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RESEARCH ARTICLE

MIMO-WiMAX system incorporated with diverse transformation for 5G applications

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Abstract Wireless systems and standards are now progressing toward the implementation of fifth generation (5G) to combat with an expected and explosive growth of demands of wireless services in future. Consequently, wireless interoperability for microwave access (WiMAX) with orthogonal frequency division multiplexing (OFDM) technology at its physical layer is being utilized for the uplink and downlink transmission to afford the high spectral efficiency in fading environments. However, the 5G implementation requires additional improvements to meet the futuristic stress. This work proposes an innovative solution that combines WiMAX system with multiple input multiple output (MIMO) technology to meet the required elevated data rates as desired by the growing application needs of 5G. MIMO is capable to fulfil the vision of 5G to realize a huge number of base stations equipped with a large number of terminals to be served in the same time-frequency resource without severe inter-user interference. Furthermore, the proposed system is demonstrated incorporation with discrete wavelet transform (DWT), and fractional Fourier transforms (FrFTs) in the physical layer of the WiMAX system. The evaluated outcomes exemplify a considerable improvement in bit error rate (BER) performance in contrast with the earlier reported work.

Keywords wireless interoperability for microwave access (WiMAX), orthogonal frequency division multiplexing (OFDM), multiple input multiple output (MIMO), fast Fourier transform (FFT), discrete wavelet transform (DWT), fractional Fourier transform (FrFT)

1 Introduction

The impeccable integration of diverse communication services like voice signals, high-speed data, multimedia traffic as well as video is the prime objective of fifth generation (5G) mobile communication system [1]. The main reason of this efficient integration in 5G is a hybrid combination of orthogonal frequency division multiplexing (OFDM) and multiple input multiple output (MIMO) systems. This unique merger of OFDM and MIMO results in a significant increase in channel capacity and reliability of wireless communication systems without increasing the requirement of the operational bandwidth [2]. OFDM has emerged as a promising alternative for providing the broadband wireless services in many of the existing wireless systems/standards like IEEE 802.11 wireless local area networks (WLAN), IEEE 802.16 wireless interoperability for microwave access (WiMAX), and ultra-wide band (UWB) systems [3,4]. On the other hand, MIMO technology also has a prominent role to play in improving the system capacity and performance in terms of bit error rate (BER)/symbol error rate (SER) performance in wireless systems. The basic idea of OFDM is to bifurcate the large bandwidth transmission into several small bandwidth sub-carriers in such a way that all these sub-carriers are orthogonal to each other and the MIMO algorithms are implemented on each of these sub-carriers in the hybrid combination of MIMO-OFDM [5]. Diversity is the method through which we can diminish the fading's effects by sending the same information for several times. We do this with the expectation of recovering back at least one of the clones without fading [6]. Some of the proposed transmission schemes utilizing the MIMO channel in various ways are spatial multiplexing, space-time coding or beam forming [7]. Tarokh et al. [8] introduce a method named space-time coding (STC) in which the symbols sent correspond to one-time interval,

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and the numbers of sender antennas are equal. Space-time encoder creates these symbols with the benefit of achievement of all diversity gain, coding gain, and spectral efficiency gain. Some of the methods of coding are named as STTC, STBC and LST codes. STTC stands for space-time trellis codes, STBC stands for space-time block codes, and LST stands for layered space-time codes [9]. The major problem in these coding methods is taking advantage of redundancy to attain reliability gain, spectral efficiency gain and efficiency gain. The main aim of STC scheme is to maintain the simplicity of decoding algorithm, to attain low error probability and to maximize the data rates. But, there exist the trade-offs among all these three aims.

A significant improvement in the performance of OFDM system on replacing the conventional fast Fourier transform (FFT) by other transforms, like discrete wavelet transform (DWT), discrete cosine transform (DCT), discrete sine transform (DST), fractional Fourier transform (FrFT), etc [10,11], has been reported in the literature. The traditional OFDM physical layer based on FFT for providing the orthogonal subcarriers. But, with the advancement in signal processing techniques, other transforms like FrFT and DWT comes out to be an efficient alternative to FFT. The DWT can be utilized in the multi-carrier modulation techniques to provide high data rates, as well as lower probability of error. The FFT was able to present the frequency domain description of the signal whereas the DWT will enable us to analyze the signal in both time and frequency domain. Because of this attribute, the FFT is getting replaced by DWT in the existing wireless communication technologies/systems [12,13]. On the other hand, FrFT also provides better results in comparison to FFT in terms of BER performance and spectral efficiency [14]. The same methodology can be implemented in MIMO-OFDM systems, i.e., 5G mobile communication systems to enhance its performance. Organisation of this work is Section 1, elaborates the basic introduction of OFDM & MIMO techniques along with the reasons for using DWT and FrFT in the existing wireless communication systems. Section 2 provides a brief overview of the work done till date on OFDM and MIMO and use of diverse transforms in OFDM systems. The OFDM physical layer model is described in Section 3, followed by the description of MIMO methodology in Section 4. The simulation results are depicted in Section 5, and the inferences drawn from the simulation results are presented in Section 6.

2 Related works

MIMO-OFDM transmission technologies have been emerged in the recent past due to speedily growing requirements of high-speed data. These transmission technologies are highly efficient in terms of spectrum usage and transmission power requirements [15]. OFDM is widely popular due to its supreme resilience and high-speed data transmission capabilities over frequency selective fading channels. Current wireless communication systems make extensive use of wavelets for diverse applications. Wavelets can be incorporated in diverse fields of mobile as well as fixed wireless access systems such as channel modeling, channel coding, and designing of transceivers for better performance in diverse operational environments. The complex wavelet packet transform based OFDM reduce the effects of inter-carrier interference (ICI) and some guard intervals to be inserted in between OFDM symbols. The BER of the wireless system improves significantly on the use of wavelets [12]. The DWT-OFDM performs better than the FFT-OFDM regarding BER performance for a particular signal to noise ratio (SNR) value. Further, the bior5.5 and rbior3.3 outperforms the others wavelets in the wavelet family [16]. Diverse transforms like FFT, DWT, and discrete cosine transform (DCT) are also being used in OFDM systems to analyze the BER performance over additive white Gaussian noise (AWGN) channel [17]. The analysis is carried out for different wavelets also, and the results demonstrate that the BER performance is better in the case of Haar wavelet in comparison to all other wavelets, FFT, and DCT [11].The OFDM systems are implemented using both FFT and DWT over AWGN channel by employing the diverse order of digital modulation techniques such as M-ary phase shift keying (M-PSK) and M-ary quadrature amplitude modulation (M-QAM) [18]. The performance analysis depicts an improvement of SNR to achieve a particular BER for both modulation techniques. The DWT-OFDM outperforms the FFT-OFDM regarding BER performance and spectral efficiency over Rayleigh fading channel also [19]. The BER performance of DWT-OFDM is better than FFT-OFDM without the cyclic prefix (CP), but it is not that much better when CP is included in the FFT-OFDM. FrFT is a more advanced version of FFT, which offers many advantages over the conventional Fourier analysis. FrFT can be used in diverse filed of signal processing. FrFT are closely related to other time, frequency and canonical transforms. FrFT appended OFDM has been analyzed over diverse wireless channels such as AWGN, Rayleigh, Rician, and Nakagami [20]. The OFDM system was implemented using 512-PSK and 1024-PSK, at this modulation level the probability of BER is high. This probability of error can be reduced by using the FrFT in place of conventional FFT [21]. The FrFT can also be used in addition to the FFT for OFDM systems. In that, the FrFT will work as the precoding technique. The BER performance analysis depicts a considerable improvement in comparison to convention FFT based OFDM over AWGN, Rayleigh, Rician and Nakagami channels [22]. In the recent past, a significant improvement in the transmission capacity of modern wireless communication systems has been reported by many researchers on using the massive MIMO system [23]. This increase in capacity is being achieved on using large antenna arrays at the mobile terminals as well as base stations [24]. Diversity gain in MIMO systems will enhance the system reliability and signal quality in multipath fading channels. Multiplexing gain will elevate the data capacity by sending the independent data stream through the diverse antennas [25–27]. In multi-user MIMO (MU-MIMO) systems, all the users will transmit and receive without having any mutual encoding or detecting algorithm, i.e., all the users will share same wireless channel spatially. In massive MIMO transmission, MU-MIMO scenario is considered. In massive MIMO multiple antennas are installed at the base station, which will serve multiple users in the same time-frequency resources available [28]. MIMO-OFDM system is very well integrated into IEEE 802.16 standard family also. The use of MIMO-OFDM transmission in WiMAX systems results in elevated data rate, throughput, resilience against multipath fading and efficient bandwidth usage. Both the two MIMO physical layer modifications are applicable as per the specification of IEEE, i.e., spatial diversity and spatial multiplexing. The efficient switching between the two modifications can be done adaptively depending upon the fading channel condition.

2.1 Discussion

Based on the study of the research work reported in the literature survey, the following are the research gaps which are required to be addressed:

1) Wavelet transform can be utilized to improve the BER performance in place of Fourier transform in the MIMO-WiMAX system.

2) Most of the existing methods have not considered FrFT as a valid alternative to Fourier transform in the MIMO-WiMAX system.

3) MIMO augmented with WiMAX system has never been evaluated for varying number of antennas in the downlink and for diverse transforms.

3 WiMAX physical layer model description

The MATLAB$^{\text{TM}}$ simulations are used to present the performance analysis of FFT-MIMO-WiMAX, DWT-MIMO-WiMAX and FrFT-MIMO-WiMAX regarding SNR vs BER variations and peak to average power ratio (PAPR) reduction. Figure 1 depicts the physical layer model description of WiMAX system. The transmitter side of the WiMAX system involves following processes:

1) Randomization: This is required to scramble the data to ensure that the effectiveness of the coding scheme can be optimised. Randomization also helps to maintain data integrity, with the same seed being used for all forward error correction blocks. It is also helpful in reducing the error probability for specific data streams.

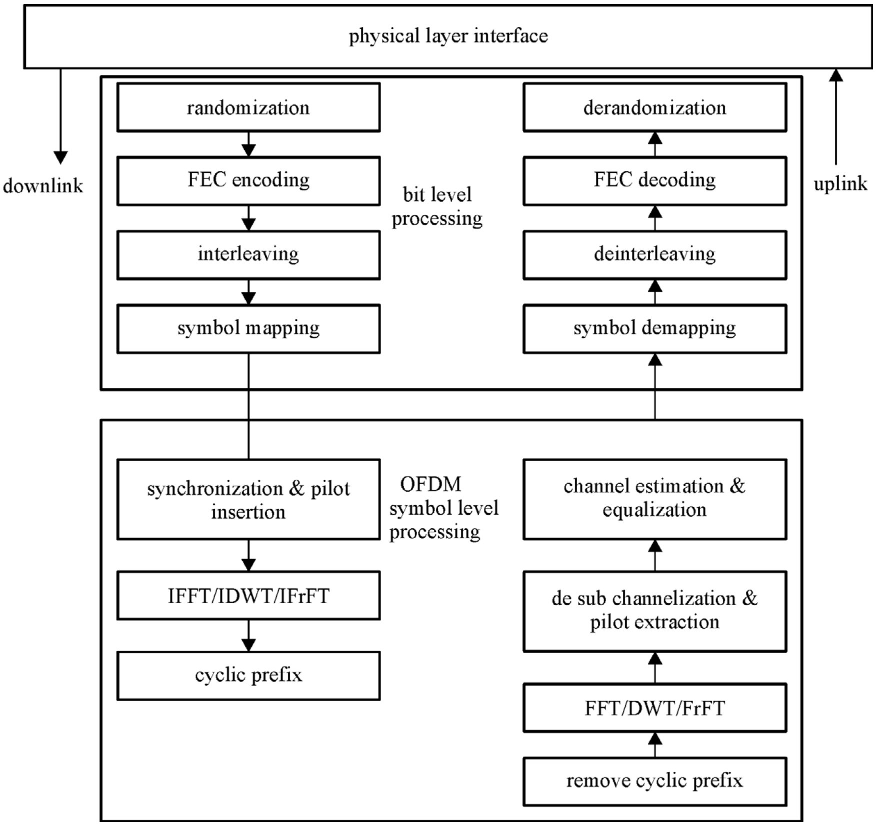


Fig. 1 WiMAX physical layer model

2) Forward error correction (FEC): Channel encoding scheme, i.e., FEC, is required to detect and correct the errors at the receiver end thereby making the performance of the system more reliable. There is a variety of coding schemes available which can be used as FEC such as low-density parity check (LDPC), Reed-Solomon (RS) codes, Turbo codes, convolutional codes, etc. The FEC will add some redundancy to the data, which is directly responsible for the error reduction at the receiver end. Convolutional codes are mostly used in the OFDM physical layer as FEC codes. The encoding process in convolutional encoding is based on the generator matrix, code rate, and constraint length. The shift register is utilized to generate the encoded sequence for a particular input sequence by utilizing the modulo-2 addition of the input sequence and contents of the shift register. The decoding process for the convolutional encoding uses the Viterbi algorithm.

3) Interleaving: The interleaving is employed to reduce the burst errors. In the WiMAX physical layer, the block interleaving is used with block size equal to the encoded block size in bits. The interleaving dispenses the bits in frequency, time, and time-frequency both domains to achieve minimum burst error at the receiver end.

4) Symbol mapping: Modulation or symbol mapping in the WiMAX is attained through the digital modulation schemes such as M-PSK and M-QAM. The basic use of mapping is to map the digital data onto the analog carriers. In WiMAX physical layer, the modulations which are mostly employed are binary phase shift keying (BPSK), QPSK, 16-PSK, 64-PSK, & QAM. The higher order modulation levels will enhance the data rates at the cost of increased BER.

5) Synchronization and pilot insertion: After the symbol mapping process, pilots are then inserted in predefined places. The role of these pilots is to ensure that the exact timing information is made available to the receiver to maintain synchronization. The pilots also help the detector to predict the channel behavior.

6) IFFT/IDWT/IFrFT: The inverse FFT (IFFT), inverse DWT (IDWT) and inverse FrFT (IFrFT) are used to generate orthogonal subcarriers for data symbol transmission. Various IFFT sizes are mentioned in the standard, including 2048, 1024, 512, and 128 bits. However, most vendors have adopted 512 and 1024 bit sizes as their IFFT sizes as per the specifications published by the WiMAX Forum. Similarly, various types of wavelets are included in the wavelet family, such as Haar, Coiflet, Symlet, biorthogonal, and reverse biorthogonal wavelets. In our system, the Haar wavelet is used. The implementation of the IDWT and the DWT is depicted in Fig. 2.

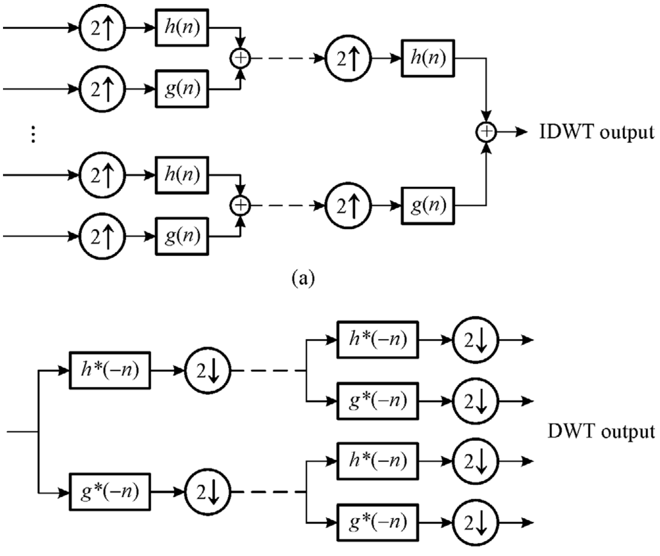
Here, $h(n)$ and $g(n)$ are the half-band impulse responses of the high-pass and low-pass filters, respectively. The two filters are related to each other by a quadrature mirror filter (QMF) relationship as follows:

$$h(n) = (-1)^n g(L-1-n). \tag{1}$$

The FrFT also can be treated as a generalized form of the Fourier transform. The FrFT is by definition a chirp basis expansion that defines the time-frequency plane rotation. The expansion results in a transformation from the time domain to the frequency domain in a unified manner. The FrFT is defined as

$$F_{a[x(t)](u)} = \int_{-\infty}^{\infty} x(t)K_a(t,a)\mathrm{d}t. \tag{2}$$

Here, $x(t)$ is the input signal, $K_a(t,a) = A_a \mathrm{e}^{\mathrm{j}\pi(t^2+u^2)\cot a - \mathrm{j}2\pi t u \csc a}$ and is known as the transform kernel, and 'a' is given by a = aπ/2 and is known as the rotation angle of the transformed signal. The signal



(a)

(b)

Fig. 2 (a) IDWT and (b) DWT block diagrams characteristics can be transformed from the time domain to the frequency domain by varying the values of 'a' from 0 to 1 [23].

7) Cyclic prefix (CP): To eliminate the inter-symbol interference (ISI) the concept of the guard interval is being utilized in the physical layer of OFDM which is also known as the addition of CP. In the CP, each of the symbols is headed by the extension of the symbol itself. The guard time must be chosen carefully so that the multipath components from one symbol will not interfere with the next symbol. As per the specifications issued by the various forums, the guard interval/CP, i.e., T_g, can be T/4, T/8, T/16, T/32. The choice of a particular value of guard interval is dependent upon the amount of delay spread in the multipath fading channel.

At the receiver, all the processes done at the transmitter end will be reversed starting from eliminating the guard interval. Then the symbols will be processed by FFT/DWT/IFrFT followed by channel estimation/equalisation. Then the bits will be recovered back from the symbols by utilizing the symbol de-mapping (digital demodulation) schemes. After this, the bits will be rearranged by the block interleaver followed by the FEC decoding to mitigate the redundancy present in the data. In the last, the de-randomizer will descramble the data to present the data in the original form to the upper layer of the hierarchy.

4 MIMO-Alamouti encoding

Alamouti is a two-branch transmit diversity technique, used to transmit the two signals at time by employing two antennas in which the symbols grouped of two are transmitted via two antennas within two time intervals with the optional receiver diversity, i.e., two symbols are transmitted at once only but sill the requirement of 2nd time interval is there in order to transmit them again. Figure 3 illustrates the generic block diagram of Alamouti space-time code.

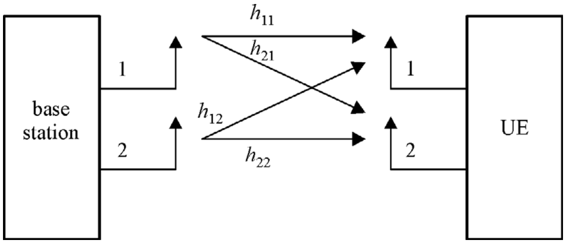


Fig. 3 Basic representation of Alamouti space-time block encoder

The spatial dimensions are utilized by the space-time processing (STP). The modulation and the encoding are done at the sender side as shown in Fig. 4 that represents spatial transmit diversity with Alamouti's space-time block. The transmissions made are parallel which fulfils the idea of STP [2]. The performance of spectral efficiency can be enhanced along with the coverage area by utilizing STP. It utilizes the spectrum in the better way, allowing the support of various recipients and reducing the requirements of power by exploiting spatial multiplexing and spatial diversity. On the contrary to spatial multiplexing, the spatial diversity is utilized to make the system reliable by diminishing the fading effects, occurred because of multipath propagations, by sending the same information for several times with the expectation of recovering back at least one of the clones without fading [3]. Between spatial multiplexing and spatial diversity, the trade-off occurs as complete spatial multiplexing offers the enhancement in system capacity and spectral efficiency but with limited reliability and the spatial diversity offers the enhancement in system reliability but with limited system capacity and spectral efficiency.

Alamouti allows the transmission of two signals at a time by utilizing two transmit antennas [6]. The diversity is optional at the receiver side, i.e., the receiver antennas can be 1 or 2. The information generated from the information source is given to the modulator for the desired modulation. STBC encoder is utilized after modulating the information. In Alamouti scheme, let's have a sequence $[a_1,a_2,a_3,\ldots,a_n]$. The symbols given in the sequence are grouped into two and are transmitted at once for 2 time intervals by sending the following matrix:

$$\boldsymbol{A}=\begin{bmatrix} a_1 & -a_2^* \\ a_2 & a_1^* \end{bmatrix}. \tag{3}$$

For 1st time interval a_1 and a_2 are sent via antenna X_1 and X_2 and for the 2nd-time interval, $-a_2^*$ *and* a_1^* are sent via antenna X_1 and X_2. The grouping of symbols still

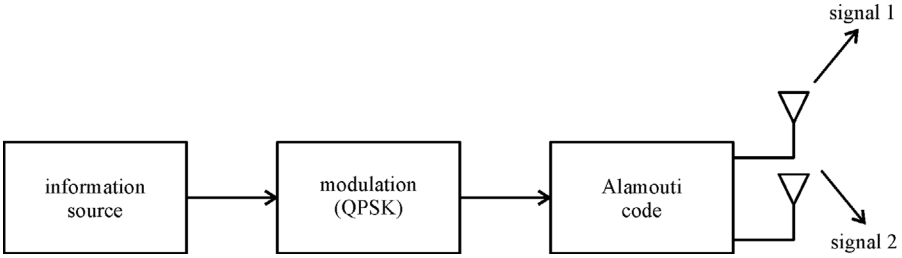


Fig. 4 Spatial transmit diversity with Alamouti's space-time block code

requires two-time intervals to transfer 2 symbols, i.e., unchanged data rate [9]. Now, on the receiver side, using receiver diversity scheme, the signal received in the 1st time interval is

$$B_1 = h_1 a_1 + h_2 a_2 + n = (h_1 \ \ h_2)\begin{pmatrix} a_1 \\ a_2 \end{pmatrix} + u_1. \quad (4)$$

And the signal received in the 2nd time interval is

$$B_2 = -h_1 a_2^* + h_2 a_1^* + n_2 = (h_1 \ \ h_2)\begin{pmatrix} -a_2^* \\ a_1^* \end{pmatrix} + u_2, \quad (5)$$

where B_1 and B_2 are the symbols arrived on the 1st and 2nd interval, h_1 is the channels from 1st sender to receiver antennas, and h_2 is the channels from 2nd sender to receiver antennas, a_1 and a_2 are symbols to be sent and u_1 and u_2 are 1st and 2nd-time interval's noise.

$$\boldsymbol{E} = \begin{pmatrix} u_1 \\ u_2^* \end{pmatrix}(u_1^* \ \ u_2) = \begin{pmatrix} |u_1|^2 & 0 \\ 0 & |u_2|^2 \end{pmatrix}. \quad (6)$$

5 Results and discussion

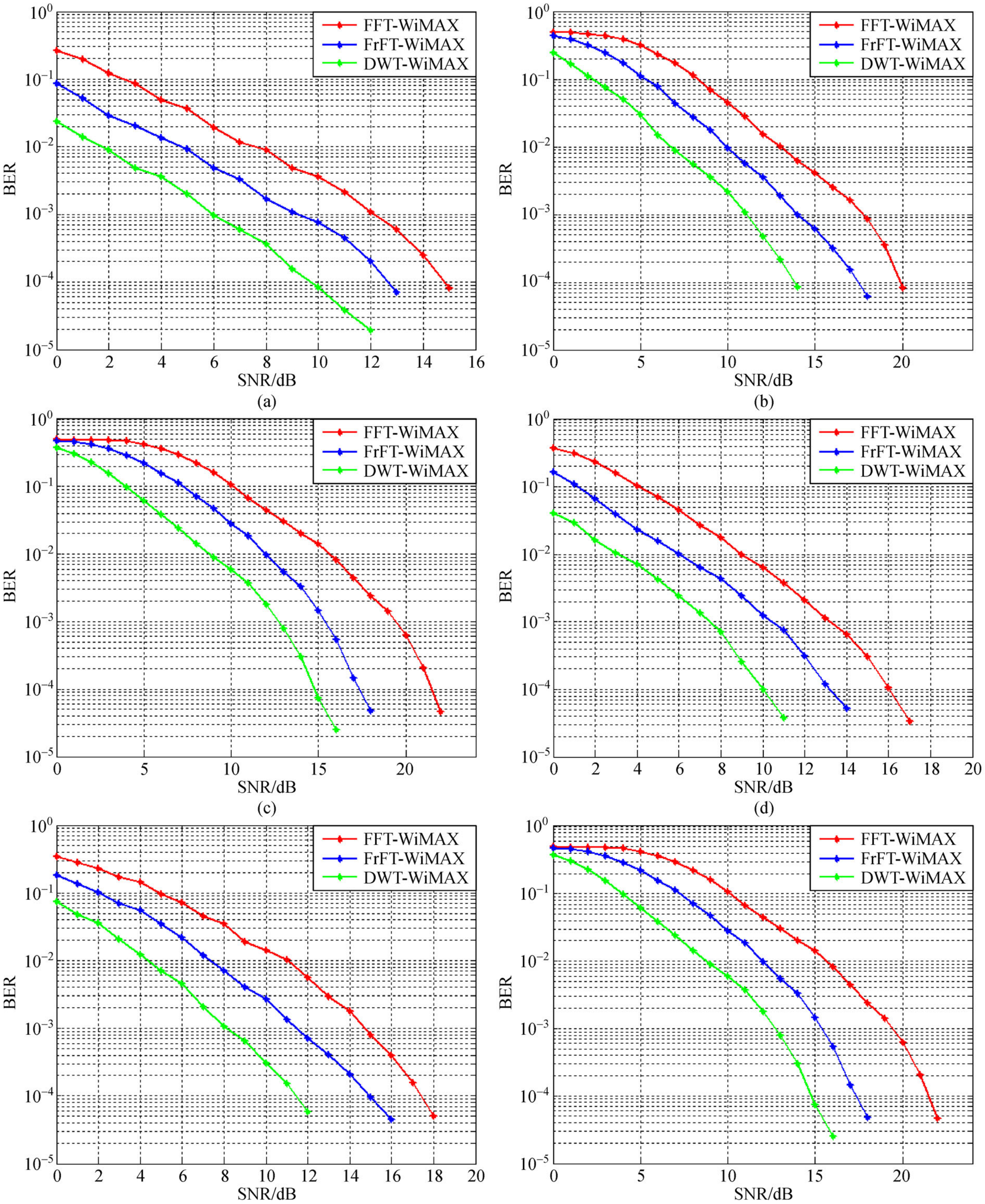
In MIMO, the users transmit and receive without joint encoding and detection as they spatially share the same wireless channel among them. The base station communicates with all the users simultaneously by exploiting the differences in spatial signatures at the base station antenna array induced by spatially dispersed users. Because of this spatial differences the performance gains will be impressive when considered in terms of sum-rates of all the users. However, the interference between the co-channel users will still remain the major challenge. Also, the presence of multipath fading result in degradation of the orthogonality of the subcarriers in the conventional FFT based-OFDM. Further, the multipath fading results in the time-varying effects of ISI due to varying delay spread which further effects the BER performance of the system. The deployment of the guard interval of duration higher than the delay spread will certainly decrease the effect of ISI, but at the same time, the presence of guard interval results in wastage of system bandwidth. On the other hand, the wavelet-based multi-carrier modulation (MCM) techniques are indeed offering a considerable out-of-band side-lobe elimination. The DWT based-OFDM is very robust against the time varying nature of the multipath fading channel. Also, no guard band is required in the case of DWT-OFDM, which will further improve its efficiency in comparison to FFT-OFDM [29,30].

Figures 5(a)–5(g) show the comparison of the BER performance for Alamouti encoded MIMO-WiMAX system augmented with FFT, FrFT and DWT over Rayleigh fading channel with 2 transmitting antennas and 1 receiving antenna. The analysis depicts that the FrFT based MIMO-WiMAX system outperforms the FFT based MIMO-WiMAX system. However, the DWT based MIMO-WiMAX system performs even better than the FrFT based MIMO-WiMAX system. The performance improvement originates from the fact that the orthogonality between the subcarriers is better maintained in the DWT based MIMO-WiMAX system in comparison to FFT based MIMO-WiMAX system and FrFT based MIMO-WiMAX system [10,11,20–22,29,30]. It is apparent from Fig. 5(a), that in order to achieve a BER of 10^{-4}, for BPSK modulated signal over Rayleigh fading channel FFT based MIMO-WiMAX system requires an SNR of 14.8 dB and requirement fall to 12.7 dB for FrFT based MIMO-WiMAX system, but this SNR requirement decreases even further to 9.8 dB for DWT based MIMO-WiMAX. As the level of modulation keeps on increasing the SNR required to achieve a BER of 10^{-4} will also be higher for M-PSK and M-QAM modulation. The change of convolution encoding code rate will also impact the BER performance of the system. A similar observation can be drawn from Figs. 5(b)–5(g).

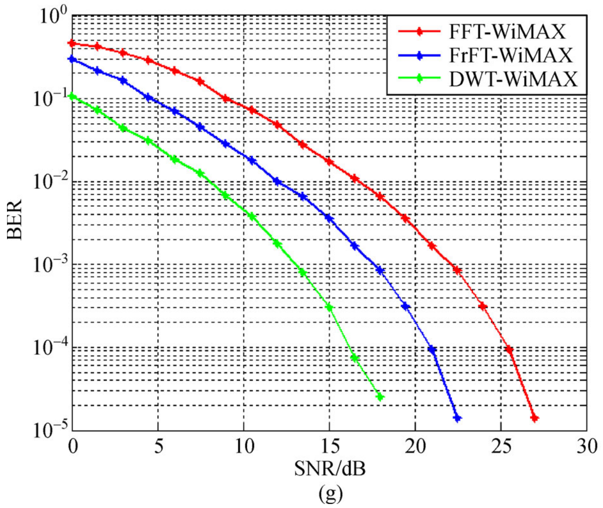
Figures 6(a) and 6(b) presents an idea about the impact of varying convolutional code rates on the BER performance of MIMO-WiMAX system. In Fig. 6(a), comparison is shown for MIMO-WiMAX augmented with diverse transforms with 2 transmitting and 1 receiving antenna over Rayleigh fading channel using BPSK modulation with the convolutional code rate varying from 1/2 to 3/4. It is very evident from the figure that on decreasing the code rate the BER performance of MIMO-WiMAX system degrades. Similar inferences can be drawn from Fig. 6(b), which presents the BER performance for MIMO-WiMAX augmented with diverse transforms with 2 transmitting and 1 receiving antenna over Rayleigh fading channel using QPSK modulation with the convolutional code rate varying from 1/2 to 3/4.

The spectral efficiency performance of Alamouti encoded MIMO-WiMAX system augmented with FFT, FrFT and DWT over Rayleigh fading channel with 2 transmitting antennas and 1 receiving antenna is shown in Figs. 7(a) – 7(g). This is evident from Figs. 7(a) – 7(g) that DWT augmented MIMO-WiMAX outperforms the FFT and FrFT augmented MIMO-WiMAX for diverse modulation schemes since it has better BER performance. As shown in Fig. 7(a), a SNR of 9.8 dB is required for DWT augmented MIMO-WiMAX with BPSK modulation and convolutional code (CC) rate of 1/2 to achieve a desired spectral efficiency, but this SNR requirements increases to 12.7 and 14.8 dB for FrFT augmented MIMO-WiMAX and FFT augmented MIMO-WiMAX respectively for same modulation level and CC rate. A similar observation can be made on analyzing the simulated results for other modulation schemes and CC code rates.

The exact value of SNR required to achieve a BER of 10^{-4} for FFT based MIMO-WiMAX system, FrFT based

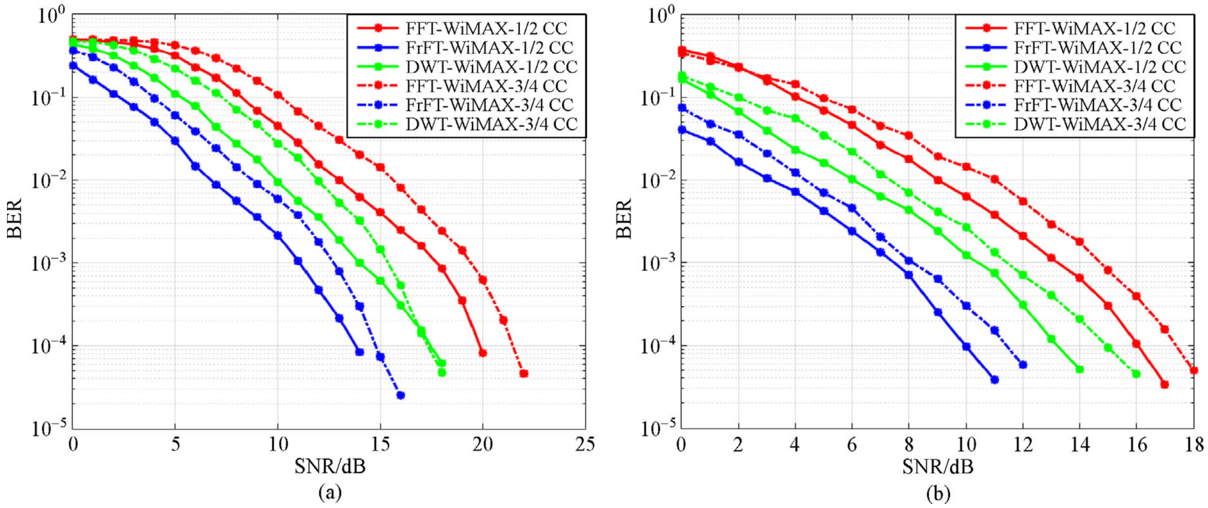

FFT-WiMAX
FrFT-WiMAX
DWT-WiMAX
BER
SNR/dB
10^0
10^{-1}
10^{-2}
10^{-3}
10^{-4}
10^{-5}
0 2 4 6 8 10 12 14 16
0 5 10 15 20
0 2 4 6 8 10 12 14 16 18 20

(a) (b) (c) (d) (e) (f)



(g)

Fig. 5 SNR vs BER comparison for MIMO-WiMAX augmented with diverse transforms with 2 transmitting and 1 receiving antenna over Rayleigh fading channel. (a) BPSK with CC 1/2; (b) QPSK with CC 1/2; (c) QPSK with CC 3/4; (d) 16-QAM with CC 1/2; (e) 16-QAM with CC 3/4; (f) 64-QAM with CC 2/3; (g) 64-QAM with CC 3/4



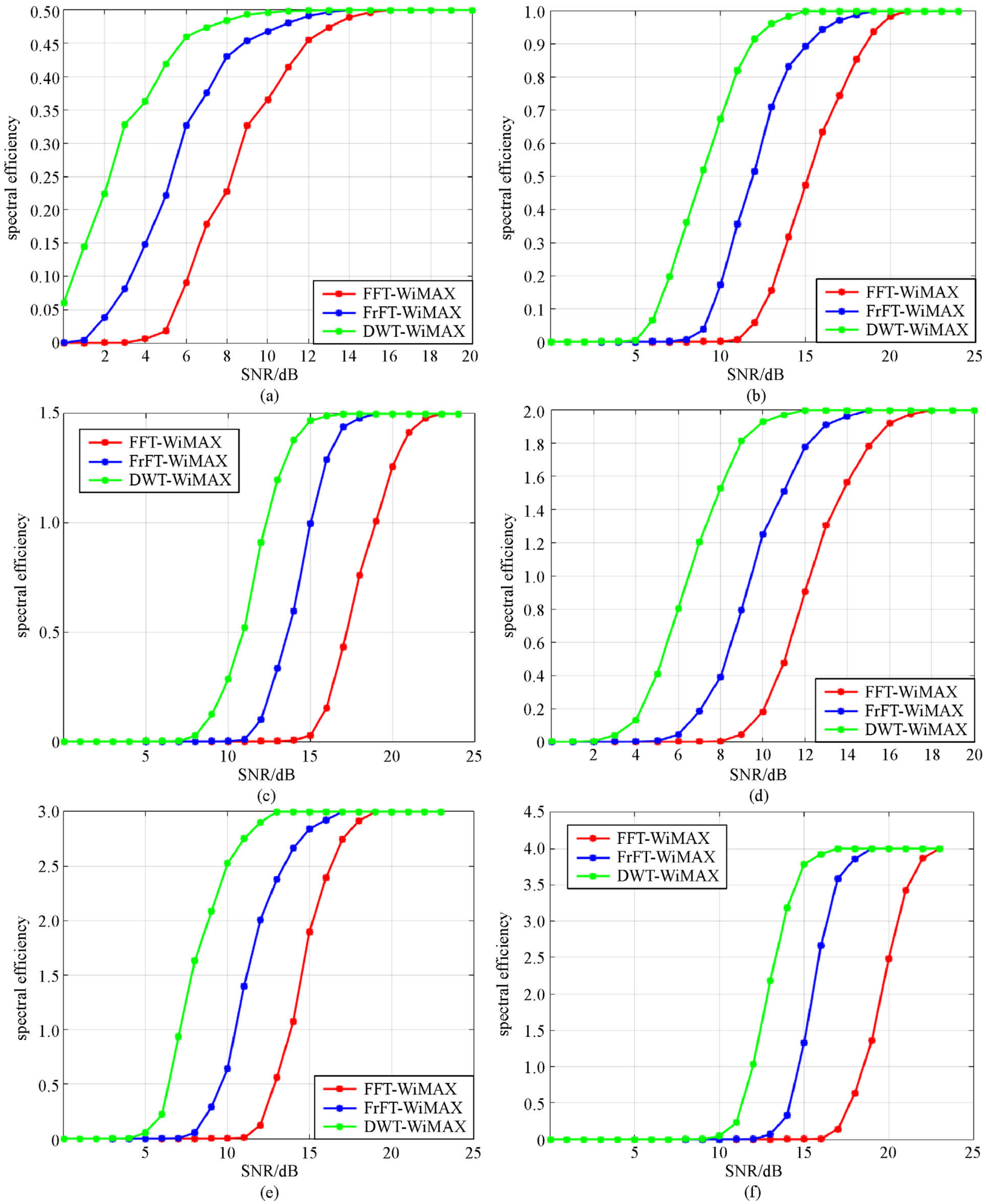
(a)

(b)

Fig. 6 SNR vs BER comparison for MIMO-WiMAX augmented with diverse transforms with 2 transmitting and 1 receiving antenna over Rayleigh fading channel. (a) BPSK; (b) QPSK

MIMO-WiMAX system and DWT based MIMO-WiMAX system considering a diverse number of users in the downlink are presented in Table 1. The entire system is simulated for diverse modulation levels under Rayleigh fading channel, and the SNR values for all the possible scenarios are also listed in Table 1.

Figures 8(a)–8(g) show the comparison of the BER performance for Alamouti encoded MIMO-WiMAX system augmented with FFT, FrFT and DWT over Rayleigh fading channel with 2 transmitting antennas and 2 receiving antennas. The analysis depicts that the FrFT based MIMO-WiMAX system outperforms the FFT based MIMO-WiMAX system. However, the DWT based MIMO-WiMAX system performs even better than the FrFT based MIMO-WiMAX system. The performance improvement originates from the fact that the orthogonality between the subcarriers is better maintained in the DWT based MIMO-WiMAX system in comparison to FFT based MIMO-WiMAX system and FrFT based MIMO-WiMAX system [10,11, 20–22,29,30]. It is apparent from Fig. 8(a) that in order to achieve a BER of 10^{-4}, for BPSK modulated signal over Rayleigh fading channel FFT based MIMO-WiMAX system requires an SNR of 5.7 dB and requirement fall to 3.6 dB for FrFT based MIMO-WiMAX system, but this SNR requirement decreases even further to 0.7 dB for DWT based MIMO-WiMAX. As the level of modulation keeps on increasing the SNR required to achieve a BER of 10^{-4} will also be higher for M-PSK and


spectral efficiency
SNR/dB
FFT-WiMAX
FrFT-WiMAX
DWT-WiMAX
0
0.05
0.10
0.15
0.20
0.25
0.30
0.35
0.40
0.45
0.50
2
4
6
8
10
12
14
16
18
20
0.1
0.2
0.3
0.4
0.5
0.6
0.7
0.8
0.9
1.0
5
15
25
0.5
1.0
1.5
0.2
0.4
0.6
0.8
1.2
1.4
1.6
1.8
2.0
2.5
3.0
3.5
4.0
4.5

(a)

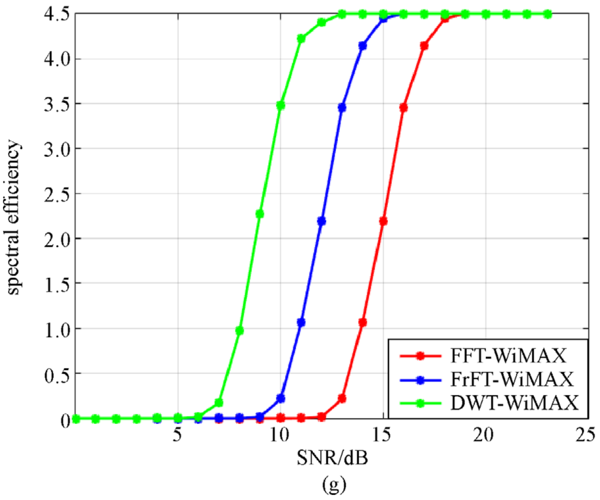
(b)

(c)

(d)

(e)

(f)



(g)

Fig. 7 Spectral efficiency comparison for MIMO-WiMAX augmented with diverse transforms with 2 transmitting and 1 receiving antenna over Rayleigh fading channel. (a) BPSK with CC 1/2; (b) QPSK with CC 1/2; (c) QPSK with CC 3/4; (d) 16-QAM with CC 1/2; (e) 16-QAM with CC 3/4; (f) 64-QAM with CC 2/3; (g) 64-QAM with CC 3/4

Table 1 SNR required to achieve a BER of 10^{-4} for MIMO-WiMAX augmented with diverse transforms with 2 transmitting and 1 receiving antenna over Rayleigh fading channel

modulation types	SNR (dB) required to achieve a BER of 10^{-4} using diverse transforms		
	FFT	FrFT	DWT
BPSK (1/2 CC)	14.8	12.7	9.8
QPSK (1/2 CC)	19.8	17	13.5
QPSK (3/4 CC)	22	17	14.8
16-QAM (1/2 CC)	16	13.2	10
16-QAM (3/4 CC)	17.5	15	11.5
64-QAM (2/3 CC)	22.2	17	14.7
64-QAM (3/4 CC)	25.5	21	16.5

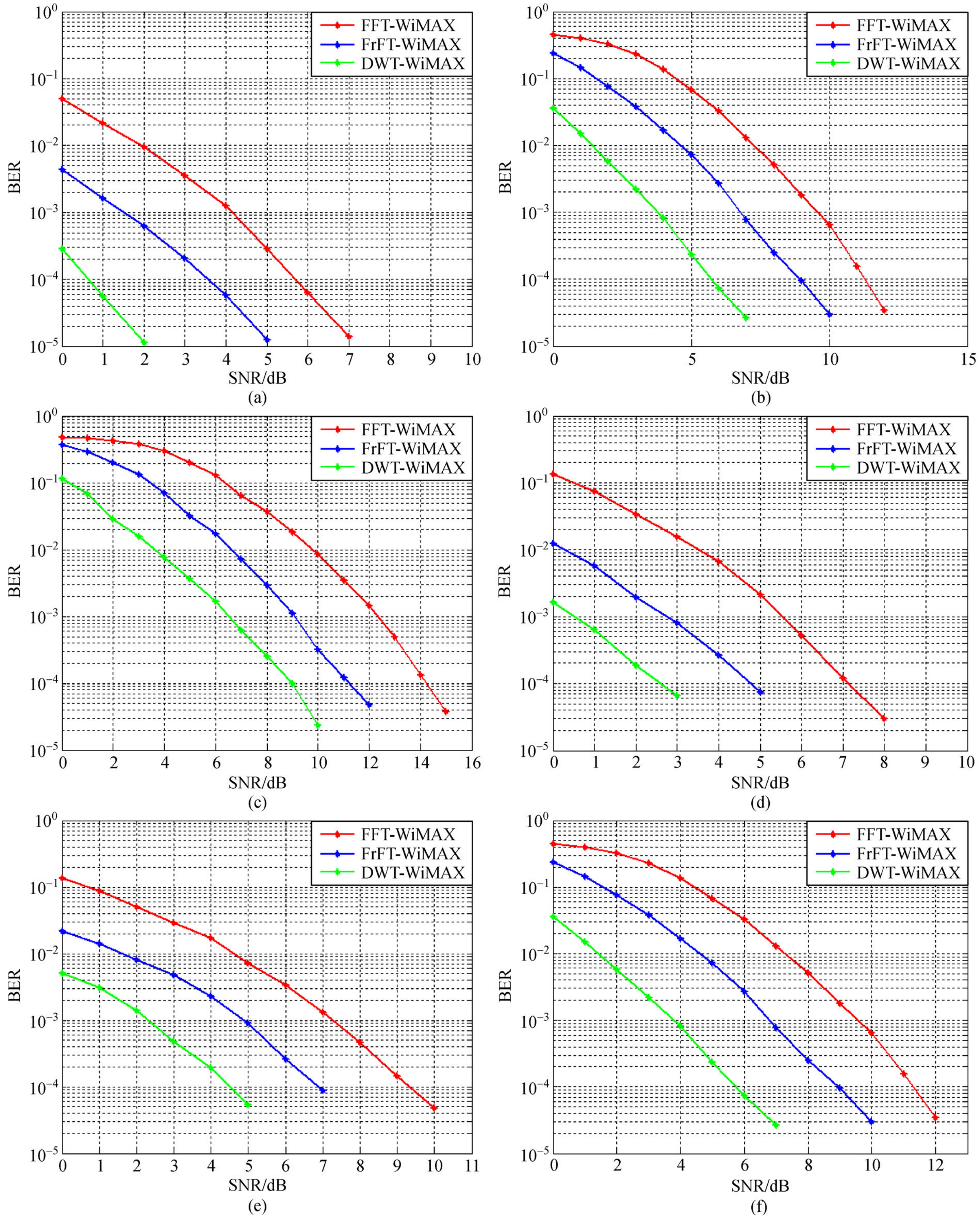
M-QAM modulation. A similar observation can be drawn from Figs. 8(b)–8(g).

The spectral efficiency performance of Alamouti encoded MIMO-WiMAX system augmented with FFT, FrFT and DWT over Rayleigh fading channel with 2 transmitting antennas and 2 receiving antenna is shown in Fig. 9. This is very much from Figs. 9(a) – 9(g) that DWT augmented MIMO-WiMAX outperforms the FFT and FrFT augmented MIMO-WiMAX for diverse modulation schemes since it has better BER performance. As depicted in Fig. 9 (a), in order to achieve the desired spectral efficiency in case of BPSK modulation with CC code rate 1/2 0.7 dB of SNR is required for DWT augmented MIMO-WiMAX which is less than 3.6 dB of SNR required for FrFT augmented MIMO-WiMAX and 5.7 dB of SNR required for FFT augmented MIMO-WiMAX. A similar observation can be made on analyzing the simulated results for other modulation schemes and CC code rates.

The exact value of SNR required to achieve a BER of 10^{-4} for FFT based MIMO-WiMAX system, FrFT based MIMO-WiMAX system and DWT based MIMO-WiMAX system considering a diverse number of users in the downlink are presented in Table 2. The entire system is simulated for diverse modulation levels under Rayleigh fading channel, and the SNR values for all the possible scenarios are also listed in Table 2.

6 Conclusions

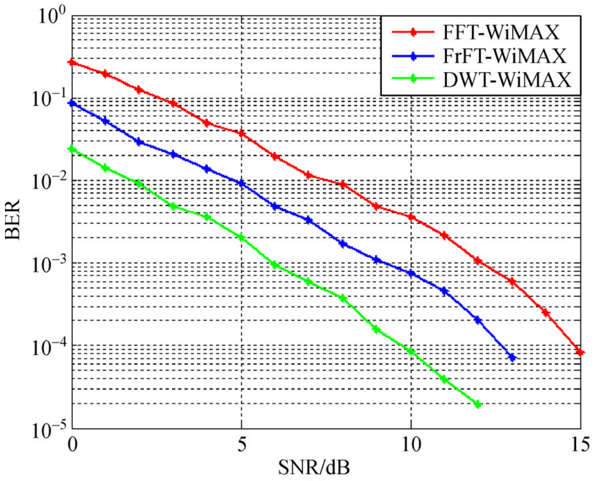
The performance investigation reveals that the DWT/FrFT augmented MIMO-WiMAX is a feasible substitute to FFT based MIMO-WiMAX system though at the expense of considerably elevated complications of the equalisation. After analyzing the SNR vs BER results, it is very much evident that the FrFT based MIMO-WiMAX offers an SNR improvement of 2 – 3 dB in comparison to FFT based MIMO-WiMAX for achieving a BER of 10^{-4} in Rayleigh


FFT-WiMAX
FrFT-WiMAX
DWT-WiMAX
BER
SNR/dB
10^0
10^{-1}
10^{-2}
10^{-3}
10^{-4}
10^{-5}
0 1 2 3 4 5 6 7 8 9 10
0 5 10 15
0 2 4 6 8 10 12 14 16
0 1 2 3 4 5 6 7 8 9 10
0 1 2 3 4 5 6 7 8 9 10 11
0 2 4 6 8 10 12

(a) (b)

(c) (d)

(e) (f)

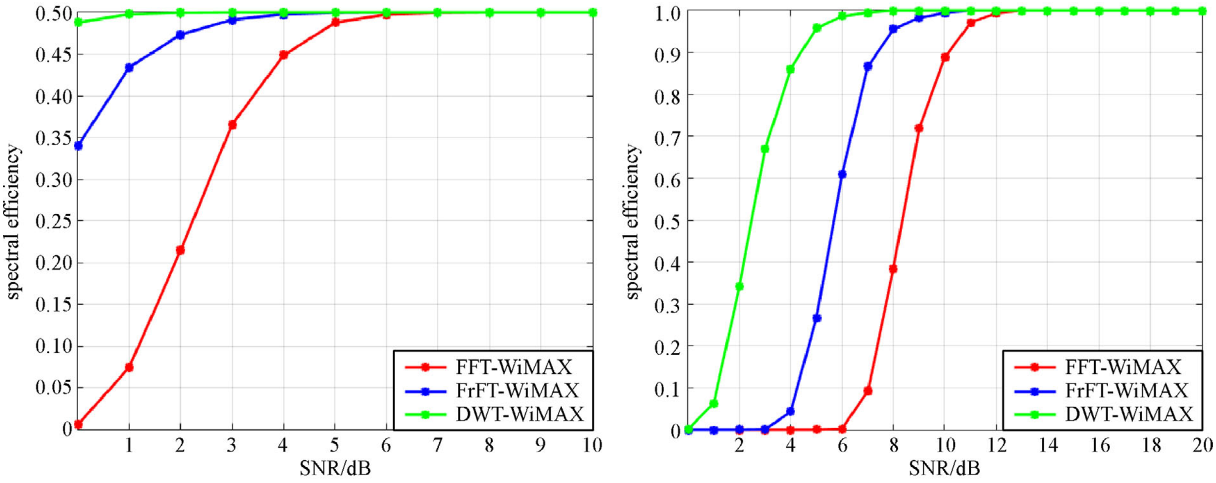


(g)

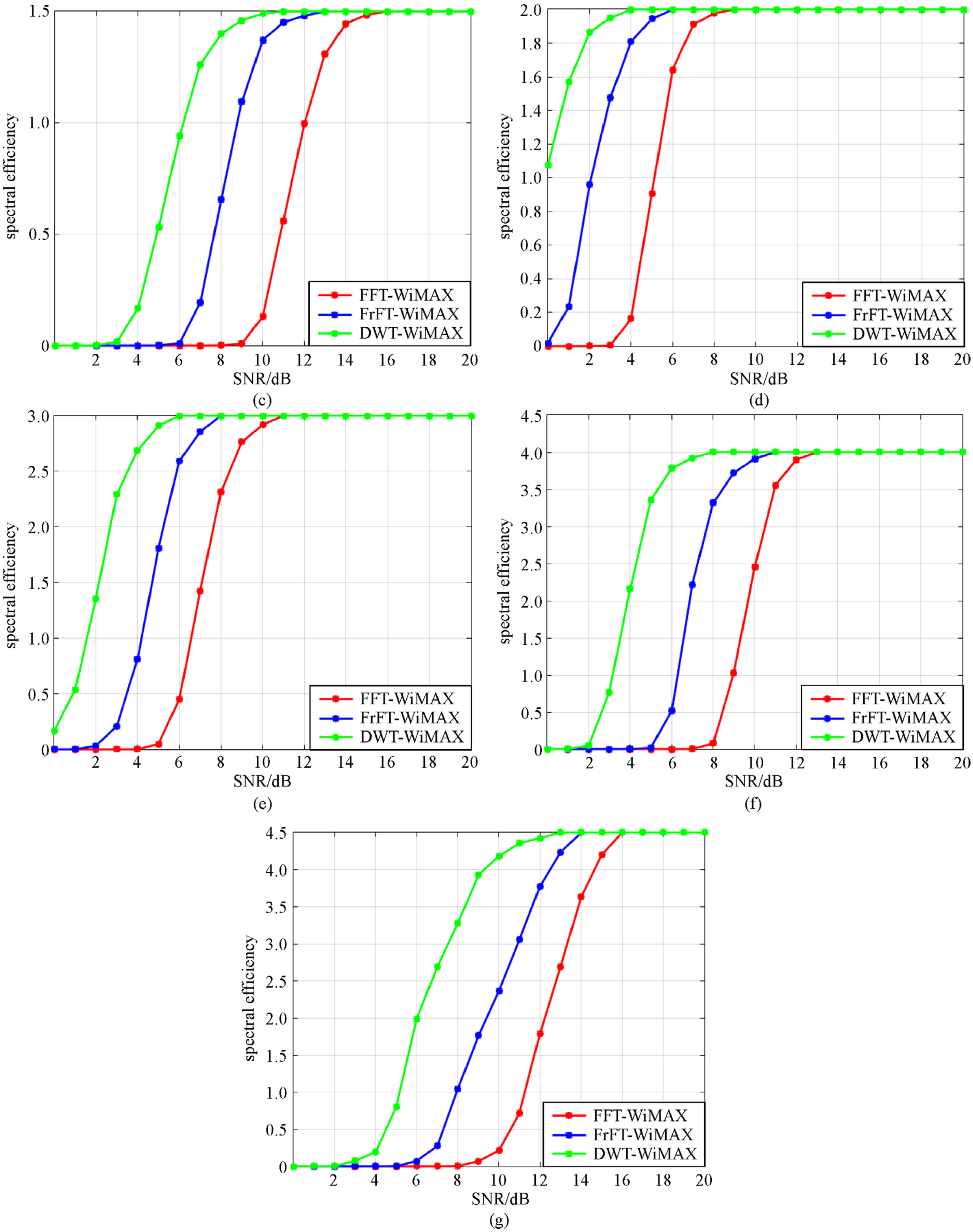
Fig. 8 SNR vs BER comparison for MIMO-WiMAX augmented with diverse transforms with 2 transmitting and 2 receiving antenna over Rayleigh fading channel. (a) BPSK with CC 1/2; (b) QPSK with CC 1/2; (c) QPSK with CC 3/4; (d) 16-QAM with CC 1/2; (e) 16-QAM with CC 3/4; (f) 64-QAM with CC 2/3; (g) 64-QAM with CC 3/4

Table 2 SNR required to achieve a BER of 10^{-4} for MIMO-WiMAX augmented with diverse transforms with 2 transmitting and 2 receiving antenna over Rayleigh fading channel

modulation types	SNR (dB) required to achieve a BER of 10^{-4} using diverse transforms		
	FFT	FrFT	DWT
BPSK (1/2 CC)	5.7	3.6	0.7
QPSK (1/2 CC)	11	8.5	5.7
QPSK (3/4 CC)	14.5	11.2	9.2
16-QAM (1/2 CC)	7.2	4.8	2.6
16-QAM (3/4 CC)	9.4	6.8	4.6
64-QAM (2/3 CC)	11.3	9	5.8
64-QAM (3/4 CC)	14.9	12.5	9.8



(a) (b)



(c) (d)

(e) (f)

(g)

Fig. 9 Spectral efficiency comparison for MIMO-WiMAX augmented with diverse transforms with 2 transmitting and 2 receiving antenna over Rayleigh fading channel. (a) BPSK with CC 1/2; (b) QPSK with CC 1/2; (c) QPSK with CC 3/4; (d) 16-QAM with CC 1/2; (e) 16-QAM with CC 3/4; (f) 64-QAM with CC 2/3; (g) 64-QAM with CC 3/4 fading channel for diverse modulation levels and varying number of users in the downlink. Further, this SNR improvement is elevated to 3 – 4 dB in DWT based MIMO-WiMAX to achieve the same BER of 10^{-4}. So, it can be concluded that the performance of MIMO-WiMAX will be improved by replacing the conventional FFT by diverse transforms such as DWT & FrFT in WiMAX physical layer. Also, an additional cost of SNR is required with the higher level of M-PSK schemes and on decreasing the number of antennas in the downlink to achieve the desired BER.

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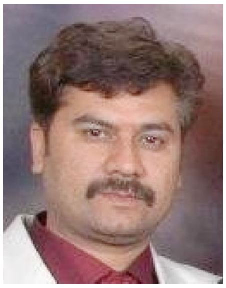

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