A Proposed Turbo Coded Discrete Multiwavelet Critical-Sampling Transform Based OFDM System

Sameer A. Dawood [#1], F. Malek [*2], M. S. Anuar [#3], Suha Q. Hadi [#4]
[#] School of Computer and Communication Engineering, Universiti Malaysia Perlis (UniMAP)
Pauh Putra, 02000, Arau, Perlis, Malaysia
[1] sameer.ad80@yahoo.com
[3] anuarms@unimap.edu.my
[4] suhaqasim84@yahoo.com
[*] School of Electrical Systems Engineering, Universiti Malaysia Perlis (UniMAP)
Pauh Putra, 02000, Arau, Perlis, Malaysia
[2] mfareq@unimap.edu.my

Abstract—In this paper, a turbo coded discrete multiwavelet critical-sampling transform (TC-DMWCST) based orthogonal frequency division multiplexing (OFDM) system has been proposed to improve the bit error rate performance and increase the throughput of the traditional turbo coded fast Fourier transform (TC-FFT) based OFDM system over wireless channels. The new system is more flexible in terms of data rate and more robust with respect to inter-symbol interference (ISI) and inter-carriers interference (ICI) than traditional system. The proposed system has been tested using MATLAB software according to different modulation schemes over different channel conditions and its performance has been compared with the TC-FFT based OFDM system. Simulation results are shown that the proposed system offers significant bit-error-rate gains compared with that of the traditional system.

Keyword-OFDM, multiwavelet transform, turbo codes, wireless channels, data rate

I. INTRODUCTION

The high quality communication and high data rate for multimedia applications are the demand for the present mobile communication systems. One of the promising multicarrier modulation schemes to fulfill the requirement of high data rate is orthogonal frequency division multiplexing (OFDM) [1]. OFDM system divides the high data rate stream into a number of lower rate streams that are transmitted simultaneously over a number of orthogonal subcarriers to achieve frequency flat fading [2-4].

Inverse fast Fourier transform (IFFT) and fast Fourier transform (FFT) are normally used in implementation of traditional OFDM systems to achieve the multicarrier modulation and demodulation, respectively [2].

Moreover, using cyclic prefix (CP) technique in traditional OFDM systems, the inter-symbol interference (ISI), which is caused due multipath channels, is effectively removed [6]. However, the CP introduces a loss in transmission power and bandwidth.

Due to the weak point of traditional OFDM systems caused by using CP, other types of modulation were studied to generate the subcarriers and reducing the effect of using CP. Many authors are proposed the use of the wavelet transform instead of FFT [6-9]. One of the most important distinctions between wavelet based OFDM and FFT based OFDM is that the wavelet based OFDM signals overlap in both, time and frequency domains. This allows the system to exclude the use of CP that is commonly used in FFT based OFDM system. Hence, the data rate in wavelet based OFDM can surpass that of FFT based OFDM.

Multiwavelet transform is a new concept proposed recently [10-12], which is a natural extension of wavelet transform. Multiwavelet transform is designed to possess symmetry, orthogonality and higher order of approximation simultaneously, which is impossible for scalar wavelet [10].

Dawood et.al [13] proposed the discrete multiwavelet critical-sampling transform (DMWCST) based OFDM system. In this system, an inverse discrete multiwavelet critical-sampling transform (IDMWCST) and discrete multiwavelet critical-sampling transform (DMWCST) are simply used instead of IFFT and FFT, respectively. They found that the proposed design achieves much lower bit error rate (BER) and better performance than wavelet based OFDM and FFT based OFDM under additive white Gaussian noise (AWGN), flat Rayleigh fading and frequency-selective Rayleigh fading channels.

Further high bit error rates of the wireless communication system require employing robust and powerful channel coding techniques on the data transferred to reducing the error in transmission [14]. As a powerful coding technique, turbo codes are a prime candidate for wireless applications and being considered for future mobile radio communications [14,15]. Turbo codes can achieve a remarkably low BER with iterative decoding at an signal-to-noise ratio (SNR) close to the Shannon capacity limit on AWGN channel [16].

In this work, a turbo codes are used as a channel coding scheme to be used with the DMWCST based OFDM system to achieve the desired performance at higher data rates. The performance of the turbo coded DMWCST (TC-DMWCST) based OFDM system is compared with the traditional turbo coded FFT (TC-FFT) based OFDM system under different channel conditions.

The rest of the paper is arranged as follows. Section II gives the turbo codes design criteria. Section III presents the proposed system. Section IV shows the simulation results and discussion of these results. Our conclusions are presented in section V.

II. TURBO CODES

The fundamental turbo code encoder is built using two identical recursive systematic convolutional (RSC) codes with parallel concatenation [16]. RSC encoder is typically of rate 1/2 and is termed a component or a constituent encoder. The two component encoders are separated by an interleaver (π). Only one of the systematic outputs from the two component encoders is used, because the systematic output from the other component encoder is just a permuted version of the systematic input. Fig. 1, shows the fundamental turbo code encoder.

Fig. 1, shows a rate 1/3 turbo code encoder. The first RSC encoder outputs the systematic x_1 (equal to u) and recursive convolutional x_2 sequences while the second RSC encoder discards its systematic sequence and only outputs the recursive convolutional x_3 sequence.

Fig. 2, shows the decoding process of turbo code, which was done by iterative decoding using a soft-input/soft-output (SISO) module based on the Log-MAP (Maximum A Posteriori) algorithm. The symbols $\lambda(.,I)$ and $\lambda(.,O)$ at the input and output ports of SISO refer to log-likelihood ratio (LLR). The LLR of a binary bit $z\in$ (-1,1) is defined as [17]:

$$y(z) = \ln\left[\frac{\rho(z=1/y)}{\rho(z=-1/y)}\right] \tag{1}$$

where y is the noisy received codewords and ρ is probability.

The decoder works in an iterative way. The received sequence from demodulator denote by $\lambda(C_1,I)$ and $\lambda(C_2,I)$ are fed to the input port of SISO1 and SISO2 respectively at the same time. Here, the number 1 and, 2 is referred to the first and second encoders (or decoders) respectively. At the first iteration, $\lambda(U_1,I)$, and $\lambda(U_2,I)$ are zero (there is no prior information available on the input information bits of each encoders). $\lambda(U_1,O)$ are passed through interleaver (π) that rearranges the ordering of sequence of symbols in a deterministic manner to obtain $\lambda(U_2,I)$, while $\lambda(U_2,O)$ are deinterleaved using deinterleaver (π^{-1}) that applies the inverse permutation to restore the original sequence to obtain $\lambda(U_1,I)$ and start the second iteration. At the final iteration, $\lambda(U_2,I)$ and $\lambda(U_2,O)$ will be added together, and a hard decision is made on the summation to obtain the estimated information bits.

SISO Log-MAP decoder uses max( ) operation which is defined as [17]:

$$\max(a_j) = \ln\left(\sum_j \exp(a_j)\right) \tag{2}$$

The SISO Log-MAP algorithm requires a forward and backward recursion. The forward recursions of state s at time t are given by [17]:

$$\alpha_t(s) = \max_{e:s^E(e)=s}\left\{\alpha_{t-1}(s^S(e)) + \sum_{j=1}^{k} u^j(e)\lambda_t(u^j,I) + \sum_{j=1}^{n} c^j(e)\lambda_t(c^j,I)\right\} \tag{3}$$

where: e describes the transition (edge) between states of the trellis at time instants t and t+1, $s^S(e)$ is the starting state of edge (e), $s^E(e)$ is the ending state of edge (e), $u(e)$ is the input symbol of edge (e), $c(e)$ is the output symbol of edge (e), and k/n is the code rate.

The forward recursions will be initialized as [17]:

$$\alpha_0(s) = \begin{cases} 0 & s = s_0 \\ -\infty & otherwise \end{cases} \tag{4}$$

The backward recursions of state s at time t are given by [17]:

$$\beta_t(s) = \max_{e:s^E(e)=s}\left\{\beta_{t+1}(s^E(e)) + \sum_{j=1}^{k} u^j(e)\lambda_{t+1}(u^j,I) + \sum_{j=1}^{n} c^j(e)\lambda_{t+1}(c^j,I)\right\} \tag{5}$$

The backward recursions will be initialized as [17]:

$$\beta_0(s) = \frac{1}{2^m} \tag{6}$$

where m is the maximum number of stages (memory size) in the encoder.

Then, the two outputs of the SISO decoder at time t are defined as given in equations (7) and (8) [17].

$$\begin{aligned}\lambda_t(u^j,O) = &\max_{e:u^j(e)=1}\left\{\alpha_{t-1}(s^S(e)) + \sum_{j=1}^{n} c^j(e)\lambda_t(c^j,I) + \beta_t(s^E(e))\right\} - \\ &\max_{e:u^j(e)=-1}\left\{\alpha_{t-1}(s^S(e)) + \sum_{j=1}^{n} c^j(e)\lambda_t(c^j,I) + \beta_t(s^E(e))\right\}\end{aligned} \tag{7}$$

$$\begin{aligned}\lambda_t(c^j,O) = &\max_{e:c^j(e)=1}\left\{\alpha_{t-1}(s^S(e)) + \sum_{i=1}^{k} u^i(e)\lambda_t(u^i,I) + \sum_{\substack{i=1\\ i\neq j}}^{n} c^i(e)\lambda_t(c^i,I) + \beta_t(s^E(e))\right\} \\ - &\max_{e:c^j(e)=-1}\left\{\alpha_{t-1}(s^S(e)) + \sum_{i=1}^{k} u^i(e)\lambda_t(u^i,I) + \sum_{\substack{i=1\\ i\neq j}}^{n} c^i(e)\lambda_t(c^i,I) + \beta_t(s^E(e))\right\}\end{aligned} \tag{8}$$

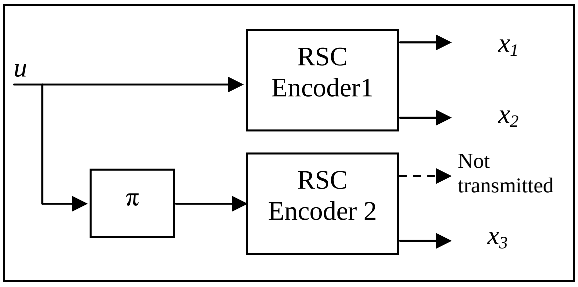

Fig. 1. Fundamental turbo codes encoder

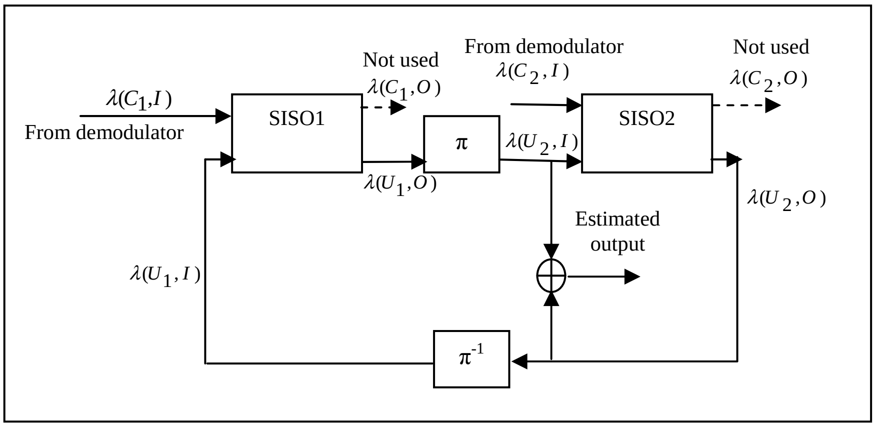

Fig. 2. Iterative decoder of turbo codes

III.PROPOSED MODEL

The block diagram in Fig. 3, gives the proposed TC-DMWCST based OFDM system. Random binary data are generated at the transmitter. These data are encoded by turbo code of rate 1/3. The serial coded bits is converted to parallel using serial-to-parallel (S/P) conversion, and mapped according to the mapping technique (in this paper, QPSK and 16-QAM mapping techniques are considered). Then, the training sequence (pilot subcarriers) is inserted and sent prior to information frame. This training sequence will been used to make channel estimation that's used to compensate the channel effects on the signal. After that, *N*-point IDMWCST is applied to the signal to achieve the multicarrier modulation technique. Zeros are inserted in some bins of

IDMWCST to reduce interference of the adjacent carriers. Finally, parallel to serial converter (P/S) converts parallel data into serial data stream and transmit over channel.

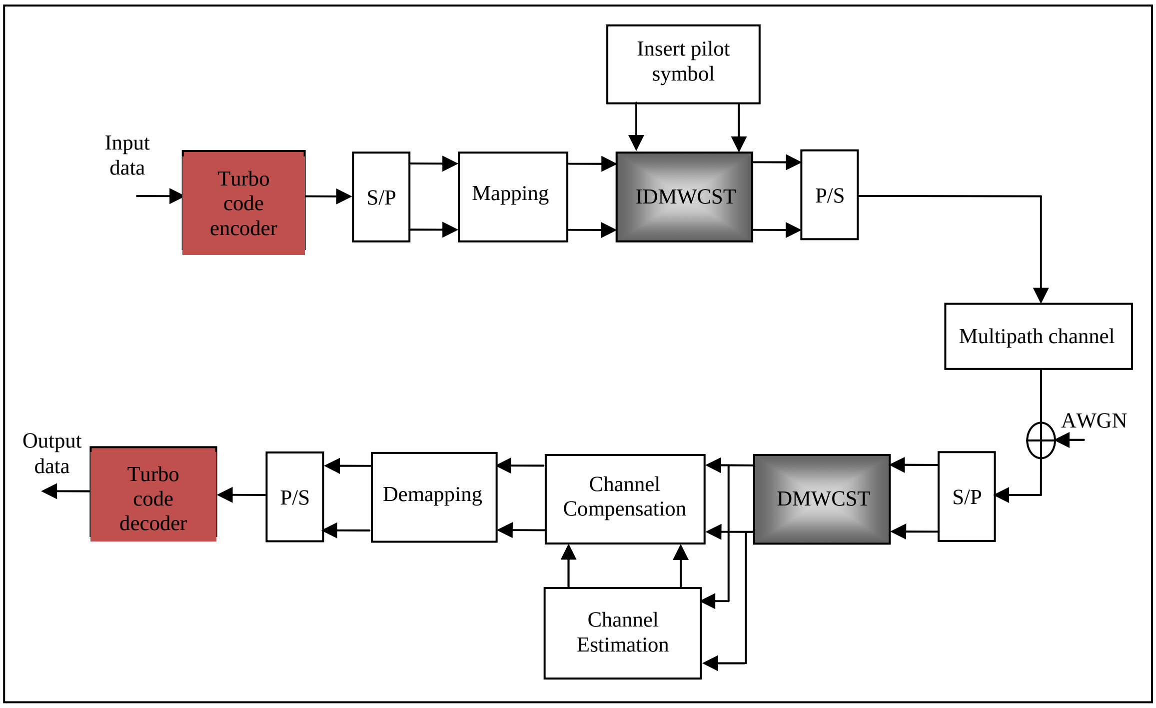

Fig. 3. Block diagram of the proposed system

Given that CP is not added to OFDM symbols in the proposed system, the data rates in TC-DMWCST based OFDM are therefore higher than those in traditional TC-FFT based OFDM system.

The received signal from the channel can be expressed as [18]:

$$y(n) = x(n) * h(n) + w(n) \tag{9}$$

where * refers to the convolution process between the transmitted signal *x(n)* and the channel impulse response *h(n)*, *w(n)* is AWGN.

At the receiver, the inverse operations are performed to recover the correct data stream. The received signal is converted to a parallel version via S/P conversion. Now, *N*-point DMWCST are performed to achieve the multicarrier demodulation technique, and the zero pads are removed. Then, the training sequence is utilized to estimate the channel frequency response ($H(k)$) as follows:

$$H(k) = \frac{Y_p(k)}{X_p(k)}, \qquad k = 1,2,......,N_c \tag{10}$$

where $Y_p(k)$ represents the received pilot subcarriers, $X_p(k)$ is the transmitted pilot subcarriers, and N_c is the number of active subcarriers. The channel frequency response obtained in equation (10) is used to compensate for the channel effects on the data. Estimated data ($\hat{X}(k)$) can be found using the following equation.

$$\hat{X}(k) = H^{-1}(k)Y(k), \qquad k = 1,2,.....,N_c \tag{11}$$

Finally, the output of the channel compensator passes through signal demapping, and it is decoded by the turbo code decoder. The BER can be calculated by the following expression:

$$\text{BER} = \frac{\text{Number of received bits in error}}{\text{Total number of transmitted bits}} \tag{12}$$

The readers can refer to [13,19] for the details of computing DMWCST and IDMWCST.

IV. SIMULATION RESULTS AND DISCUSSION

The proposed TC-DMWCST based OFDM system was simulated with MATLAB (version 7.8), and its BER performance was compared with that of TC-FFT based OFDM system over AWGN, flat fading and frequency selective fading channels. The length of CP in TC-FFT based OFDM was (1/4) of total symbol length of OFDM. The fading channel was considered a Rayleigh fading channel modeled as Jake's model [20]. Table I, shows the parameters and their values in the system utilized in the simulation.

TABLE I. Simulation Parameter

Parameter	**Value**
System bandwidth	10 MHz
Number of DMWCST points (*N*)	64
Number of FFT points (*N*)	64
Number of useful data subcarriers (N_c)	48
Turbo codes rate (*k*/*n*)	1/3
Encoder generator	$[1,5/7]_8$, $d_{free}=5$
Number of decoding iteration	5
Modulation type	QPSK, and 16-QAM

Figs. 4 and 5 present the performance of the proposed system (TC-DMWCST based OFDM) compared with that of the traditional system (TC-FFT based OFDM) in the AWGN channel using QPSK and 16-QAM, respectively. The Figures show that the proposed system performs much better than the traditional system in both types of modulation because the orthogonality between subcarriers in DMWCST is more significant than that in FFT. As shown in Fig. 4, it can be noticed that BER = 10^{-3} was achieved at SNR = 7.5 dB for proposed system and 21.3 dB for traditional system with gain of 13.8 dB was obtained by the proposed model. While in Fig. 5, the same BER was achieved at SNR = 11.7 dB for proposed system and 26.5 dB for traditional system with gain of 14.8 dB.

Figs. 6 and 7 show the performance of the proposed system in comparison with that of the traditional system in a flat Rayleigh fading channel using QPSK and 16-QAM, respectively. It's clear form these figures that the performance of the proposed system is superior to that of the traditional system in both types of modulation. As shown in Fig. 6, the proposed system has BER of 10^{-3} at SNR = 10 dB. TC-FFT based OFDM has the same BER at SNR = 24.4 dB. Hence, the proposed system gives a gain of 14.4 dB over TC-FFT based OFDM. Also, as shown in Fig. 7, the proposed system has BER of 10^{-3} at SNR = 14.9 dB. TC-FFT based OFDM has the same BER at SNR = 29.5 dB. Hence, the proposed system gives a gain of 14.6 dB over TC-FFT based OFDM.

The comparison of the performance of the two systems in a frequency-selective Rayleigh fading channel using QPSK and 16-QAM is illustrated in Figs. 8 and 9, respectively. Two paths were selected; the second path has a path gain of -10 dB and a path delay of 8 samples. Obviously, as seen in these figures, the proposed system is more robust to the frequency-selective fading channel compared with the traditional system. Fig. 8 shows that, the TC-DMWCST based OFDM system has a BER of 10^{-3} at SNR = 11.8 dB, while, TC-FFT based OFDM has the same BER at SNR = 23.4 dB. Hence, the performance of the TC-DMWCST based OFDM outperformed the TC-FFT based OFDM by about 11.6 dB. Fig. 9 shows that, the TC-DMWCST based OFDM system has a BER of 10^{-3} at SNR = 18 dB, while, TC-FFT based OFDM has the same BER at SNR = 30 dB. Hence, the performance of the TC-DMWCST based OFDM outperformed the TC-FFT based OFDM by about 12 dB.

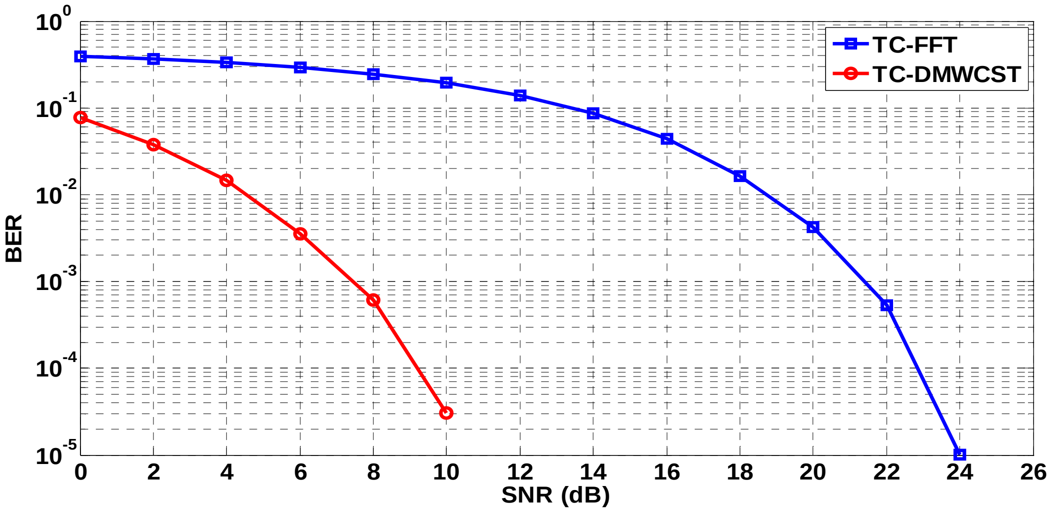

Fig. 4. Performance of OFDM system in AWGN at QPSK

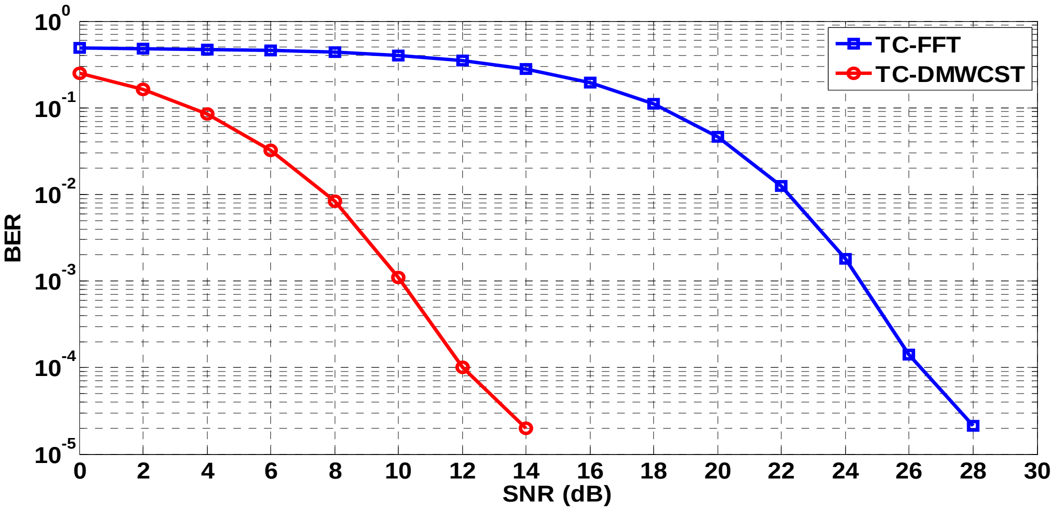

Fig. 5. Performance of OFDM system in AWGN at 16-QAM

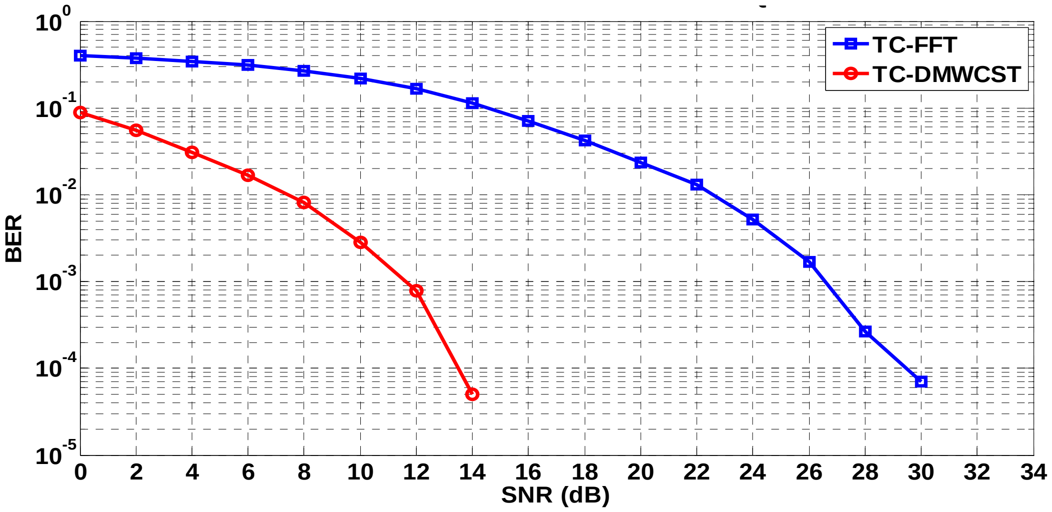

Fig. 6. Performance of OFDM system in flat fading channel at QPSK

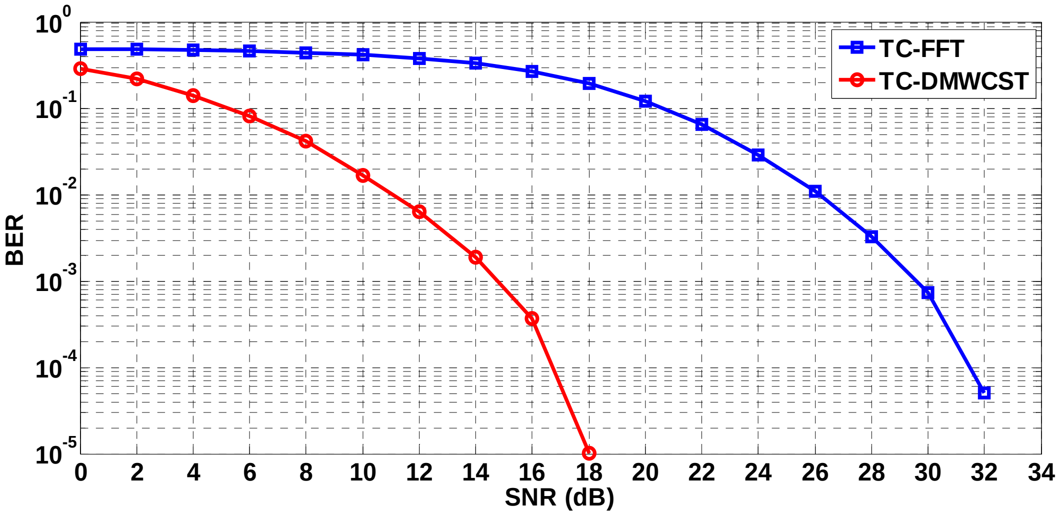

Fig. 7. Performance of OFDM system in flat fading channel at 16-QAM

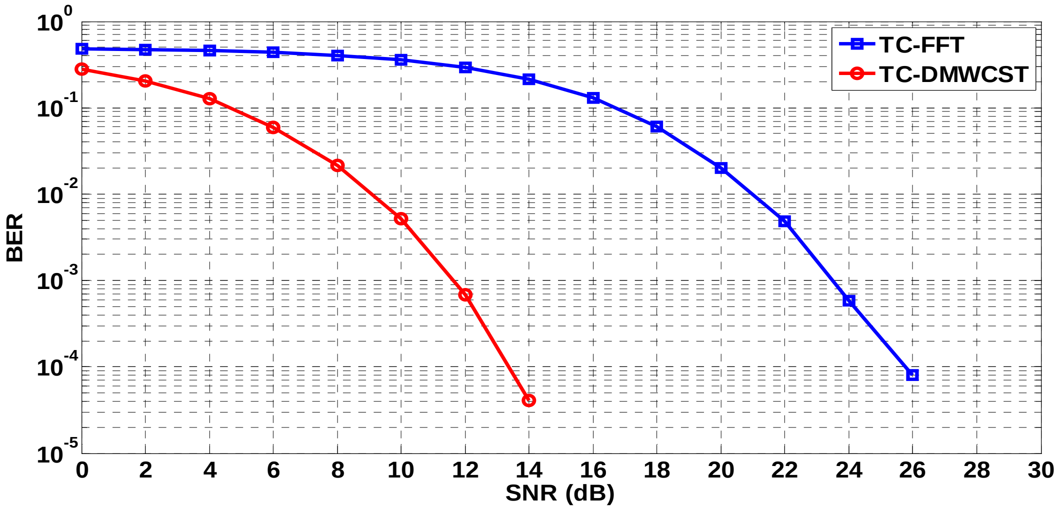

Fig. 8. Performance of OFDM system in frequency-selective fading channel at QPSK

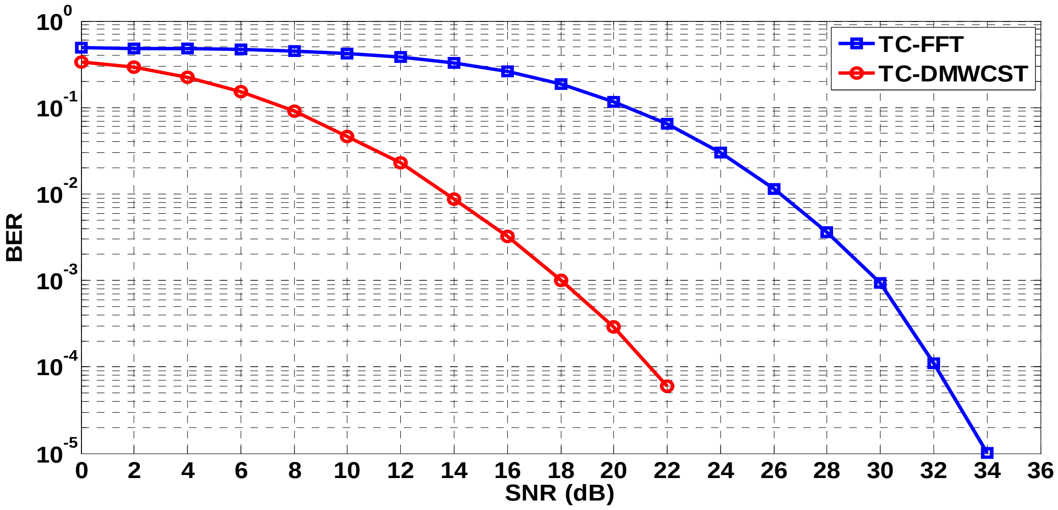

Fig. 9. Performance of OFDM system in frequency-selective fading channel at 16-QAM

V. CONCLUSION

A new OFDM system based on TC-DMWCST has been proposed in this paper. The performance of the proposed system was compared with the traditional OFDM system based on TC-FFT through the use of QPSK, and 16-QAM modulation techniques. The performance analysis of the TC-DMWCST based OFDM system is evaluated by simulations in different channels including AWGN, flat Rayleigh fading and frequency-selective Rayleigh fading. Simulation results are shown that TC-DMWCST based OFDM can provide a much better performance than TC-FFT based OFDM system in all channels. Also, TC-DMWCST based OFDM has higher bandwidth efficiency than TC-FFT based OFDM because of the good orthogonality of DMWCST. ISI and ICI are reduced. Thus, the use of CP in the proposed system is unnecessary. Hence, the data rate of the proposed system can surpass that of traditional system. Therefore, The proposed system can be utilized as an alternative to traditional OFDM system over wireless channels.

REFERENCES

[1] A. Goel and M. K. Garg, “Comparative performance evaluation of convolutionally coded and LDPC coded OFDM system over AWGN and SUI-5 fading channel,” in Proc. ICCCT'12, 2012, pp. 250-254.

[2] R. v. Nee and R. Prasad, OFDM for wireless multimedia communications, Artech House, Inc., 2000.

[3] G. Rangaraj, M. Raghavendra, and K. Giridhar, “Improved channel estimation for OFDM based WLAN systems,” in Proc. Int. Conf. Wireless Commun. Netw'13, 2013, pp. C27-C31.

[4] M. A. Saeed, B. M. Ali, and M. H. Habaebi, “Performance evaluation of OFDM schemes over multipath fading channels,” in Proc. APCC'03, 2003, pp. 415-419.

[5] S. K. Borra and S. K. Chaparala, “Performance evaluation of OFDM system with Rayleigh, Rician and AWGN channels,” International Journal of Emerging Technology and Advanced Engineering, vol. 3, 2013.

[6] A.R. Lindsey, “Wavelet packet modulation for orthogonally multiplexed communication,” IEEE Trans. in Signal Processing, vol. 45, pp. 1336–1337, 1997.

[7] B. G. Negash and H. Nikookar, “Wavelet based OFDM for wireless channels,” in Proc. VTC'01, 2001, vol. 1, pp. 688-691.

[8] M. Oltean, “Wavelet OFDM performance in flat fading channels,” Scientific Bulletin of University Politehnica Timisoara, ETC Series, vol. 52, pp. 167-172, 2007.

[9] K. Abdullah and Z. M. Hussain, “Performance of Fourier-based and wavelet-based OFDM for DVB-T systems,” in Proc. ATNAC'07, 2007, pp. 475-479.

[10] V. Strela, P. N. Heller, G. Strang, P. Topiwala, and C. Heil, “The application of multiwavelet filter banks to image processing,” IEEE Trans. on Image Processing, vol. 8, pp. 548-563, 1999.

[11] D. Milovanovic, A. Marincic, G. Petrovic, and Z. Barbaric, “Comparative study of scalar and multiwavelet filters in transform-based compression of IRLS images,” in Proc. TELSlKS'99, 1999, pp. 169-172.

[12] M. B. Martin and A. E. Bell, “New image compression techniques using multiwavelets and multiwavelet packets,” IEEE Trans. on Image Processing, vol. 10, pp. 500-510, 2001.

[13] S. A. Dawood, F. Malek, M. S. Anuar, and S. Q. Hadi, “Performance comparison of OFDM system based on DMWCST, DWT, and FFT using QAM modulation technique,” ARPN Journal of Engineering and Applied Sciences, vol. 9, pp. 2823- 2830, 2014.

[14] B. Sklar, Digital Communications, Second Edition, Prentice Hall, 2001.

[15] H. Nikopour, A. K. Khandani, and S. H. Jamali, “Turbo-coded OFDM transmission over a nonlinear channel,” IEEE Trans. on Vehicular Technology, vol. 54, pp. 1361-1371, 2005.

[16] C. Berrou and A. Glavieux, and P. Thitimajshima, “Near Shannon limit error-correcting coding and decoding: turbo-codes,” in Proc. ICC'93, 1993, pp. 1064-1070.

[17] S. Benedetto, D. Divsalar, G. Montorsi, and F. Pollara, “A soft-input soft-output maximum a posteriori (MAP) module to decode parallel and serial concatenated codes,” TDA progress report, vol. 42, pp. 1-20, 1996.

[18] A. Zaier and R. Bouallègue, “Channel estimation study for block-pilot insertion in OFDM systems under slowly time varying conditions,” International Journal of Computer Networks and Communications, vol.3, no.6, pp. 39-54, November 2011.

[19] L. A. Abdul-Rahaim, and R. S. Mohammad, “Video compression using multiwavelet critically sampling transformation,” Journal of Telecommunications, vol.20, issue-2, pp. 7-13, June 2013.

[20] W. Wu, V. V. G. Srinivasan, C. Hsu, Y. Kim, C. Lee, and T. Rappaport, “Wireless communication project (EE381K-11) technical report optimal channel estimation for capacity maximization in OFDM systems,” Department of Electrical and Computer Engineering, University of Texas, Austin, pp.1-24, May 2003.