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*Research Article*

# Performance Analysis of WOFDM-WiMAX Integrating Diverse Wavelets for 5G Applications

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In the 5$^{th}$ generation (5G) and 6$^{th}$ generation (6G) of wireless mobile telecommunication networks, the requests for an elevated data rate with access to stationary as well as portable customers are going to be overwhelming. Mobile worldwide interoperability for microwave access (WiMAX) comes out as a favourable alternative that is intelligibly developed and more matured than wireless fidelity (Wi-Fi). Mobile WiMAX makes use of the orthogonal frequency division multiple access (OFDMA) technology for its two-way communication to enhance the system performance in fading environments making it more suitable for 5G applications. The diverse OFDM forms deliberated here are the fast Fourier transform- (FFT-) based WiMAX and discrete wavelet transform- (DWT-) based WiMAX. The suggested study exhibits the bit error rate (BER) and peak to average power ratio (PAPR) reduction by integrating different wavelet families, i.e., Haar, symlet, coiflet, and reverse biorthogonal over Rayleigh fading channel. The simulation results obtained by MATLAB depicts an improvement in PAPR reduction, and signal to noise ratio (SNR) requirement is also reduced by 6-12 dB by using DWT-incorporated WiMAX at a BER of $10^{-4}$.

## 1. Introduction

WiMAX organizations specifically designed WiMAX system to have unanimity and consistency of the IEEE 802.16 guidelines, as of now called a wireless metropolitan area network (MAN). IEEE 802.16c operating in the 10-66 GHz frequency range for the line of sight (LOS) propagation was introduced by IEEE in 2002. The IEEE 802.16c includes the specifications for connectivity between remote areas and data distribution over a wide area network for both point to point (PPP) and point to multipoint (PMP) communication over microwave frequencies. Further, IEEE introduced a new version, i.e., IEEE 802.16a operating over the frequency range of 2-11 GHz and suitable for nonline of sight (NLOS) signal propagation. IEEE 802.16d, an improved form of IEEE 802.16, was proposed in 2004 for providing wideband connectivity to indoor clients. The IEEE affirmed the 802.16 benchmarks in June 2004, and three working groups were framed to access and rate the guidelines. WiMAX can be termed completely as an inheritor of the Wi-Fi system. The standard when extended to IEEE 802.16e-2005 popularly called as mobile WiMAX standard provides various solutions for wireless broadband data that provides ease for meeting requirements of the mobile and fixed broadband networks

[1, 2]. WiMAX provides a way through which anyone can be in touch with another person regardless of their location anytime and anywhere. 5G has a crucial role in operation of society along with IoT. It needs to think about new trust model [3], increased privacy concerns [4, 5], and IoT-based health care [6].

The modulation level and the minimum BER requirements and the SNR are major factors that impact the spectral effectiveness of the WiMAX scheme. An appropriate selection of the modulation techniques/level is the trade-off between BER and spectral efficiency, i.e., as we keep on increasing the level of modulation from QPSK to 16-PSK and so on the BER performance keeps on decreasing, the increase in the modulation level results in an enhancement in the spectral effectiveness of the module. In addition to this elevated PAPR is a key shortcoming of the modern-day multicarrier transmission systems, i.e., 4G and 5G. As we know, to transmit the signal over a wide coverage area, the power amplifier is being employed at the transmitter side, and to achieve maximum coverage area and adequate signal strength, the OFDM system forced the amplifier to operate in the nonlinear region. The operation of power amplifiers in the linear region will result in high PAPR. High PAPR leads to certain distortions, i.e., out-band and in-band radiation. The outcome of the OFDM/WiMAX system can be improved by using diverse transforms like discrete cosine Stockwell transform (DCST), fractional Fourier transform (FRFT), wavelet Haar transform (WHT), and DWT instead of conventional fast Fourier transform (FFT). DWT offers the frequency and time domain depiction of signals, whereas in contrast, DFT gives the depiction of the signal in the frequency domain [7]. The wavelet characteristics, which comprise demonstration in time and frequency domain, orthogonality by means of a scale, and translation, highlight an entire new viewpoint in wireless mobile communication. The DWT is being used as a signal processing technology in several modern-day wireless communication applications, assimilating MCM and mobile wireless communication. Many researchers have proposed a replacement of FFT by DWT in modern-day wireless telecommunication systems (4G, 5G) due to its inferior time-frequency localization, poor bandwidth efficiency due to utilization of cyclic prefix, poor BER performance, etc. In the wavelet-based WiMAX, the cyclic prefix will not be utilized which will result in efficient utilization of the bandwidth. Technically, the DWT is a highly advanced transform in comparison to the DFT.

*1.1. Our Contribution.* On carefully studying the investigation work described in the literature survey, the following research gaps are addressed to realize the goal of efficient transmission of information over 5G network:

(1) Diverse wavelets are being utilized to analyse the performance outcome of the WiMAX system

(2) SNR vs. BER and PAPR reductions are the parameters using which the performance of WiMAX system is studied to establish wavelets as a reliable alternative to FFT

(3) The simulation outcome also presents the variation of received signal quality for diverse modulation type/levels

The entire manuscript is structured as follows: Section 1 explains the reasons for using wavelet transforms in the existing wireless communication systems by citing the issues related to WiMAX. A brief insight on the existing work based on FFT-OFDM, WHT-OFDM, FFT-WiMAX, and WHT-WiMAX is provided in Section 2. The basic model description is provided in Section 3, followed by an insight into the simulation parameters and channel models in Section 3. Section 4 presents the interpretations extracted from the MATLAB simulation results, and finally, conclusion remarks for the proposed work are presented in Section 5.

## 2. Related Work

In the preliminary stages, the DWT-based OFDM was simulated to lessen the influence of ICI/ISI and to elevate the bandwidth efficiency. The DWT-OFDM proved to be more resilient to the ICI and ISI because the wavelet filters enable spectral containment capabilities which in result decrease the ICI and ISI [8]. Moreover, in DWT-OFDM, the guard bands were not required, thereby making DWT-OFDM more bandwidth effective in comparison to FFT-OFDM. DFT-based OFDM was the most popular methodology for the efficient implementation of the OFDM system. But those systems suffer from certain drawbacks such as the requirement of a cyclic prefix, low QOS, ISI, and ICI. A new model for the OFDM system which incorporates the complex wavelet packet transform (WPT), i.e., CWP-OFDM, was proposed [9]. The time-varying Doppler shift affects the orthogonality of the OFDM subcarriers drastically [10]. The DWT-OFDM was proved to be more resilient to the shift and also offers side lobes of far lower magnitude in comparison to FFT-OFDM. The accurate reconstruction of the symbols with much lower complexity was a squeezing characteristic of WHT-OFDM [11]. The WHT-OFDM offered a considerable improvement regarding transmission efficiency and spectrum leakage in comparison to FFT-OFDM over power line channels [12]. A wavelet-based OFDM system that satisfies the impeccable reconstruction property by virtue of their properties of orthonormal bases was proposed. Due to the orthogonal basis and accurate reconstruction of the symbols, the OFDM system incorporating the wavelet transforms, i.e., DWT-OFDM and WPM-OFDM exhibits a significant improvement in BER, was in contrast to Fourier-based OFDM [13, 14]. In addition to the wavelets, the BER assessment of the OFDM system was also be improved by using other transforms like discrete cosine transforms (DCT) and discrete sine transforms (DST) in comparison to FFT. Multiwavelet design also offers a substantial enrichment in the BER performance thereby reducing the minimum SNR required to attain the anticipated BER performance [15–17]. Because of their time-frequency localization property, the utilization of wavelets was having a robust influence on the BER outcome of the OFDM system over both the flat fading and fading channels which are frequency selective in nature [18]. It was presented that the

Table 1: Comparative analysis of work presented in literature and the proposed methodology.

| Article | Research outcome |
|---|---|
| BER assessment of FFT-OFDM against WHT-OFDM over different fading channels [30] | In this research article, Haar transform is utilized to showcase the BER improvement in OFDM systems. However, the effects of other wavelet transform families such as symlet, coiflet, and reverse biorthogonal were not studied in this paper. |
| Comparative analysis of wavelet and OFDM-based systems [31] | In this paper, the appropriateness of constant envelope multicarrier modulation methodology, OFDM, and wavelet-based systems is deliberate. The prime idea of this paper is to do the assessment of wavelet-based and OFDSM-based systems by using BER vs. SNR performance metrics. In our present research, we have proposed an adaptive system which will select any of the optimum wavelets that will give us best PAPR and BER reduction. |
| On BER assessment of conventional- and wavelet-OFDM over AWGN channel [19] | Performance of OFDM system based on DFT and DWT transform is evaluated in this paper using the BER matric. Diverse modulation schemes (PSK and QAM) and levels (2, 4, 8, and 16) are being utilized to analyse the performance over AWGN channel for both DFT- and DWT-based OFDM system. However, in the present work, Rayleigh fading channel is explored for the assessment of the performance of conventional and proposed system model. |

BER outcome was superior in flat fading channel but it degrades drastically in the frequency selective fading channels which are time-varying in nature. The suggested methodology performs exceptionally well in the frequency selective and time-varying channel condition due to the excellent time-frequency localization capabilities of the wavelet-based OFDM systems. ICI and ISI generated by vanishing effect of orthogonality in the OFDM system were significantly condensed by employing wavelet transform instead of DFT in the conventional OFDM-WiMAX system. In addition to the reduction of ICI and ISI, the wavelet-incorporated OFDM also enhances the spectral efficiency contrary to the DFT-incorporated OFDM system [18]. The WHT-OFDM outperforms the FFT-OFDM over the AWGN channels also, mainly due to the robust orthogonality of the subcarriers exhibited by WHT-OFDM in contrast to FFT-OFDM [19]. The impact of exponential power delay profile in conjunction with Rayleigh fading channel was also less on the WHT-OFDM contrary to FFT-OFDM [20]. Wavelet packet modulation (WPM) was also incorporated in the WiMAX, and the performance was evaluated over the AWGN channel, which again shows BER improvement on the use of wavelets in place of Fourier transforms [21]. DVB-T based on DWT-OFDM was also investigated in the literature, and the BER outcome of the wavelet family was superior to that of Fourier transforms. Also, out of all the members of the wavelet family, the Haar transform performed the best-regarding BER improvement for a given value of SNR [22]. It has been observed that precoding techniques [23–29], as well as the use of transform other than FFT [27–49], improve the BER and PAPR reduction performance for OFDM/WiMAX/MIMO/OFDM-MIMO system.

*2.1. Research Gaps*

(1) The work presented in the literature does not describe the effect of diverse wavelet families on WiMAX system's performance

(2) In most of the existing schemes presented in Table 1, only the Haar wavelet has been utilized to assess the BER and PAPR outcome of the OFDM/WiMAX system. Symlets, coiflets, and reverse biorthogonal wavelet families were not utilized for the analysis purpose in most of the cases

(3) While doing the performance assessment of the receiver section, the signal quality at the input of the demodulator was not presented in most of the recent work presented on OFDM/WiMAX. It is significant to study the behaviour of the signal at the receiver side as it will be useful while modelling the receiver section to give an optimum outcome

## 3. Model Description, Channel Model, and Signal Detection

The physical layer of the proposed model of WiMAX is presented in Figure 1, and the system parameters are considered as same as that of [32]. The multipath channel that is used for assessing the behaviour of the FFT-incorporated WiMAX and DWT-incorporated WiMAX is Rayleigh fading channel. The $n^{\text{th}}$ element of complex OFDM symbol in discrete-time domain is written as

$$X_n = \frac{1}{N}\sum_{k=0}^{N-1} X_k e^{j((2\pi kn)/N)},\ 0 \le n \le N-1, 0 \le k \le N-1. \quad (1)$$

Here, Equation (1) represents the discrete-time complex OFDM symbol. $N$ represents the number of samples, $X_k$ represents the input signal, and $X_n$ represents the OFDM symbols obtained after the Fourier transform. Diverse form of wavelets are comprised in the wavelet family, such as Haar, coiflet, symlet, biorthogonal, and reverse biorthogonal wavelets. However, in the proposed methodology, Haar wavelet is being utilized. The operating principle of the DWT and IDWT is presented in Figure 2. Here, $h(n)$ is the half band impulse response of high-pass filters, and $g(n)$ is the half-band impulse responses of the low-pass filters. The two filters are associated to each other by a quadrature mirror filter (QMF) relationship as follows:

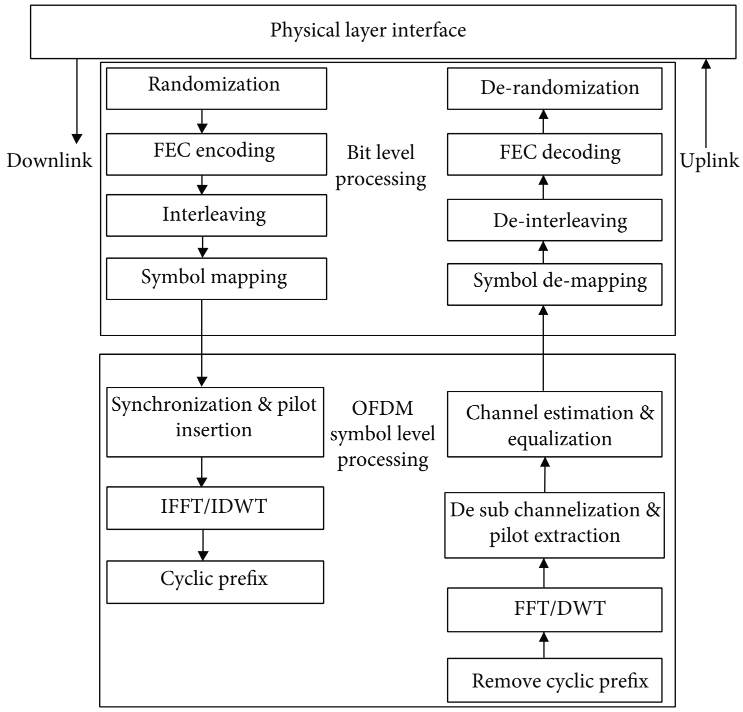



Figure 1: Physical layer model of proposed WiMAX system.

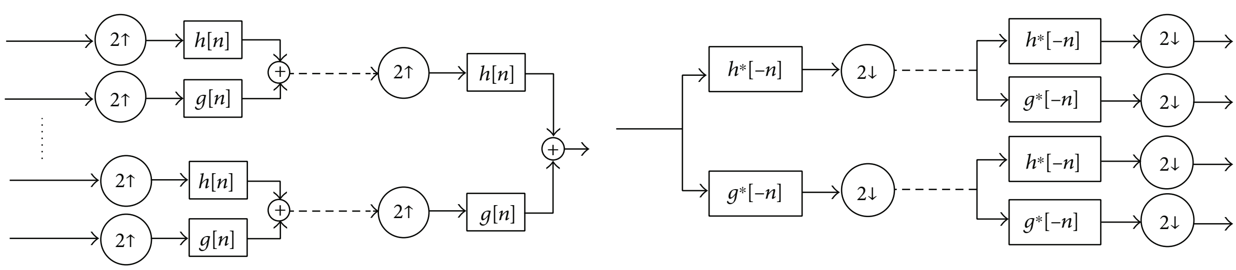



Figure 2: (a) IDWT and (b) DWT block diagram.

Table 2: Basic parameters of system simulations.

| Parameter | Value |
|---|---|
| $N_{FFT}$ | 256 |
| Cyclic prefix | 1/8 |
| Wavelets used | Haar, symlet, coiflet, and reverse biorthogonal |
| Channel coding rate | 1/2, 2/3, 3/4 |
| Modulation type | M-PSK and M-QAM |
| Modulation levels | 2, 4, 16, and 64 |
| Channel model | Rayleigh channel |
| Symbols used for simulation | $10^6$ |

$$(-1)^n h(n) = g(L-1-n). \tag{2}$$

These independently modulated subcarriers when summed up coherently produce a large PAPR. The PAPR value for OFDM signal is defined as

$$\mathrm{PAPR}_{dB} = 10 \log \left( \frac{\max\left[x(t)\, x^*(t)\right]}{E[x(t)x^*(t)]} \right), \tag{3}$$

Here, $E[.]$ denotes the expectation operation. The PAPR will increase if we keep on increasing the number of

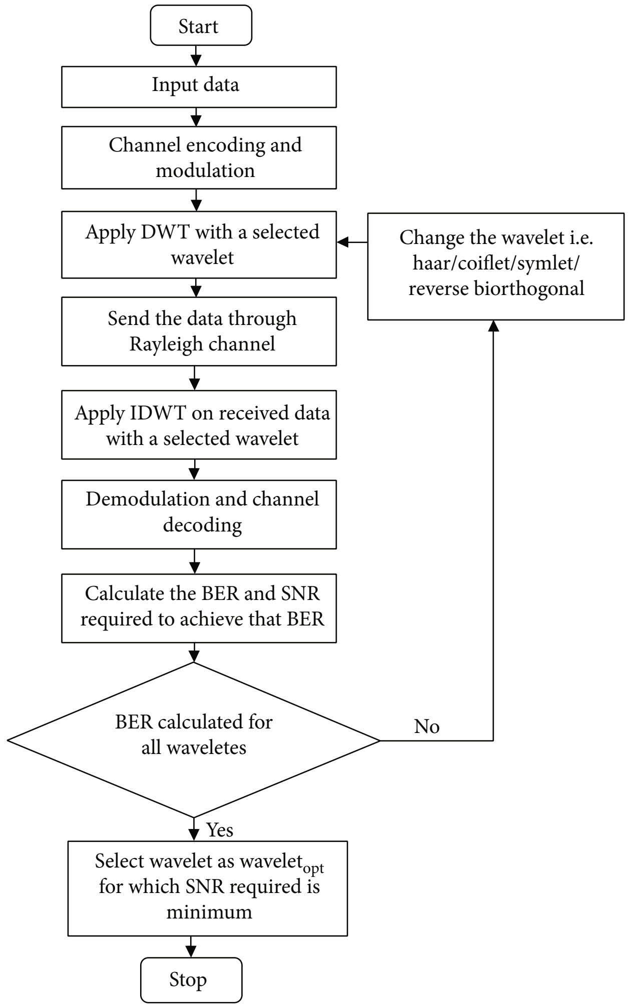



Figure 3: Proposed methodologies for DWT-incorporated WiMAX.

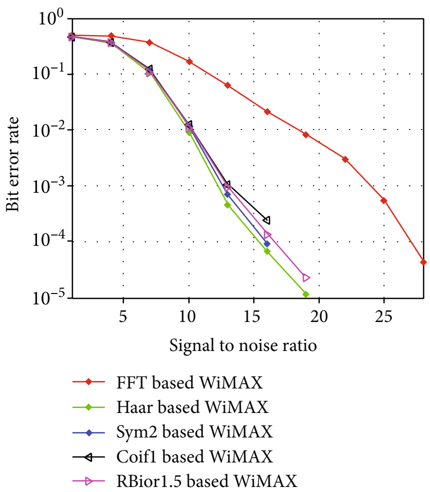
Table 3: SNR requirement analysis for WiMAX incorporating diverse wavelet families.

| Modulation types/level with variable channel encoding rates | SNR (dB) requirement for the achievement of the minimum BER ($10^{-4}$) in WiMAX incorporated with FFT and diverse wavelets | | | | |
|---|---|---|---|---|---|
| | FFT | Wavelet transform | | | |
| | | Haar | Symlet | Coiflet | Reverse biorthogonal |
| BPSK (1/2 CC) | 28 | 15.1 | 16 | 16.5 | 17.5 |
| QPSK (1/2 CC) | 37 | 22 | 23.5 | 24 | 23 |
| QPSK (3/4 CC) | 40 | 27 | 28 | 28 | 29 |
| 16-QAM (1/2 CC) | 27 | 16.5 | 17.5 | 18.5 | 18 |
| 16-QAM (3/4 CC) | 28 | 21.5 | 22 | 22.5 | 23 |
| 64-QAM (2/3 CC) | 29.5 | 22 | 27 | 27.5 | 24 |
| 64-QAM (3/4 CC) | 35.5 | 25 | 25.5 | 26.5 | 27 |

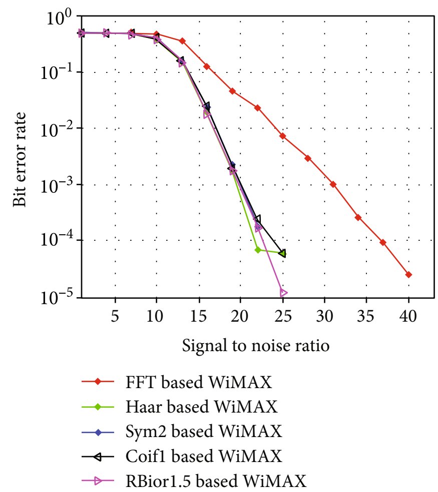
subcarriers. The prime objective of the PAPR reduction methodologies is to decrease the value of max $|x(n)|$. Rayleigh Channel is an additive, and subtractive quality of different paths segments in flat fading channels which are estimated by Rayleigh distribution having none observable pathway which implies if none immediate way is there amongst sender and receiver. The simplification of the arrived signal can be

$$r(t) = s(t) * h(t) + n(t), \tag{4}$$

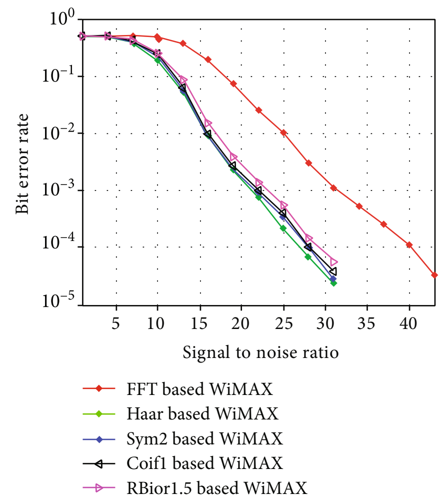
where $r(t)$ is the received signal, $s(t)$ is the transmitted



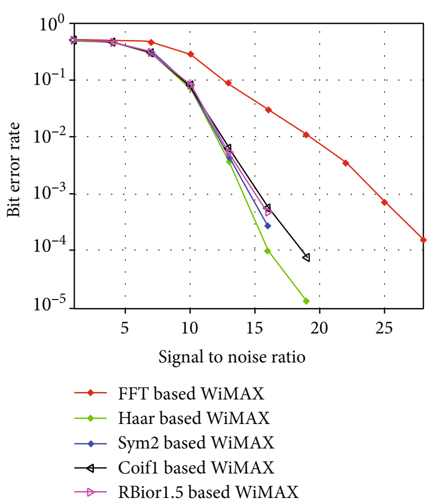

(a) BPSK (1/2 CC rate)



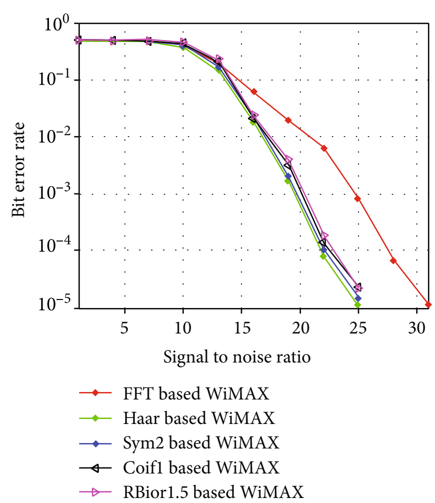

(b) QPSK (1/2 CC rate)



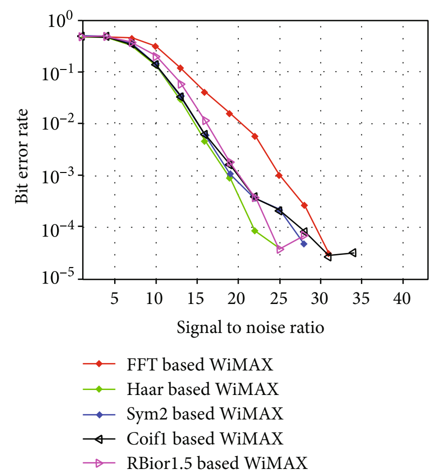

(c) QPSK (3/4 CC rate)



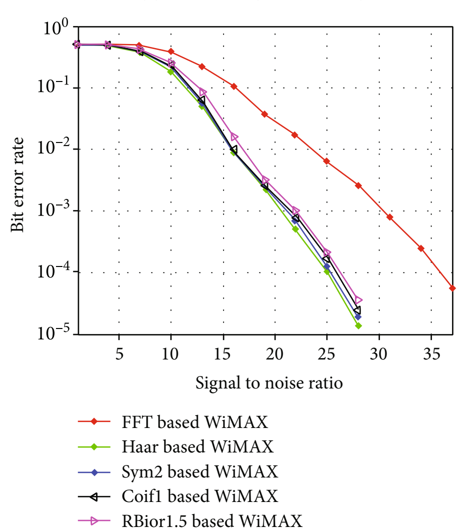

(d) 16-QAM (1/2 CC rate)




(e) 16-QAM (3/4 CC rate)




(f) 64-QAM (2/3 CC rate)




(g) 64-QAM (3/4 CC rate)

Figure 4: (a–g) SNR vs. BER measurements.

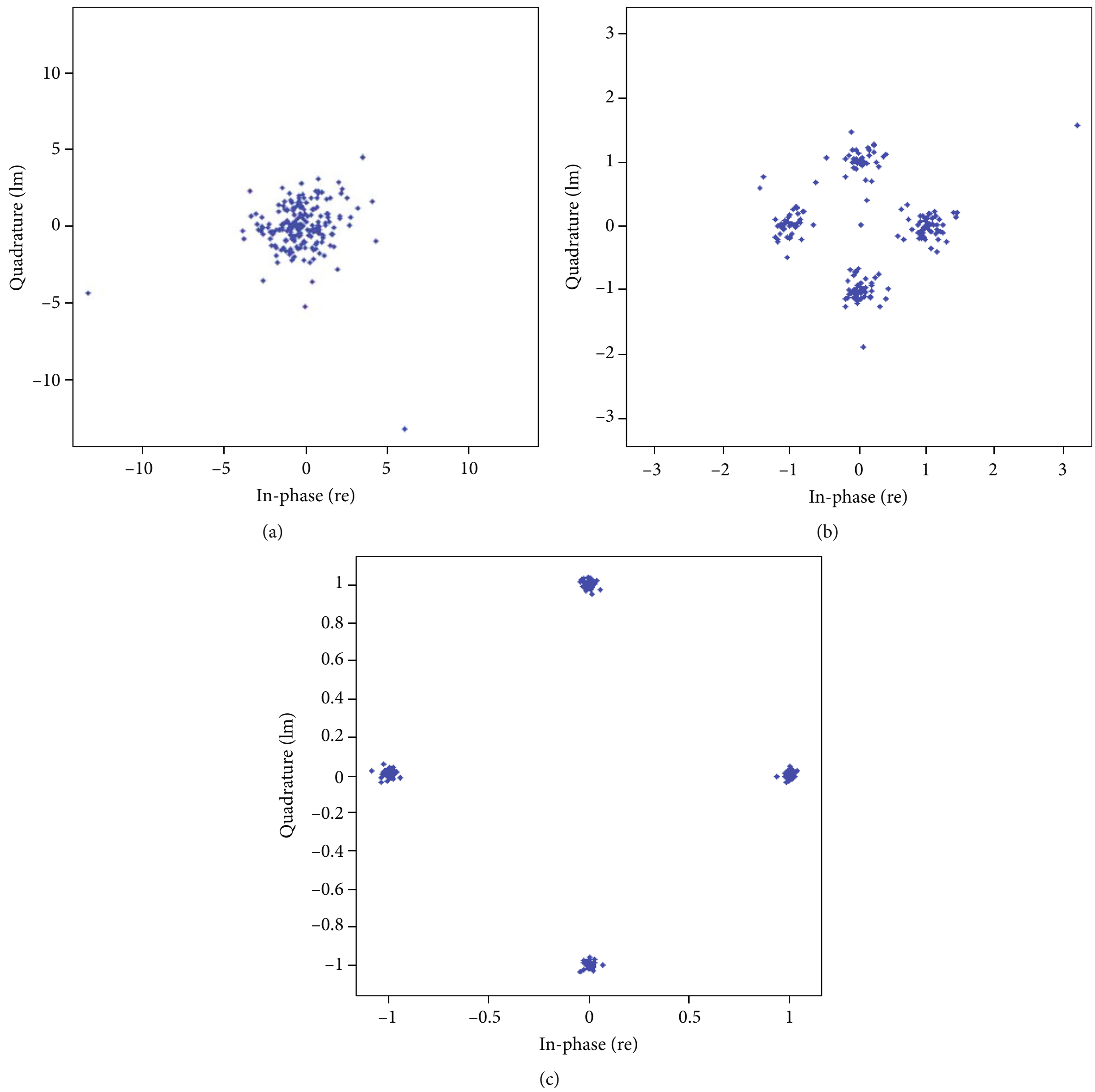



Figure 5: (a–c) Input to QPSK demodulator on using "Haar" wavelet for WiMAX system with variable SNR (a) 5 dB, (b) 15 dB, and (c) 30 dB.

signal, $h(t)$ symbolizes the channel matrix, and $n(t)$ symbolizes the AWGN. The probability density function (pdf) of "$r$ " having Rayleigh distribution is expressed as

$$f(r) = \frac{r}{\sigma^2} e^{-r^2/2\sigma^2}, \ 0 \le r \le \infty, \tag{5}$$

where received signal's time-average power is represented by $\sigma^2$. The phase and the gain components of a channel's deformation are symbolized as a complex number often. Here, it is assumed for the exhibition of Rayleigh fading that the modelling of response's real and imaginary parts is done by individual allocated zero-mean Gaussian processes.

An issue experienced in the plan of receivers for exchanging information digitally is the recognition of information from estimations with the noise of the sent data. For a practical solution, the receiver is because of the disturbance bound making incidental mistakes or errors. Accordingly, planning a receiver with the characteristics of a likelihood of blunder is insignificant engaging practically and hypothetically. Lamentably, such outlines tend to bring out computationally complex receivers, and hence, they are frequently surrendered for computationally less complex yet problematic recipients.

ZF equalizer is a linear detection strategy that is utilized in transmission systems for detection purposes and was introduced by Lucky [33]. In this algorithm, the frequency response of the channel is reversed. It is ideal for a channel without having any noise, whereas, for a channel with noise, the noise also gets amplified greatly at frequency $f$ where the little magnitude is there in channel response $H(j2\pi f)$ in the attempt to reduce the channel completely. At the side of the

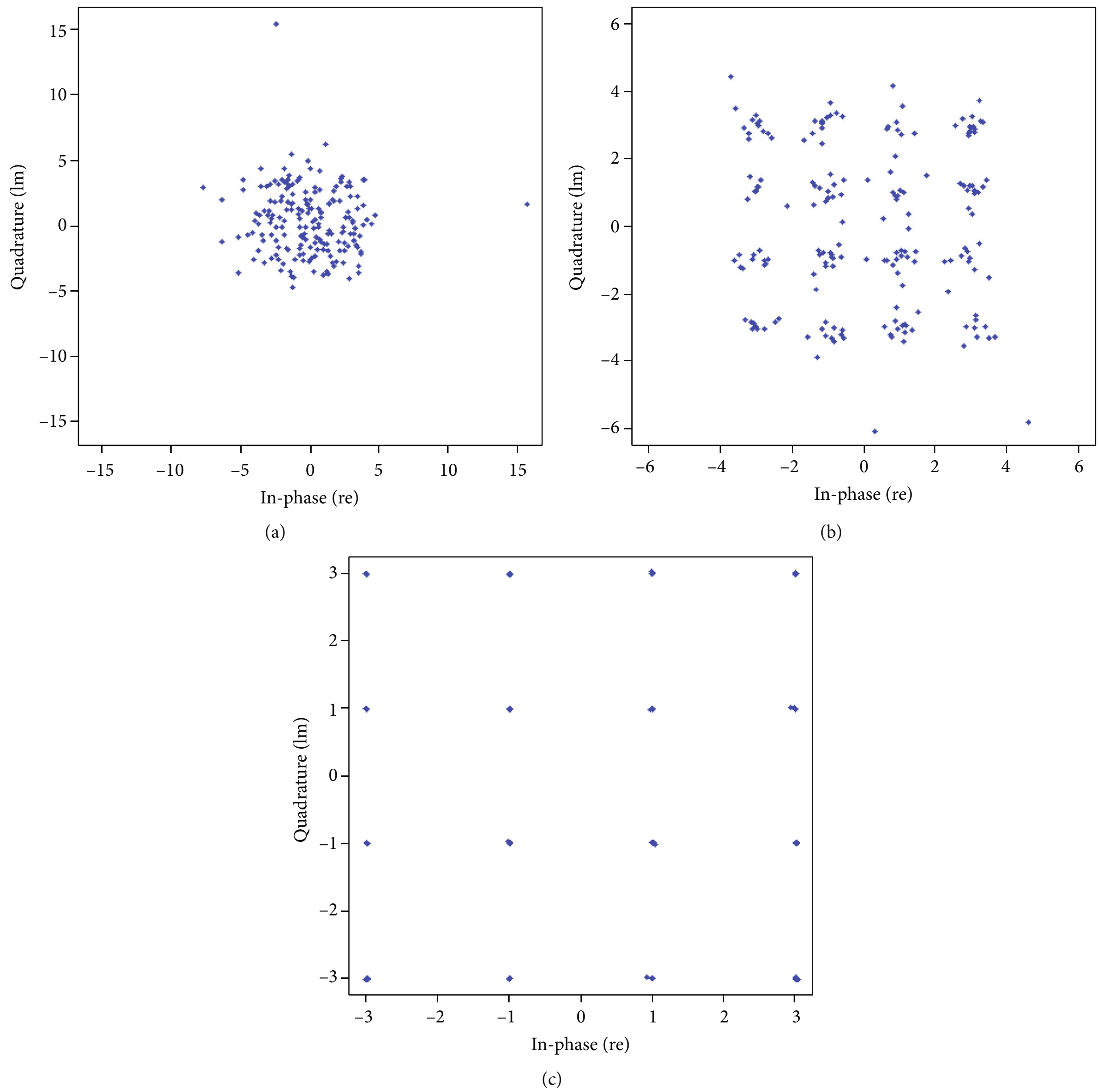



Figure 6: (a–c) Input to 16 QAM demodulator on using “Haar” wavelet for WiMAX system with variable SNR (a) 5 dB, (b) 15 dB, and (c) 30 dB.

transmission, if the CSI is known perfectly, then the system capacity can be achieved for the huge number of users by ZF precoding. To attain the complete multiplexing gain, ZF precoding requires the essential feedback overhead. Table 2 presents the basic simulation parameters along with values.

Due to the presence of cascaded 2 tap finite impulse response (FIR) filters and down samplers, the number of complex multiplications in Haar wavelet transform is higher than FFT. Therefore, the computational complexity of DWT-incorporated WiMAX is higher than the FFT-incorporated WiMAX. Besides, DWT performs well with nonstationary signals, whereas FFT is more suited for stationary signals.

The proposed methodology for carrying out the simulation of the WOFDM-WiMAX system incorporating diverse transforms is explained through a flowchart depicted in Figure 3. The proposed methodology in Figure 3 symbolises the principle of utilizing the optimum wavelet from the family of the wavelets to guarantee the finest BER outcome. The utilization of wavelets results in enhancements in the BER outcome of WiMAX systems [30]. Figure 3 depicts the methodology that are being utilized to do the MATLAB simulations for the DWT-based WiMAX system, in the endeavour to decide the optimum wavelet from the family of the wavelets. Table 3 presents the thorough BER outcome enhancements over Rayleigh channel presented in the form of the SNR that is essential to accomplish a BER of $10^{-4}$ for DWT-based WiMAX systems.

## 4. Result Discussion

The outcome of the WiMAX system incorporating diverse wavelet families is analysed over the Rayleigh fading channel

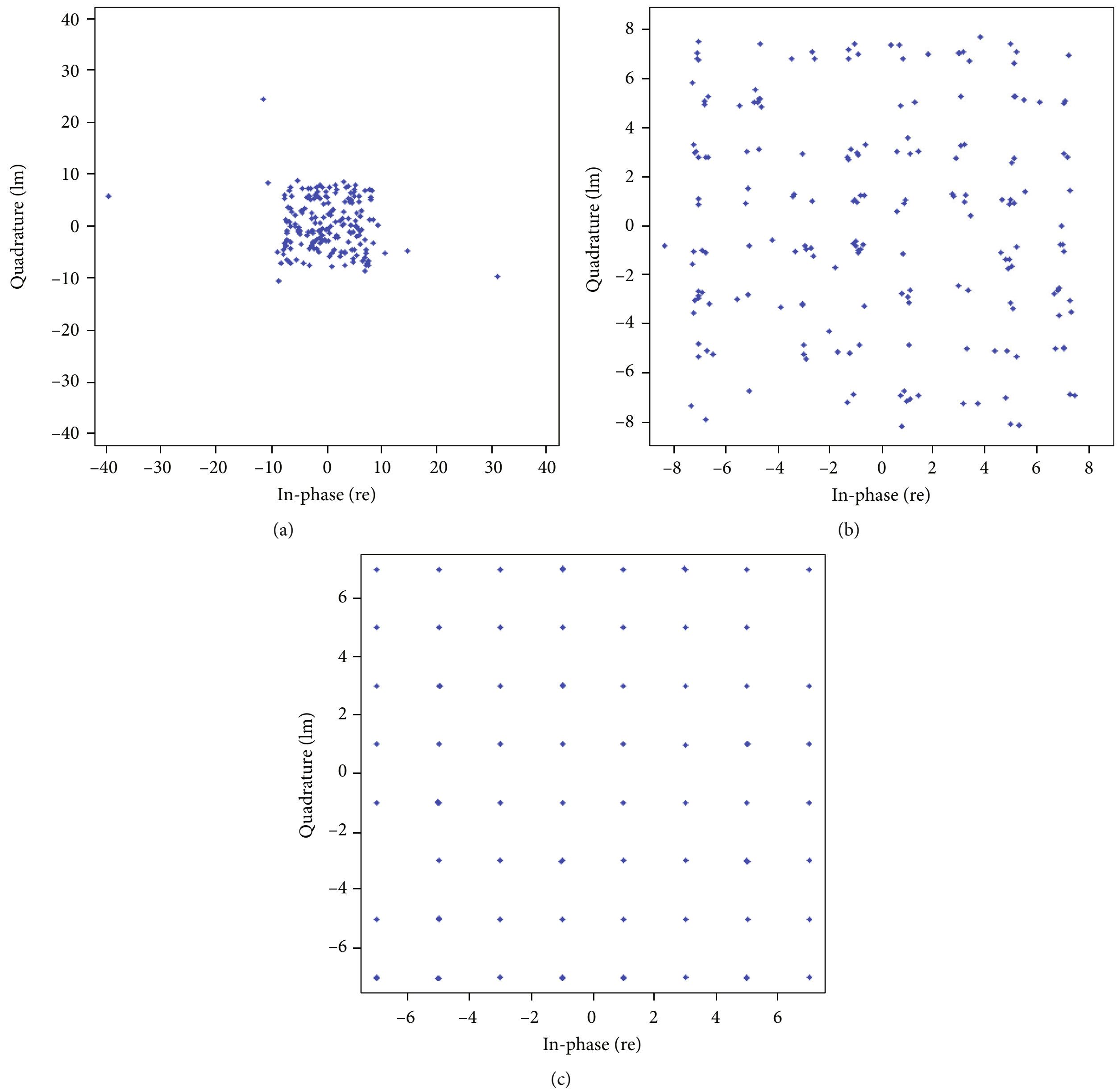



FIGURE 7: (a–c) Input to 64 QAM demodulator on using "Haar" wavelet for WiMAX system with variable SNR (a) 5 dB, (b) 15 dB, and (c) 30 dB.

using the comparison of SNR vs. BER deviations and PAPR reductions through the MATLAB simulations. It is assumed that the required BER for satisfactory performance is $10^{-4}$, and the same is used to compare the SNR requirement for FFT-incorporated WiMAX and diverse wavelet-incorporated WiMAX. Figures 4(a)–4(g) depicts the simulation evaluation over the Rayleigh fading channel for both DWT-WiMAX and FFT-WiMAX using SNR vs. BER matrices for variable modulation levels and convolution coding (CC) rates, i.e., 1/2, 2/3, and 3/4. After drawing inferences from the simulation results, it is evident that the DWT-incorporated WiMAX performs superior to the FFT-incorporated WiMAX. DWT ensures that the orthogonality between the subcarriers remains intact even under the severe effects of the multipath fading [19, 20, 30, 32, 34]. It is apparent from Figure 4(a) that FFT-WiMAX necessitates an SNR of 28 dB; however, this SNR prerequisite falls to 15.1 dB, 16 dB, 16.5 dB, and 17.5 dB for Haar, symlet, coiflet, and reverse biorthogonal wavelet-based WiMAX, respectively, to achieve a desired level of BER over Rayleigh fading channel. Rayleigh fading channel is used for the analysis purpose instead of AWGN channel as its distribution is more close to practical wireless channel. AWGN channel on internal noise component is considered for simulation of channel environment, whereas Rayleigh fading channel random noise and Rayleigh fading distribution are considered to model the channel environment. Also, in Rayleigh fading channel distribution, it is assumed that no direct path is available between transmitter and receiver side, which is quite equivalent to practical channel condition. Similar inferences can also be achieved in carefully analysing Figures 4(b)–4(g).

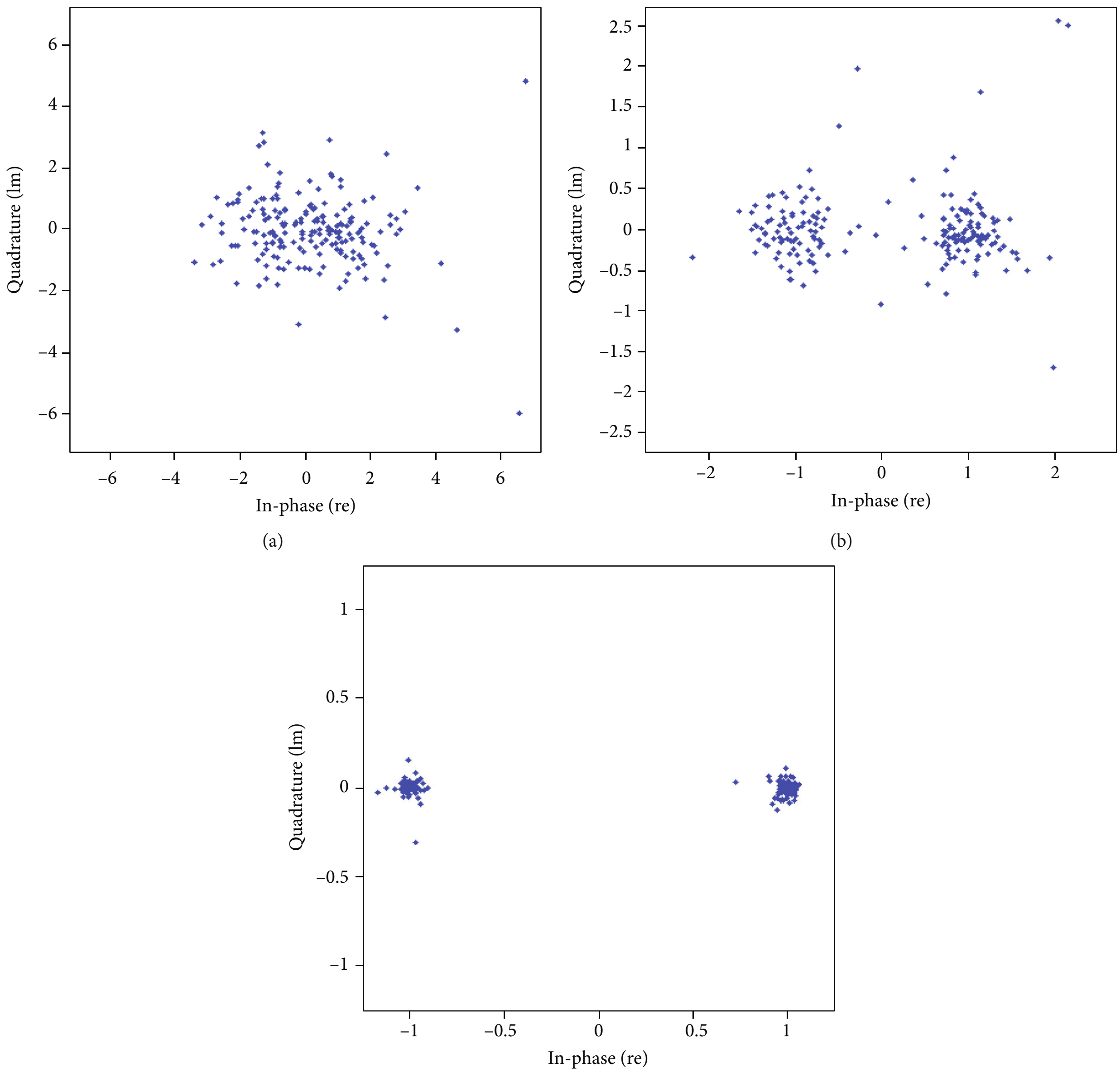
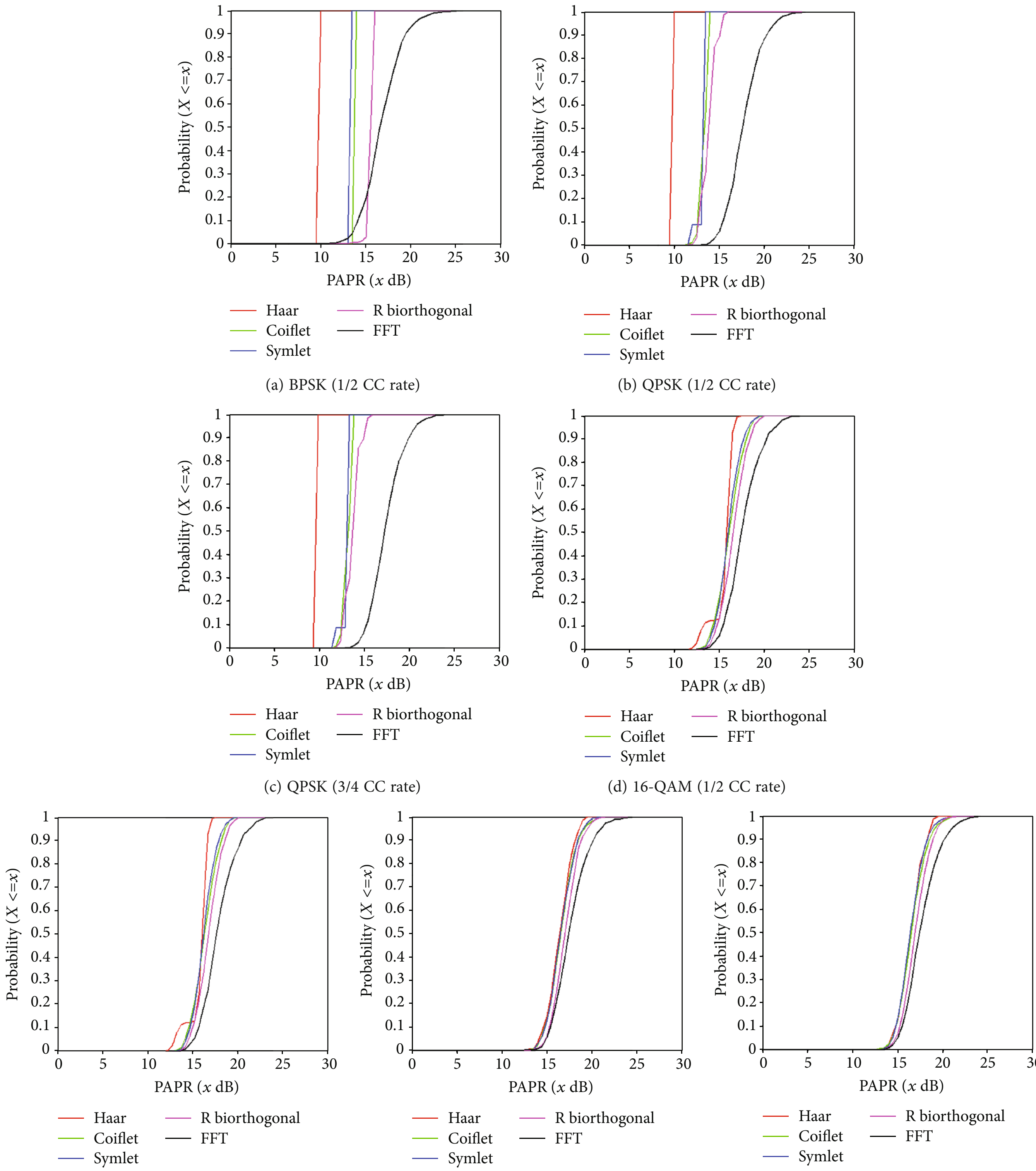



FIGURE 8: (a–c) Input to the BPSK demodulator on using "Haar" wavelet for WiMAX system with variable SNR (a) 5 dB, (b) 15 dB, and (c) 30 dB.

Table 3 provides the tabulated representation of the SNR requirements for the achievement of the minimum BER ($10^{-4}$) in WiMAX incorporated with FFT and diverse wavelets. It is very much evident from Table 3 that the DWT-incorporated WiMAX propose an enhancement of 10-15 dB of SNR in contrast to FFT-incorporated WiMAX. Also, the Haar transform outperforms the other wavelets, i.e., symlet, coiflet, and reverse biorthogonal wavelets in the wavelet family by a margin of .5 to 5 dB. The Haar wavelet performs better in comparison to other wavelet families due to the fact that it is the modest orthonormal wavelet basis. It comprises of only 2 taps, whereas there are 8 taps in the other wavelet families but with diverse features (orthogonal, biorthogonal, etc.). The Haar wavelet is theoretically modest, memory efficient, exactly changeable, and computationally inexpensive. The Haar transform does not suffer from the effect of overlapping windows, whereas the Daubechies wavelet uses overlapping windows. Daubechies wavelets are the originating point of the coiflets. However, the coiflets suffer from the effects of overlapping windows and elevated computational complexities.

From the SNR vs. BER plots, it is quite clear that the Haar turns out to be most robust followed by the symlets and then the coiflets and reverse biorthogonal in the last in the wavelet family. The error is still there for all the modulation levels even at high values of SNR. An analysis of received symbols at the input of the demodulator is presented in Figures 5–7. In Figures 8(a)–8(c), the analysis is shown for BPSK modulation using the Haar wavelet transform. It is apparent from Figure 8(b) that even at 15 dB of SNR, the constellation




(a) BPSK (1/2 CC rate)

(b) QPSK (1/2 CC rate)

(c) QPSK (3/4 CC rate)

(d) 16-QAM (1/2 CC rate)

(e) 16-QAM (3/4 CC rate)

(f) 64-QAM (2/3 CC rate)

(g) 64-QAM (3/4 CC rate)

FIGURE 9: (a–g) PAPR evaluation.

points of the transmitted signal do not map to the constellation points of the received signal. Now, if we increase the SNR up to 30 dB as shown in Figure 8(c), still, the point does not exactly map on to the ideal constellation. Further, the same observation can be drawn out of Figures 5(a)–5(c), 6(a)–6(c), and 7(a)–7(c) which displays the constellation diagram of diverse modulation types/levels. The primary purpose for this is that in the wavelet transform, the parts of information being transmitted are contained by upper and lower subbands independently [22].

The PAPR performance of FFT-based WiMAX is matched with the DWT-based WiMAX. It is very much apparent from Figures 9(a)–9(g) that DWT-incorporated WiMAX performs superior to FFT-incorporated WiMAX diverse modulation types/levels. It is very much evident from Figure 9(a) that WiMAX based on diverse wavelets provides reduced PAPR of around 7-13 dB over FFT-based WiMAX for BPSK modulation that is favourable for the operation of RF amplifier. Similar inference can be drawn out after the analysis of subsequent results of PAPR reduction. However, from the overall analysis, it is also very much clear that Haar wavelet offers the highest PAPR reduction among the family of wavelets.

Most of 5G application requires rapid information correspondence for significant distance places with tolerable signal strength; the existence of elevated PAPR affects the excellence of the signal and range of the telecommunication system. Due to elevated PAPR, the distortions in the transmitted signal would increase, and due to condense high PAPR, the power amplifiers situated at the transmitter side must be operated at moderate or below moderate power levels. The consequence of the decreased power level leads to lessening in range of the telecommunication system. Therefore, the PAPR reduction achieved on incorporating the proposed methodology decrease the effects of elevated PAPR and deliver an optimum signal strength at the remote places for all the fixed as well as mobile users.

## 5. Conclusion

Overall performance analysis clearly depicts that wavelet-based WiMAX offers significant improvements regarding BER and PAPR reduction in comparison to FFT-based WiMAX. It has been observed that Haar wavelet is the most robust in the wavelet family followed by symlets, coiflets, and reverse biorthogonal. The DWT-incorporated WiMAX presents an SNR enhancement of 10-15 dB over the conventional FFT-WiMAX over Rayleigh fading channel links to achieve the desired BER outcome of $10^{-4}$. Further, it is also reported that as keep on increasing the modulation level (BPSK, QPSK, 16-QAM, and 4-QAM) or convolution coding rates (1/2, 2/3, 3/4) to achieve the higher data rates, SNR requirements to achieve the required BER also increase. It is also very clear from the simulation results that the signal quality at the receiver side is much improved in the case of DWT-incorporated WiMAX in contrast to FFT-incorporated WiMAX. Furthermore, the results reveal out that wavelet-incorporated WiMAX proffers a reduced level of PAPR in the range of 7-13 dB over FFT-WiMAX for diverse modulation types/levels and is preferred for the operation of RF amplifier.

In the future, the hybrid combination of multiuser MIMO-OFDM/WiMAX system can also be utilized to achieve higher spectral efficiency and robust BER outcome. Also, the suggested methodology can also be utilized to study the outcome of OFDM/WiMAX or MIMO-OFDM/WiMAX system for transmission of multimedia information.

## Data Availability

All data are included within this manuscript.

## Conflicts of Interest

The authors declare that they have no conflicts of interest to report regarding the present study.

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