

Simulation of WiMAX Physical Layer: IEEE 802.16e

M.A. Mohamed¹, F.W. Zaki¹, R.H. Mosbeh²

¹ Faculty of Engineering-Mansoura University-Egypt

² New Damietta Higher Institute of Engineering and Technology- Egypt:

Summary

In modern world wireless communication systems are involved in every part of life. WiMAX is the upcoming wireless system which uses IEEE standard 802.16. By using WiMAX technology we can overcome the limitations of the existing wireless communication like short coverage area, lack of security and low data rate. WiMAX is an eminent technology that provides broadband and IP connectivity on "last mile" scenario. It offers both line of sight and non-line of sight wireless communication. Orthogonal Frequency division multiple access is used by WiMAX on its physical layer. Orthogonal frequency division multiple accesses use adaptive modulation technique such as (BPSK,QPSK,16-QAM,64-QAM) on the physical layer of WiMAX and it uses the concept of cyclic prefix that adds additional bits at the transmitter end. The signal is transmitted through the channel and it is received at the receiver end. Then the receiver removes these additional bits in order to minimize the inter symbol interference, to improve the bit error rate and to reduce the power spectrum.

Keywords

Worldwide interoperable Microwave Access (WiMAX); orthogonal frequency division multiplexing (OFDM); Line-of-Sight (LoS); Physical (PHY) layer.

1. Introduction

The demand for broadband mobile services continues to grow. Conventional high-speed broadband solutions are based on wired-access technologies such as digital subscriber line (DSL). This type of solution is difficult to deploy in remote rural areas, and furthermore it lacks support for terminal mobility. Mobile Broadband Wireless Access (BWA) offers a flexible and cost-effective solution to these problems [1]. The IEEE WiMAX/802.16 is a promising technology for broadband wireless metropolitan areas networks (WMANs) as it can provide high throughput over long distances and can support different qualities of services. WiMAX/802.16 technology ensures broadband access for the last mile up to 30 miles (50 km) for fixed stations, and 3 - 10 miles (5 - 15 km) for mobile stations. It provides a wireless backhaul network that enables high speed Internet access to residential, small and medium business customers, as well as Internet access for WiFi hot spots and cellular base stations [2]. It supports both point-to-multipoint (P2MP) and multipoint-to-multipoint (mesh) modes. WiMAX will substitute other broadband technologies competing in the same segment and will become an excellent solution for the deployment

of the well-known last mile infrastructures in places where it is very difficult to get with other technologies, such as cable or DSL, and where the costs of deployment and maintenance of such technologies would not be profitable. In this way, WiMAX will connect rural areas in developing countries as well as underserved metropolitan areas. It can even be used to deliver backhaul for carrier structures, enterprise campus, and Wi-Fi hotspots. WiMAX offers a good solution for these challenges because it provides a cost-effective, rapidly deployable solution [3]. Additionally, WiMAX will represent a serious competitor to 3G cellular systems as high speed mobile data applications will be achieved with the 802.16e specification. The original WiMAX standard only catered for fixed and Nomadic services. It was reviewed to address full mobility applications, hence the mobile WiMAX standard, defined under the IEEE 802.16e specification. Mobile WiMAX supports full mobility, nomadic and fixed systems [4].

In this paper, we focused on WiMAX and physical layer simulation. Initially, we analyzed the basic concept of WiMAX including its standards and relationship with other technologies. Then, it presents a model for simulating WiMAX physical layer using Simulink in Matlab. Finally, performance of the system implementation with different SNR is tested and BER versus SNR curves are presented.

A. Relationship with other wireless technologies

WiMAX is a revolutionary wireless technology that has a rich set of technological improvements compared to the other broadband access technology. The following table gives an overview on the comparison between the mentioned systems, WiMAX and its two closest competitors, WiFi and universal mobile telecommunications system (UMTS). A deeper analysis of these three systems will be developed next [5, 6].

B. Features of WiMAX

WiMAX has a set of salient features: (i) OFDM based physical layer: WiMAX is based on orthogonal frequency division multiplexing that offers multipath resistance and allow NLoS communication; (ii) High data rate: WiMAX can support very high peak data rate which is as high as 74 mbps; (iii) Quality of service (QoS): WiMAX MAC layer is responsible for QoS. WiMAX MAC layer support real time, non real time and best effort data traffic and its high

data rate, sub channelization, and flexible scheduling improve the QoS; (iv) Flexible architecture: WiMAX architecture is very flexible. It can support point to point and point to multipoint connection according to its requirements. It also supports IP-based architecture that is easily converge with other networks and takes advantage of application development from the existing IP based application; (v) Mobility support: WiMAX offer optimized handover which support full mobility application such as voice over internet protocol (VoIP). It has also the power saving mechanism which increases the battery life of handheld devices; (vi) Scalability: WiMAX offer scalable network architecture that support user roaming indifferent networks. It also enhances the broadband access capability, and (vii) Strong Security: WiMAX support extensible security feature for reliable data exchange. It use Advanced Encryption Standard (AES) encryption for secure transmission and for data integrity, it use data authentication mechanism [7, 8].

Table I: Comparative table between Wi-Fi, WiMAX and UMTS

	Wi-Fi	WiMAX		UMTS HSDPA
Standard	IEEE 802.11	IEEE 802.16		IMTS 2000 ⁺⁺
Channel width	Fixed 20 Mbps	Variable ≤ 28 Mbps	Variable ≤ 20 Mbps	Fixed 5MHz
Spectrum	2.4 / 5.2 GHz	10-66 GHz	2-11 GHz	~2 GHz
Data rate	2 / 54 Mbps	240 Mbps	70 Mbps	1 / 14 Mbps
Range	100 m	12-15Km	1-7 Km	50 Km
Multiplexing	TDM	FDM / TDM	FDM / TDM	FDM
Transmission	SS ⁺⁺ / OFDM	SC	OFDM / OFDMA	WCDMA
Mobility	Pedestrian	NO	Vehicular (802.16e)	Vehicular
Advantages	Throughput and costs	Throughput And range		Mobility and range
Disadvantages	Short range	Interference Issues?		Low rates and expensive

2. IEE 802.16 WIMAX Standards

WiMAX technology is based on the IEEE 802.16 standard, which is also called Wireless MAN. The IEEE 802.16 group was formed in 1998 to develop an air interface standard for wireless broadband. The group’s initial focus was the development of a LoS-based point-to-multipoint wireless broadband system for operation in the 10–66GHz millimeter wave band. The first version of the standard IEEE802.16 was approved on December 2001 and it has gone through many amendments to accommodate new features and functionalities. The current version of the standard IEEE 802.16, approved on September 2004, consolidates all the previous versions of the standards. This standard specifies the air interface for fixed BWA

systems supporting multimedia services in licensee and licensed exempt spectrum. The Working Group approved the amendment IEEE 802.16e-2005 to IEEE802.16-2004 on February 2006. The IEEE 802.16 standard contains the specification of Physical (PHY) and Medium Access Control (MAC) layer for BWA. There are specific names for each physical layer interface [9-11].

Specific Name	Operating Band	uplexing	Noticeable Feature
Wireless MAN-SC™	10 to 66 GHz	FDD- TDD	Single-carrier
Wireless MAN-SCa™	2 to 11 GHz ,Licensed	FDD-TDD	Single-carrier, NLOS
Wireless MAN-OFDM™	2 to 11 GHz ,Licensed	FDD- TDD	OFDM technique , NLOS
Wireless MAN OFDMA™	2 to 11 GHz ,Licensed	FDD -TDD	Single frequency band,OFDM system divides signal into sub-channel
WirelessHUMAN™	2 to 11 GHz , Free	TDD	OFDMA Single-carrier, LOS,NLOS,OFDM, Frequency Selective channel

In the IEEE 802.16e–2005, this layer has been modified to scalable OFDMA, where the FFT size is variable and can take any one of the following values: 128, 512, 1,024, and 2,048 [12], [13].The variable FFT size allows for optimum operation/ implementation of the system over a wide range of channel bandwidths and radio conditions; this PHY layer has been accepted by WiMAX for mobile and portable operations and is also referred to as mobile WiMAX [13]

Table III : Basic Data on IEEE 802.16 Standards

	IEEE 802.16e-2005	IEEE 802.16 2004	IEEE 802.16a	IEEE 802.16-2001
Completed	December 2001	January 2003	June 2004	December 2005
Spectrum	10 – 66 GHz	2 – 11GHz	2 – 11 GHz	2-6 GHz
Propagation /channel conditions	LOS	NLOS	NLOS	NLOS
Bit rate	Up to 134 Mbps (28 MHz channelization)	Up to 75 Mbps (20 MHz channelization)	Up to 75Mbps (20 MHz channelization)	Up to 5 Mbps (5 MHz channelization)
Modulation	QPSK, 16-QAM, (optional in UL) ,64-QAM (optional)	BPSK, QPSK, 16-QAM, 64-QAM, 256-QAM (optional)	256 subcarriers OFDM, BPSK, QPSK, 16-QAM, 64-QAM, 256-QAM	Scalable OFMA, QPSK, 16-QAM, 64-QAM, 256-QAM (optional)
Mobility	Fixed	Fixed	Fixed / Nomadic	Portable / mobile

3. WiMAX PHYSICAL LAYER

Physical layer set up the connection between the communicating devices and is responsible for transmitting the bit sequence. It also defines the type of modulation and demodulation as well as transmission power. WiMAX 802.16 PHY-layer considers two types of transmission techniques OFDM and OFDMA. Both of these techniques have frequency band below 11 GHz and use TDD and FDD as its duplexing technology. WiMAX physical layer is based on the orthogonal frequency division multiplexing (OFDM). OFDM is a good choice of high speed data transmission, multimedia communication and digital video services. It even can maintain very fast data rate in a non line of sight condition and multipath environment. In the following subsection we provide a detailed description of the OFDM. The role of the PHY-layer is to encode the binary digits that represent MAC frames into signals and to transmit and receive these signals across the communication media. The WiMAX PHY layer is based on OFDM; which is used to enable high-speed data, video, and multimedia communications and is used by a variety of commercial broadband systems. The PHY-layer; shown in Fig.1 [6].

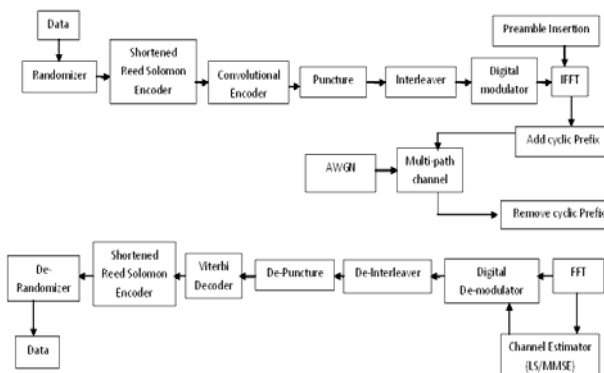


Figure 1: Physical layer of WiMAX

A. Randomizer

The Randomizer performs randomization of input data on each burst on each allocation to avoid long sequence of continuous ones and zeros. This is implemented with a Pseudo Random Binary Sequence (PRBS) generator which uses a 15stage shift register with a generator polynomial of $1 + x^{14} + x^{13}$ with XOR gates in feedback configuration as shown in Fig.2.

B. Reed-Solomon encoder

The properties of Reed-Solomon codes make them suitable to applications where errors occur in bursts. Reed-Solomon error correction is a coding scheme which works by first constructing a polynomial from the data symbols to be transmitted, and then sending an oversampled

version of the polynomial instead of the original symbols themselves. A Reed-Solomon code is specified as RS(n, k, t) with l-bit symbols. This means that the encoder takes k data symbols of l bits each and adds 2t parity symbols to construct an n-symbol codeword. Thus, n, k and t can be defined as: n: number of bytes after encoding; k: number of data bytes before encoding, and t: number of data bytes that can be corrected. The error correction ability of any RS code is determined by (n - k), the measure of redundancy in the block. If the location of the erroneous symbols is not known in advance, then a Reed-Solomon code can correct up to t symbols, where t can be expressed as $t = (n - k)/2$. As specified in the standard, the Reed-Solomon encoding shall be derived from a systematic RS(n = 255, k = 239, t = 8) code using a Galois field specified as GF(28). The primitive and generator polynomials used for the systematic code are expressed in the following two equations:

Primitive Polynomial:

$$p(x) = x^8 + x^4 + x^3 + x^2 + 1 \tag{1}$$

Generator Polynomial:

$$g(x) = (x + \lambda^0)(x + \lambda^1)(x + \lambda^2) \dots (x + \lambda^{2t-1}) \tag{2}$$

C. Convolutional Encoder

The outer RS encoded block is fed to inner binary convolutional encoder. The implemented encoder has native rate of 1/2, a constraint length of 7. The generator polynomials used to derive its two output code bits, denoted X and Y, are specified in the following expressions: G1 = 171OCT For X, G2 = 133OCT F

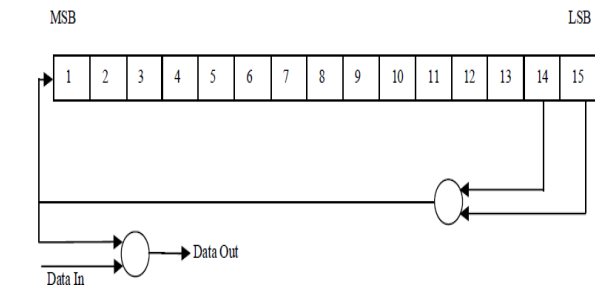


Fig.2 PRBS generator for randomization

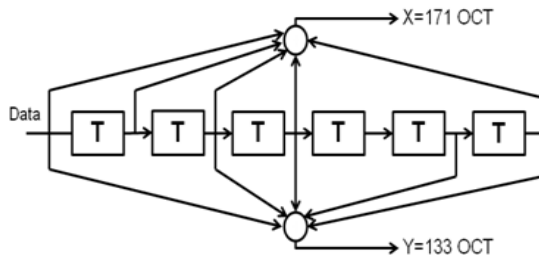


Fig.3 Convolution encoder of binary rate (1/2)

D. Puncturing Process

Puncturing is the process of systematically deleting bits from the output stream of a low-rate encoder in order to reduce the amount of data to be transmitted, thus forming a high-rate code. The process of puncturing is used to create the variable coding rates needed to provide various error protection levels to the users of the system. The different rates that can be used are rate 1/2, rate 2/3, rate 3/4, and rate 5/6. The puncturing vectors for these rates are given in Table IV.

Table IV: Puncture vectors for different convolutional coding rates:

Rate	Puncture vector
1/2	[1]
2/3	[1 1 1 0]
3/4	[1 1 0 1 1 0]
5/6	[1 1 0 1 1 0 0 1 1 0]

E. Interleaver

RSCC encoded data are interleaved by a block interleaver. The size of the block is depended on the numbers of bit encoded per sub channel in one OFDM symbol, Ncbps. In IEEE 802.16, the interleaver is defined by two step permutation. The first ensures that adjacent coded bits are mapped onto nonadjacent subcarriers. The second permutation ensures that adjacent coded bits are mapped alternately onto less or more significant bits of the constellation, thus avoiding long runs of unreliable bits. The Matlab implementation of the interleaver was performed calculating the index value of the bits after first and second permutation using the following equations:

$$fk = (Ncbps/12) \cdot k \bmod 12 + \text{floor}(k/2) ; \quad (3)$$

$$k = 0, 1, 2, \dots, Ncbps - 1$$

$$sk = s \cdot \text{floor}(fk/s) + (mk + Ncbps - \text{floor}(12 \cdot mk / Ncbps)) \bmod (s) ; \quad (4)$$

$$k = 0, 1, 2, \dots, Ncbps - 1$$

where $a = \text{ceil}(Ncbps/2)$, while Ncbps stands for the number of coded bits per subcarrier, i.e., 1,2,4 or 6 for BPSK, QPSK 16QAM, or 64QAM, respectively. The default number of subchannels i.e 16 is used for this implementation. The receiver also performs the reverse operation following the two step permutation using equations (5) and (6) respectively

$$fj = s \cdot \text{floor}(j/s) + (j + \text{floor}(12 \cdot j / Ncbps)) \bmod (s) ; \quad (5)$$

$$j = 0, 1, \dots, Ncbps - 1$$

$$sj = 12 \cdot fj - (Ncbps - 1) \cdot \text{floor}(12 \cdot fj / Ncbps) ; \quad (6)$$

$$j = 0, 1, 2, \dots, Ncbps - 1$$

F. Modulation scheme

We passed the random values through the adaptive modulation schemes according to the constellation mapped. The data was modulated depending their size and on the basis of different modulation schemes like BPSK, Gray-mapped QPSK, 16 QAM and 64 QAM. The modulation has done on the basis of incoming bits by dividing among the groups of i. That is why there are 2i points. The total number of bits represented according to constellation mapped of different modulation techniques. The size of i for BPSK, QPSK, 16 QAM and 64 QAM is 1, 2, 4 and 16 respectively.

G. Inverse FFT

The OFDM symbol threats the source symbols to perform frequency-domain into time domain. If we chose the N number of subcarriers for the system to evaluate the performance of WiMAX the basic function of IFFT receives the N number of sinusoidal and N symbols at a time. The output of IFFT is the total N sinusoidal signals and makes a single OFDM symbol. The mathematical model of OFDM symbol defined by IFFT which would be transmitted during our simulation as given below:

$$x_n = \sum_{k=0}^{N-1} X_k e^{j2\pi \frac{kn}{N}} ; N = 0, 1, 2, \dots, N - 1 \quad (7)$$

H. Cyclic Prefix Insertion

To maintain the frequency orthogonality and reduce the delay due to multipath propagation, cyclic prefix is added in OFDM signals. To do so, before transmitting the signal, it is added at the beginning of the signal. In wireless transmission the transmitted signals might be distort by the effect of echo signals due to presence of multipath delay. The ISI is totally eliminated by the design when the CP length L is greater than multipath delay. After performing Inverse Fast Fourier Transform (IFFT) the CP will be add with each OFDM symbol.. Four different duration of cyclic prefix are available in the standard. Being G the ratio of CP time to OFDM symbol time, this ratio can be equal to 1/32, 1/6, 1/8 and 1/4.

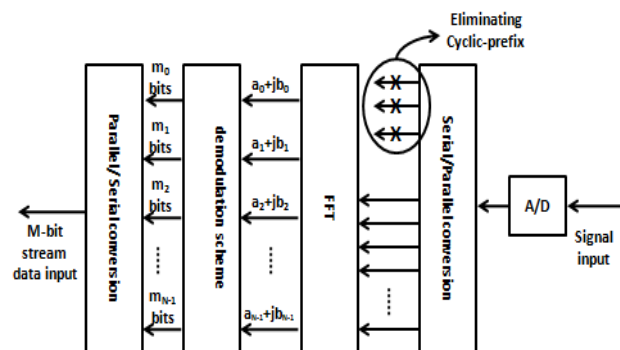


Fig.4 OFDM transmitter

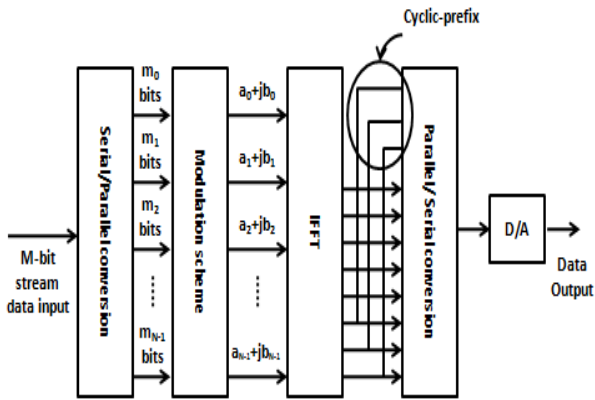


Figure 5. OFDM receiver

The receiver blocks are basically the inverse of the transmitter blocks [10]. When communicating over a wireless radio channel the received signal cannot be simply modeled as a copy of the transmitted signal corrupted by noise. At the receiving side, a reverse process (including deinterleaving and decoding) is executed to obtain the original data bits. As the deinterleaving process only changes the order of received data, the error probability is intact. When passing through the CC decoder and the RS-decoder, some errors may be corrected, which results in lower error rates.

4. Experimental Results

A. Simulation Parameters

In our MATLAB implementation of the physical layer, there are some parameters in which specified as 'OFDM_params' and some are specified as 'IEEE802.16paparams' which can be accessed globally. *OFDM Symbol Parameter*: There are two types of OFDM parameters (primitive and derived) that characterize OFDM symbol completely. The later one can be derived from the former one because of fixed relation between them. The used OFDM parameters are listed in Table V, and *IEEE802.16-OFDM physical layer parameters*: The system supports four modulation schemes and two channel models, namely Additive White Gaussian Noise (AWGN) and Rayleigh fading. The channel coding part is composed of three steps randomization, FEC and interleaving. The simulated coding, modulation schemes and also noisy channels used in the present study are shown in Table VI.

B. Simulation Results

During this simulation process cyclic prefix was used to minimize the Intersymbol Interference (ISI) on the basis of following adaptive modulation techniques. This simulation was performed using MATLAB2009a on an Intel Core2Duo 2.93 GHz/2MB Cache processor using Windows-XP service package-2 operating system. The performance of the simulated WiMAX network based on IEEE-802.16e was shown in the set of figures from Fig.6 to Fig.13.

Table V: OFDM parameters

Value	Parameters	Type
Primitive	Nominal Channel bandwidth , BW	1.75 MHz
	Number of Used Subcarrier , N_{used}	200
	Sampling factor , n	8/7
	Ratio of Guard time to useful symbol time , G	1/4 , 1/8 , 1/16 , 1/32
Derived	N_{FFT} (smallest power of 2 greater than N_{used})	255
	Sampling Frequency , F_s	Floor (n.BW / 800) x 8000
	Subcarrier Spacing , Δf	F_s / N_{FFT}
	Useful symbol Time , T_u	$1/\Delta f$
	CP Time , T_g	$G.T_u$
	OFDM Symbol Time , T_s	$T_u + T_g$
	Sampling Time	T_u / N_{FFT}

Table VI. Mandatory channel coding per modulation

Modulation	Uncoded Block Size (bytes)	Coded Block Size (bytes)	Overall coding rate	RS code	CC code rate
BPSK	12	24	1/2	(12,12,0)	1/2
QPSK	24	48	1/2	(32,24,4)	2/3
QPSK	36	48	3/4	(40,36,2)	5/6
16-QAM	48	96	1/2	(64,48,8)	2/3
16-QAM	72	96	3/4	(80,72,4)	5/6
64-QAM	96	144	2/3	(108,96,6)	3/4
64-QAM	108	144	3/4	(120,108,6)	5/6

Table VII. AMC SCHEME TO SNR RANGE.

AMC	Rayleigh channel	AWGN channel
BPSK	4 dB<SNR<9 dB	7 dB<SNR<11 dB
QPSK CC=1/2	9 dB<SNR<15 dB	11 dB<SNR<17 dB
QPSK , CC=3/4	15 dB<SNR<18 dB	17 dB<SNR<19 dB
16-QAM , CC=1/2	18 dB<SNR<23 dB	19dB<SNR<22 dB
16-QAM , CC=3/4	23 dB<SNR<28 dB	22dB<SNR<25 dB
64-QAM , CC=1/2	28 dB<SNR<40 dB	25 dB<SNR<29 dB
64-QAM , CC=3/4	SNR>40 dB	SNR>29 dB

5. CONCLUSION

This paper described current trends in WiMAX systems for achieving high speed mobile wireless access services and outlined the technologies supporting these systems. The performance of the WiMAX-PHY layer based on the IEEE 802.16e standard, was evaluated and

assessed at different: (i) modulation schemes; (ii) coding rates; (iii) FEC coding schemes, and (iv) noise levels. As a result of the comparative study, it was found that: when channel conditions are poor, energy efficient schemes such as BPSK or QPSK were used and as the channel quality improves, 16-QAM or 64-QAM was used. It adjusts the modulation method almost instantaneously for optimum data transfer, thus making a most efficient use of the bandwidth and increasing the overall system capacity. Actually, this simulation phase was done as a first step in implementing WiMAX networks using field programmable gate array (FPGA) systems.

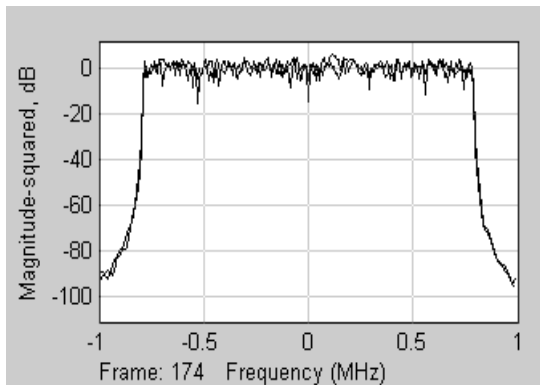


Fig.6 Transmitted signal

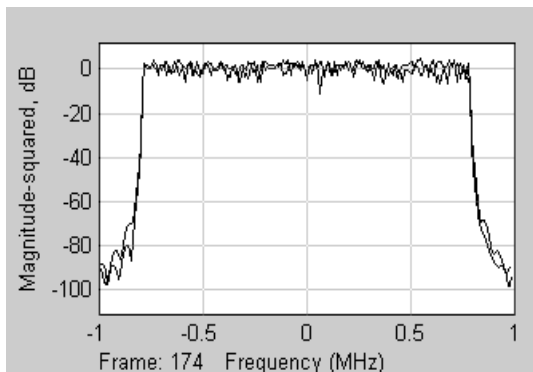


Fig.7 Received signal at 10

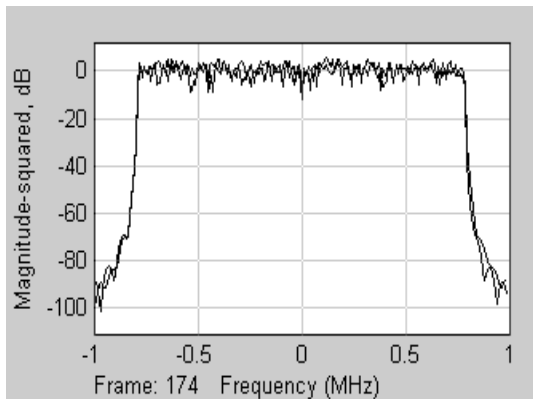


Fig.8 Received signal at 20

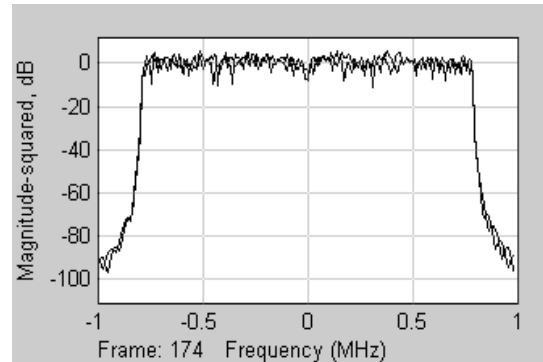


Fig.9 Received signal at 30

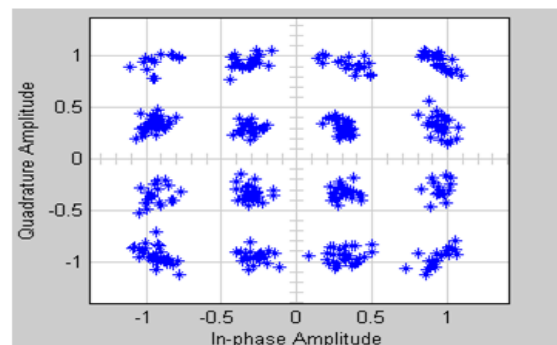


Fig.10 Scatter plot for 16-QAM at S/N=30dB

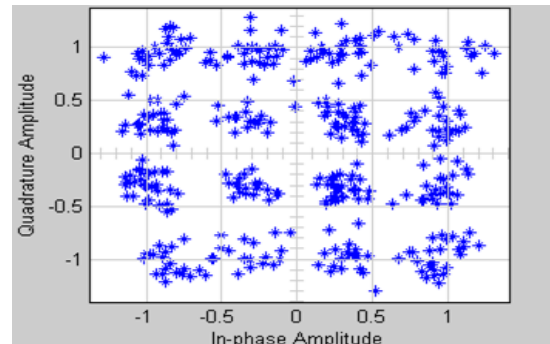


Fig.11 Scatter plot for 16-QAM at S/N=20dB

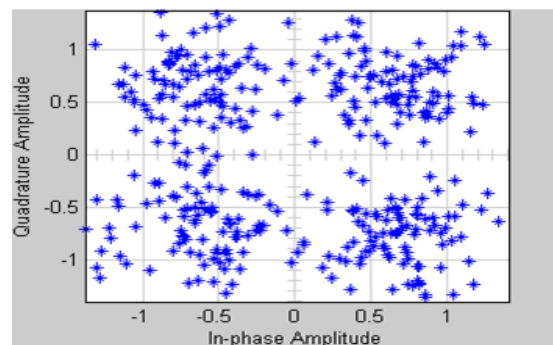


Fig.12 Scatter plot for 16-QAM at S/N=10dB

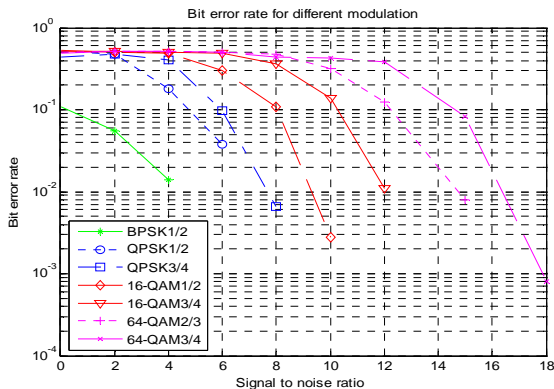


Fig.13 Performance at different modulation schemes for 1/2&3/4 code rates in AWGN channel

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