdots & r_{p-1,p+1} \\ r_{p,1} & r_{p,2} & r_{p,3} & \cdots\cdots & r_{p,p+1} \end{bmatrix} \quad (10)$$

$$\overline{\mathcal{R}} = \begin{bmatrix} r_{1,1}+jr_{1,2} & r_{1,3}+jr_{1,4} & \cdots\cdots & r_{1,p}+jr_{1,p+1} \\ r_{2,1}+jr_{2,2} & r_{2,3}+jr_{2,4} & \cdots\cdots & r_{2,p}+jr_{2,p+1} \\ \vdots\ \vdots\ \vdots & \cdots\cdots & \vdots & \vdots \\ \vdots\ \vdots\ \vdots & \cdots\cdots & \vdots & \vdots \\ r_{p-1,1}+jr_{p-1,2} & \cdots\cdots & & r_{p-1,p}+jr_{p-1,p+1} \\ r_{p1}+jr_{p2} & \cdots\cdots & & r_{p,p}+jr_{p,p+1} \end{bmatrix} \quad (11)$$

Complex matrix construction is made for a purpose of increasing bit per Hertz of mapping before resizing mapped data.

- *Step 7*: Resize the matrix $\overline{R}$ to a one dimensional vector $r(k)$ of length $p\times(p+1)/2$.

$$r(k) = \left(r_0\ r_1\ r_2\ \ldots\ldots\ r_{p(p+1)/2}\right)^T \quad (12)$$

- *Step 8*: Take the 1D-IFFT for the vector, $r(k)$ to obtain the sub-channel modulation.

$$s(k) = \frac{1}{p(p+1)/2}\sum_{k=0}^{N_C-1} r(k)\, e^{\frac{j2\pi kn}{p(p+1)/2}} \quad (13)$$

Where N_C number of carriers.

- *Step 9*: Finally, convert the vector $s(k)$ to serial data symbols: $s_0, s_1, s_2, \ldots\ldots, s_n$.

The algorithm of computing a single level Fast Discrete Wavelet Transform (FDWT) for one-dimensional signal is as follows:

- *Check Input Dimensions*: Input vector should be of length *N*, where *N* must be power of two.
- *Construct the Transformation Matrix*: If the number of coefficients is two then the transformation matrix is given by equation 14:

$$T_r = \begin{bmatrix} h(0) & h(1) & 0 & 0 & \cdots & \cdots & & \\ 0 & 0 & h(0) & h(1) & \cdots & \cdots & & \\ \vdots & \vdots & \vdots & \vdots & \cdots & \cdots & & \\ 0 & 0 & 0 & 0 & \cdots & \cdots & h(0) & h(1) \\ h(1) & -h(0) & 0 & 0 & \cdots & \cdots & & \\ 0 & 0 & h(1) & -h(0) & \cdots & \cdots & \vdots & \vdots \\ \vdots & \vdots & \vdots & \vdots & \cdots & \cdots & & \\ 0 & 0 & 0 & 0 & \cdots & \cdots & h(1) & -h(0) \end{bmatrix} \quad (14)$$

Where $\{h(0), h(1)\} = \left\{\frac{1}{\sqrt{2}}, \frac{1}{\sqrt{2}}\right\}$, and if the number of coefficients is four, then the transformation matrix is given by equation 15:

$$T_r = \begin{bmatrix} h(0) & h(1) & h(2) & h(3) & 0 & 0 & \cdots & 0 & 0 & 0 & 0 \\ 0 & 0 & h(0) & h(1) & h(2) & h(3) & \cdots & 0 & 0 & 0 & 0 \\ \vdots & \vdots & \vdots & \vdots & \vdots & \vdots & \cdots & \vdots & \vdots & \vdots & \vdots \\ h(2) & h(3) & 0 & 0 & 0 & 0 & \cdots & 0 & 0 & h(0) & h(1) \\ h(3) & -h(2) & h(1) & -h(0) & \vdots & \vdots & \cdots & 0 & 0 & 0 & 0 \\ 0 & 0 & h(3) & -h(2) & h(1) & -h(0) & \cdots & 0 & 0 & 0 & 0 \\ \vdots & \vdots & \vdots & \vdots & \vdots & \vdots & \cdots & \vdots & \vdots & \vdots & \vdots \\ 0 & 0 & 0 & 0 & 0 & 0 & \cdots & h(3) & -h(2) & h(1) & -h(0) \\ h(1) & -h(0) & 0 & 0 & 0 & 0 & \cdots & 0 & 0 & h(3) & -h(2) \end{bmatrix} \quad (15)$$

Where $\{h(0), h(1), h(2), h(3)\} = \left\{\frac{1+\sqrt{3}}{4\sqrt{2}}, \frac{3+\sqrt{3}}{4\sqrt{2}}, \frac{3-\sqrt{3}}{4\sqrt{2}}, \frac{1-\sqrt{3}}{4\sqrt{2}}\right\}$ transform the input vector by applying matrix multiplication of the $N\times N$ transformation matrix $[T_r]_{N\times N}$ by the $N\times 1$ input vector $X_{N\times 1}$.

$$[Z]_{N\times 1} = [T_r]_{N\times N} \times [X]_{N\times 1} \quad (16)$$

To reconstruct the original signal from the discrete wavelet transformed signal, Inverse Fast Discrete Wavelet Transform (IFDWT) should be used. The inverse transformation matrix is the transpose of the transformation matrix as the transform is orthogonal. The algorithm of computing a single level IFDWT for one-dimensional signal is as follows:

- Let *X* be the *N×1* wavelet transformed vector.
- Construct *N×N* reconstruction matrix, T_i, using transformation matrices.
- If the number of coefficients is two then the reconstruction matrix is given by equation17:

$$T_i = \begin{bmatrix} h(0) & 0 & \cdots & 0 & h(1) & 0 & \cdots & 0 \\ h(1) & 0 & \cdots & 0 & -h(0) & 0 & \cdots & 0 \\ 0 & h(0) & \cdots & 0 & 0 & h(1) & \cdots & 0 \\ 0 & h(1) & \cdots & 0 & 0 & -h(0) & \cdots & 0 \\ 0 & 0 & \cdots & 0 & \cdots & \cdots & \cdots & 0 \\ \vdots & \vdots & \vdots & \vdots & \cdots & \cdots & \vdots & \vdots \\ 0 & 0 & 0 & h(0) & 0 & 0 & 0 & h(1) \\ 0 & 0 & 0 & h(1) & 0 & 0 & 0 & -h(0) \end{bmatrix} \quad (17)$$

And if the number of coefficients is four, then the reconstruction matrix is given by equation 18:

$$T_i = \begin{bmatrix} h(0) & 0 & 0 & \cdots & \cdots & h(2) & h(3) & 0 & 0 & \cdots & 0 & h(1) \\ h(1) & 0 & 0 & \cdots & \cdots & h(3) & -h(2) & 0 & 0 & \cdots & 0 & -h(0) \\ h(2) & h(0) & 0 & \cdots & \cdots & 0 & h(1) & h(3) & 0 & \cdots & 0 & 0 \\ h(3) & h(1) & 0 & \cdots & \cdots & 0 & -h(0) & -h(2) & 0 & \cdots & 0 & 0 \\ 0 & h(2) & h(0) & \cdots & \cdots & 0 & 0 & h(1) & h(3) & \cdots & 0 & 0 \\ 0 & h(3) & h(1) & \cdots & \cdots & 0 & 0 & -h(0) & -h(2) & \cdots & 0 & 0 \\ 0 & 0 & h(2) & \cdots & \cdots & 0 & 0 & 0 & h(1) & \cdots & 0 & 0 \\ 0 & 0 & h(3) & \cdots & \cdots & 0 & 0 & 0 & -h(0) & \cdots & 0 & 0 \\ \vdots & \vdots & \vdots & \vdots & \vdots & \vdots & \vdots & \vdots & \vdots & \vdots & \vdots & \vdots \\ & & & 0 & & & & & & & 0 & 0 \\ & & & 0 & h(0) & & & & & & h(3) & 0 \\ & & & 0 & h(1) & & & & & & -h(2) & 0 \\ 0 & 0 & 0 & 0 & h(2) & h(0) & & & & & h(1) & h(3) \\ 0 & 0 & 0 & 0 & h(3) & h(1) & & & & & -h(0) & -h(2) \end{bmatrix} \quad (18)$$

- Reconstruct the input vector by applying matrix multiplication of the $N \times N$ reconstruction matrix T_i by the $N \times 1$ wavelet transformed vector $[X]_{N\times 1}$.

$$[Z]_{N\times I} = [Ti]_{N\times N} \times [X]_{N\times I} \quad (19)$$

4. Proposed Realization of Radon-DWT-Based MC-CDMA

The block diagram of the proposed system for Radon-DWT-MC-CDMA is depicts in Figure 6.

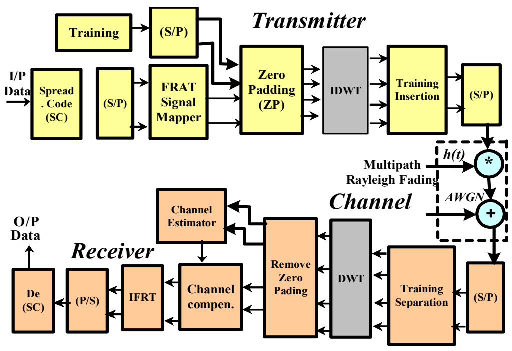

Figure 6. Block diagram of proposed Radon-DWT-MC-CDMA system.

In this design the FFT-OFDM is replaced by a Radon-DWT-OFDM which does not require a cyclic prefix, has a better performance, has a higher data rates, and has a reduced ISI and ICI compared with FFT-based OFDM. Each data symbol is multiplied with a spreading sequence, the Gold sequence spreading code can be used since it has a relatively good correlation values. Other spreading codes that have a relatively good correlation values like Walsh-Hadamard (WH) code can be used, but it can be used when a small number of users are considered, since the orthogonality of the code is reduced due to the multipath propagation [23]. Due to using FRAT in the proposed system as a signal mapper the length of the Gold sequence must be $(p \times p)$ such as (9, 25, and 49), where p is a prime number. This is because the input of FRAT must be a two dimensional matrix with size $(p \times p)$.

FRAT is used for mapping the spreading sequences. After that a pilot-carrier (training sequence) which may be a bipolar sequence $\{\pm 1\}$ previously informed to receiver is generated. The DWT-OFDM modulator-demodulator works according to procedure described in the previous section. The channel frequency response is estimated by using training and received sequences as follows:

$$H(k) = \frac{Received \;\; Training \;\; Sample \; (k)}{Transmitted \;\; Training \;\; Sample \; (k)}, k = 0,1,2,... \quad (20)$$

The channel frequency response previously found is used to compensate the channel effects on the data, and the estimated data can be found using the following equation:

$$Estimated\text{-}data(k) = H^{-1}_{estimate}(k) * Received\text{-}data(k), k = 0,1,2,... \quad (21)$$

5. Simulation Results and Discussion of the Proposed System

In this section the results of bit error performance simulations using MATLAB 7 for Radon-DWT-MC-CDMA are provided and compared with the conventional FFT-MC-CDMA, Radon-MC-CDMA, and DMWT-MC-CDMA under different channel conditions. AWGN channels, Flat Fading Channels (FFC), and multi-path frequency selective Rayleigh distributed with AWGN channels are considered during simulations. The system parameters used in the simulation are as follows: $T_s = 0.1\mu sec$, FRAT window: 5 by 5, DWT bins=32, code length $L_C = 25$.

5.1. Performance of Proposed Radon- DWT-MC-CDMA System in AWGN Channel

The BER performances of the proposed Radon-DWT-MC-CDMA and the other three MC- CDMA systems in AWGN channel are shown in Figure 7.

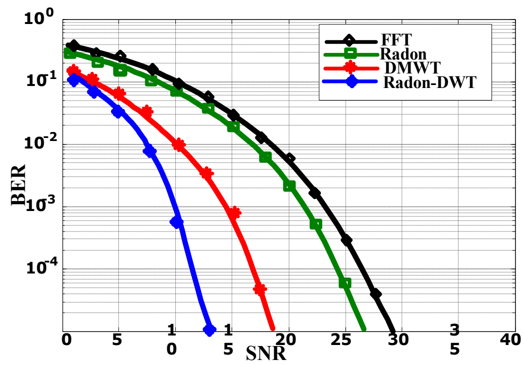

Figure 7. BER performance of FRAT-DWT based MC-CDMA in AWGN channel.

If we compare the systems when BER is equal 10^{-4}, from Figure 7 it can be noted that Radon-DWT-MC-CDMA has a SNR improvement of 5dB compared with DMWT-MC-CDMA system, a SNR gain of 13dB compared with Radon-MC-CDMA, and a SNR gain of 16dB compared with FFT-MC-CDMA system. This gain improvement achieved, increases with decreasing the required BER. Also it can be concluded that the gain achieved in CDMA when combined with OFDM is better than that achieved in OFDM only, because this combination spreads the original data stream using the spreading code and then modulates different carriers with each chip. So if a comparison is made between gain achieved in Radon-DWT-CDMA and that achieved in Radon-DWT-OFDM we can see that there is about 8dB gain.

5.2. Performance of Proposed Radon-DWT-MC-CDMA System in Flat Fading Channel with AWGN

In this channel, all signal frequency components are The BER performance of Radon-DWT-MC-CDMA in a 2-ray Rayleigh-distributed multi-path flat fading channel with a second path gain -8dB and a second path delay $\tau_{\max} = 0.1\mu\text{sec}$ is simulated. It is assumed that all frequency components of the transmitted signal are changed and correlated in phase and magnitude. Five maximum doppler shifts are used in the simulation: 4Hz, 80Hz, 300Hz, 500Hz, and 1000Hz. The results of simulation are shown in Figures 8, 9, 10, 11, and 12.

It can be shown in Figure 8 that BER performance of Radon-DWT-MC-CDMA system is much better than the other systems. It has BER=10^{-3} at SNR=10dB, DMWT-MC-CDMA has the same BER at SNR=16.5dB, Radon-MC-CDMA has BER=10^{-3} at SNR=22.5dB, while FFT-MC-CDMA system has BER=10^{-3} at SNR=25dB. This is 6.5dB gain in SNR compared with DMWT-MC-CDMA system, 12.5dB gain compared with Radon-MC-CDMA, and 15dB compared with FFT-MC-CDMA.

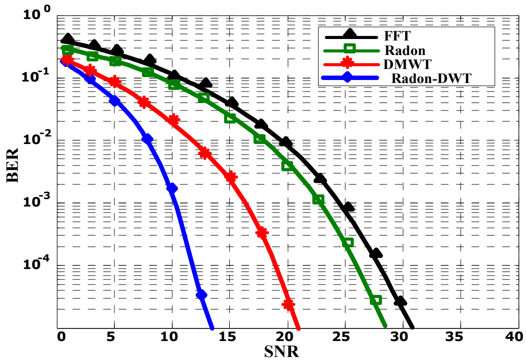

Figure 8. Performance of Radon-DWT-MC-CDMA in FFC at maximum doppler shift = 4Hz.

From the results of simulation it can be noted that all MC-CDMA systems are sensitive to variations of Doppler shift frequency however proposed system has a minimum sensitivity to variations compared with other systems. Also it can be noted that the gain achieved from proposed system increases with increasing Doppler shift frequency compared with other systems. For example to achieve BER=10^{-3} at Doppler shift=1000Hz proposed system requires SNR=15dB, while DMWT-MC-CDMA requires SNR=27dB, Radon-MC-CDMA requires SNR=32.5dB, and FFT-MC-CDMA requires SNR=37.5dB. This is a large gain improvement and an obvious advantage of proposed system.

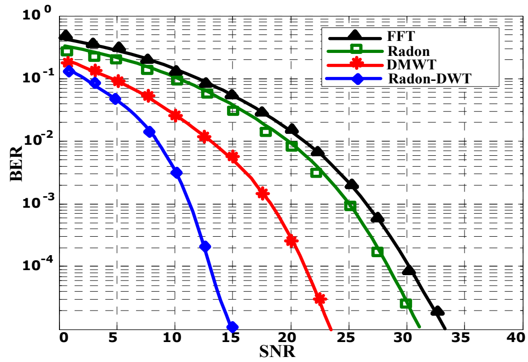

Figure 9. Performance of proposed system in FFC at max doppler shift = 80Hz.

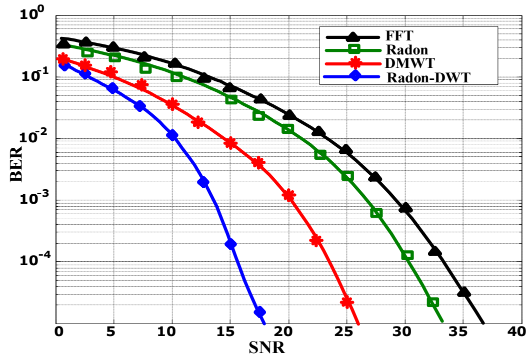

Figure 10. Performance of proposed system in FFC at max doppler shift = 300Hz.

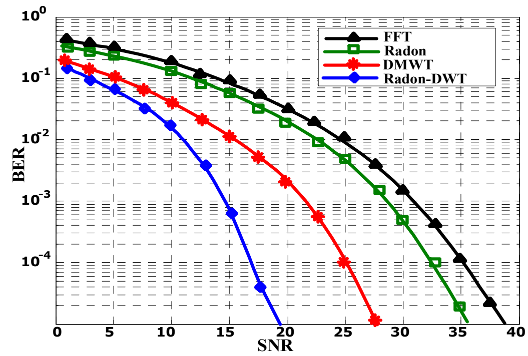

Figure 11. Performance of proposed system in FFC at max doppler shift = 500Hz.

5.3. BER Performance of the Proposed Radon-DWT-MC-CDMA System in Selective Fading Channel with AWGN

In Selective Fading Channel (SFC), the frequency complements of the transmitted signal are affected by uncorrelated changes, where the parameters of the channel correspond to two path system. For SFC many models are used in simulation and BER performance is compared for FFT-based, Radon-based, DMWT-based, and Radon-DWT-based MC-CDMA systems, the effect of path attenuation, delay and maximum Doppler shift of an echo was also taken in account. The channel in simulation is assumed to be 2-rays Rayleigh-distributed multi-path fading channel with second path gain -8dB, and second path delay $\tau_{max}=0.1\mu sec$.

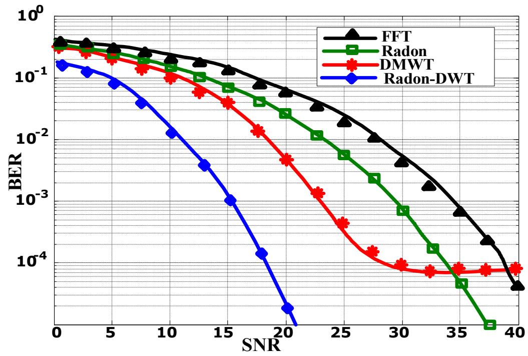

Figure 12. Performance of proposed system in FFC at max doppler shift = 1000Hz.

Figure 13 shows the BER performance simulation of the Radon-DWT-MC-CDMA, DMWT-MC-CDMA, Radon-MC-CDMA, and FFT-MC-CDMA systems for a SFC with path delay equal 1 sample, path gain equal -8dB, and Doppler shift equal 4Hz. It can be shown in Figure 13 that BER performance of Radon-DWT-MC-CDMA system is much better than the other systems for such type of channels. Proposed system has BER=10^{-5} at SNR=16dB, DMWT-MC-CDMA has the same BER at SNR=22.5dB, Radon-MC-CDMA has BER=10^{-5} at SNR=29dB, while FFT-MC-CDMA system has BER=10^{-5} at SNR=33.5dB. This is 6.5dB gain in SNR compared with DMWT-MC-CDMA system, 13dB gain compared with Radon-MC-CDMA, and 17.5dB compared with FFT-MC-CDMA.

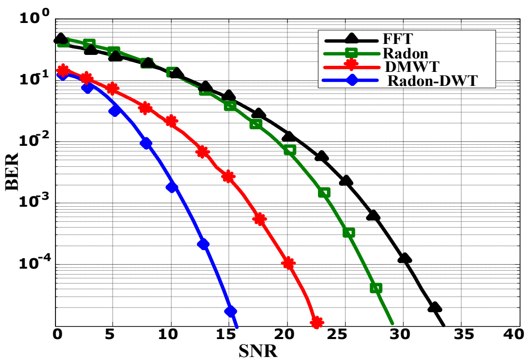

Figure 13. Performance of Radon-DWT-MC-CDMA in SFC at maximum doppler shift = 4Hz.

Figures 14, 15, 16, and 17 repeat the BER performance simulation of the four systems for SFC with the same channel parameters except changing Doppler shift to 80Hz, 300Hz, 500Hz, and 1000Hz respectively. It can be seen from plots that Radon-DMWT-MC-CDMA system has better performance than DMWT-MC-CDMA, Radon-MC-CDMA, and FFT-MC-CDMA systems. Also proposed system is very stable with variation of Doppler frequency in selective fading channel especially when Doppler frequency exceeds to 1000 Hz and this is clearly shwon in Figures 16 and 17.

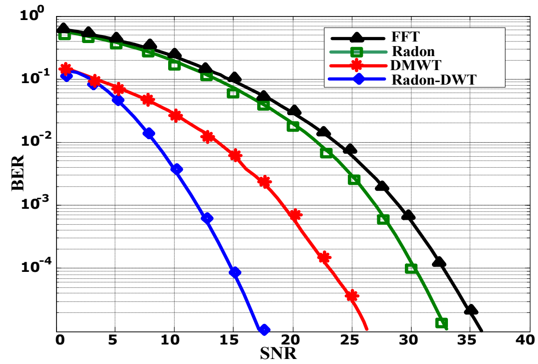

Figure 14. Performance of proposed system in SFC at max doppler shift = 80Hz.

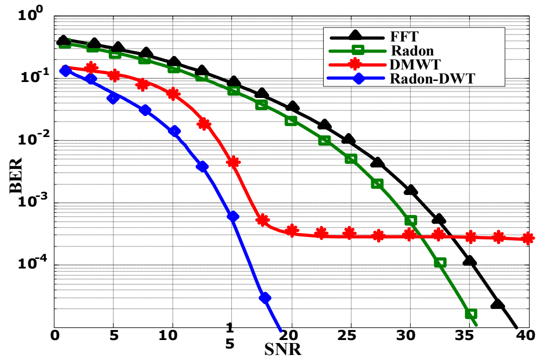

Figure 15. Performance of proposed system in SFC at max doppler shift = 300Hz.

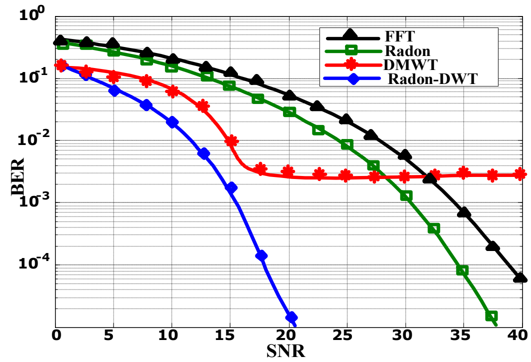

Figure 16. Performance of proposed system in SFC at max doppler shift = 500Hz.

5.4. Effect of Channel Parameters Variations on the Performance of Proposed System

The effect of variations of SFC parameters on the performance of the MC-CDMA systems is very important. With interest the effect of changing the 2nd path gain and delay on the BER performance. Simulations are made for the effect of the 2nd path gain for two cases -12dB and -4dB calculated at Doppler frequency 80Hz and 2nd path delay equal one sample (0.1µsec). The results of BER performance simulation of the four MC-CDMA systems are provided in Figures 18 and 19 respectively. From which it can be seen that proposed system has the smallest sensitivity to variations of the 2ed path gain and less affected by it.

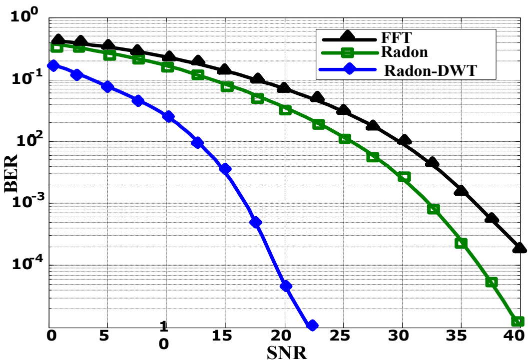

Figure 17. Performance of proposed system in SFC at max doppler shift = 1000Hz.

The effect of the 2nd path delay of SFC on the BER performance is simulated at Doppler frequency equal 80Hz and 2nd path gain=-8dB for the cases of 10 samples (1μsec). The results of simulation of the four MC-CDMA systems are shown in Figure 20. Previously in Figure 14 was provided the simulation for the same channel parameters and for the case of 1 sample (0.1μsec) path delay. From the BER simulations of the four systems when changing the 2nd path delay of SFC, it can be seen that proposed system has the best performance in all situations.

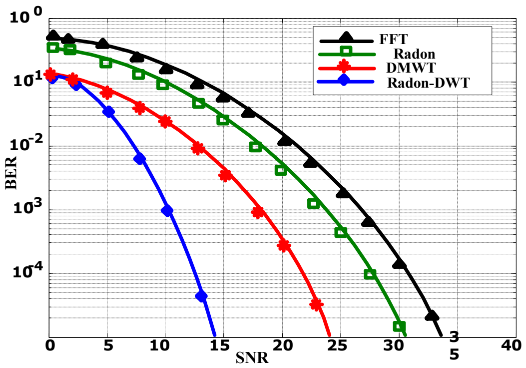

Figure 18. Performance of Radon-DWT-MC-CDMA in SFC with 2ed path gain = -12dB.

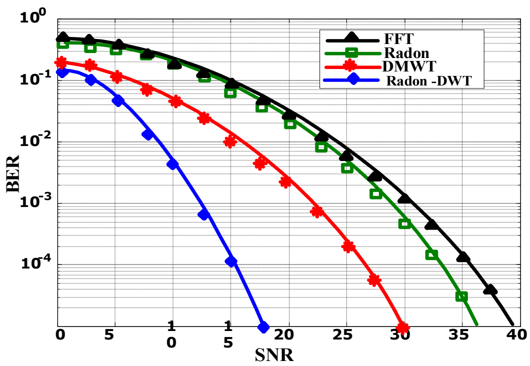

Figure 19. Performance of Radon-DWT-MC-CDMA in SFC with 2ed path gain = -4dB.

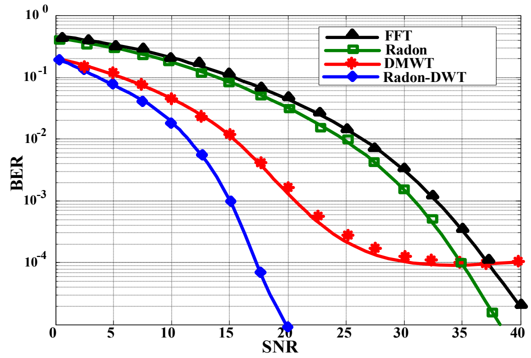

Figure 20. BER performance of Radon-DWT-MC-CDMA in selective fading rayleigh channel with path delay equal 10 samples.

6. Conclusions

In proposed design the FFT-OFDM is replaced by a Radon-DWT-OFDM which does not require a cyclic prefix, has a better performance, has a higher data rates, and has a reduced ISI and ICI compared with FFT-based OFDM. A high orthogonal robust to noise interference DWT and FRAT are used to improve the performance of the communication system without a need of using a cyclic prefix which reduces the system complexity, increase the transmission rate, and increase spectral efficiency.

Comparing the performance of Radon-DWT-MC-CDMA, DMWT-MC-CDMA, Radon-MC-CDMA, and FFT-MC-CDMA in AWGN channel, FFC, and SFC it can be concluded that for AWGN channel Radon-DWT-MC-CDMA has performance gain about 17dB compared with FFT-MC-CDMA to achieve BER=10^{-5}. For FFC and for different maximum Doppler shift frequencies, Radon-DWT-MC-CDMA system has better performance than all other systems, it has performance gain of about 19dB compared with FFT-MC-CDMA to achieve BER=10^{-5} at max Doppler shift equal 500Hz. In SFC proposed Radon-DWT-MC-CDMA has better performance than DMWT-MC-CDMA, Radon-MC-CDMA, and FFT-MC-CDMA in all cases and for changing all channel parameters. Proposed system is less affected by changing channel parameters than other systems, while DMWT-MC-CDMA performance is badly affected by max Doppler shift.

It can be noted that CDMA when combined with OFDM, has BER performance better than just using OFDM only. This can be addressed to spreading the original data stream then modulating different carriers with each chip.

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