

Digital Modulation Schemes Employed in Wireless Communication: A Literature review

Manoj Barnela

Pre-Ph.D student, Department of ECE, University Institute of Engineering & Technology,
M. D.U., Rohtak

Email: m.barnela@gmail.com

Abstract Wireless communications has become an emerging and fastly growing field in our modern life and creates enormous impact on nearly every feature of our daily life. A tremendous technological transformation during the previous two decades has provided a potential growth in the field of digital communication and lot of latest applications and technologies are coming up every day due to these valid reasons. Digital modulation schemes contribute to the evolution of mobile communications by increasing the capacity, speed as well as the quality of the wireless network. In communication, the concept of modulation is a prime factor because without an appropriate modulation scheme, it would be impossible to achieve an expected throughput. Available bandwidth, permissible power and inherent noise level of the system are the constraints which should be considered while developing the communication systems. Due to error-free capability in digital modulation, it is preferred over the analogue modulation techniques. The Worldwide interoperability for Microwave Access (Wi-max) uses combinations of different modulation schemes which are BPSK, QPSK, 4-QAM AND 16-QAM and it is a promising technology which offers high speed voice, video and data services. In this paper the literature review on the different digital modulation techniques which are generally used for the wireless communication is presented.

Keywords - Digital Modulation, BASK, BFSK, BPSK, DPSK, QAM, OQPSK, MSK, GMSK, Power efficiency, Spectral efficiency, Bandwidth efficiency, Bit error rate.

I. Introduction

The next generation wireless communication systems require higher data transmission rates in order to meet the higher demand of quality services [1]. Communicating effectively over a huge distance has always been the challenge for engineers and scientists and with the transition of modulation systems from analog to digital has further complicated the situations. The transition from analog to digital modulation provides more information capacity, compatibility with digital data services, advanced data security, faster system availability and better quality communications [2]. In the last few decades, a major transition from analog to digital communications has occurred and it can be observed in all fields of communication because digital communication system is more reliable than an analog system [3]. Digital modulation schemes provide more information carrying capacity, better quality communication, data

security and RF spectrum sharing to accommodate more services [4,5]. The digital modulation schemes are preferred over analog modulation schemes because digital modulation schemes provide larger immunity to noise at the cost of large bandwidth requirements, whereas the requirement of video, audio and data over the computer network or the mobile telephony network termed as the third generation mobile communication poses a serious problem for the bandwidth, so the existing modulation schemes need to be modified for the purpose, where it can handle both the situations of noise and bandwidth efficiency [6]. Bandwidth efficiency explains how proficiently the allocated bandwidth is utilized or the ability of a modulation scheme to accommodate data within a limited bandwidth [7]. Digital modulation has innate benefits over analog modulation because its distinct transmission states can more easily be detected at a receiver in the presence of noise than an analogue signal, which can assume an infinite number of values. But implementation of the digital modulation techniques like the Amplitude Shift Keying, Frequency Shift Keying and Phase Shift Keying comes with the different trade-offs. There is a trade-off need to be made between the available bandwidth and the number of bits/symbol that can be transmitted over the line, which in turn limits the maximum data rate on the link. Thus the selection of digital modulation techniques is absolutely critical, especially in an environment like the satellite uplink-downlink where resources are very limited and time slots are auctioned at very high rates.

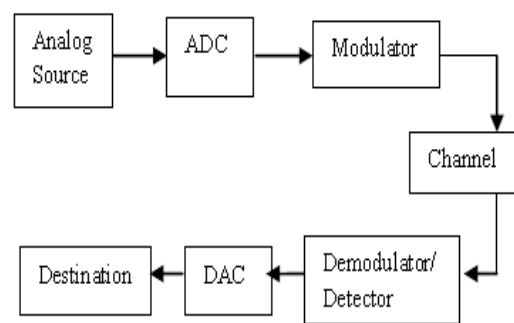


Fig.1 Basic Digital Communication System [3]

In the basic digital communication system, Analog source, Analog to Digital converter and Modulator comprise the transmitter. If the information received is in analog form then it must be converted into digital form to make the communication process easier. This analog to digital conversion is performed by the ADC. The modulator converts the digital signal into base

band signal and is transmitted through the channel. The three blocks which are Demodulator, DAC and Destination, form the receiver. The destination data is the same as that of the transmitted data, in the case when there is no transmission error occurred. The digital demodulator reverses the process of modulator and extracts the binary base-band information from the received modulated signal which has been subjected to noise during its transmission over the channel.

In analog communications an analog signal is taken and it is modulated using an analog carrier, whereas in the digital communications a digital signal or binary data is taken and modulated using an analog carrier. Modulator is a device which performs the modulation and demodulator performs the process of demodulation or detection. The digital detector performs the reverse operation as that of the modulator and extracts the binary baseband information from the received modulated signal which has been affected by noise, interference and other distortions. The output of the demodulator/detector is a sequence of the binary signal which are the estimates of the transmitted data.

II. Digital Modulation Techniques

In digital modulation techniques, an analog carrier signal is modulated by a binary code. The digital modulator device acts an interface between the transmitter and the channel. The digital modulation schemes can be categorized basically either on the basis of their detection characteristics or in terms of their bandwidth compaction characteristics. The basic criteria for best modulation scheme depends on Bit Error Rate (BER), Signal to Noise Ratio (SNR), Available Bandwidth, Power efficiency, better Quality of Service, cost effectiveness [8]. The performance of each modulation scheme is measured by estimating its probability of error with an assumption that system are operating with Additive White Gaussian Noise [9]. Modulation methods which are capable of transmitting more bits per symbol are more immune to error caused by noise and interference induced in the channel [10]. The delay distortion can be an important measure while deciding modulation scheme for digital radio [11].

There are various digital modulation schemes which are used in the telecommunication system. The basic types of digital modulation scheme are Amplitude Shift Keying (ASK), Frequency Shift Keying (FSK) and Phase Shift Keying (PSK) respectively [12,13,14]. The ASK, FSK and PSK with nyquist pulse shaping at the baseband form the basic technique of digital modulation, but other methods are also possible by incorporating two or more basic digital modulation techniques with or without introducing pulse shaping. Thus, hybridized modulation can be designed depending upon the type of signal and the application. The implementation of ASK is simple but they are limited to deliver low amount of power and achieve low data transmission rates. The PSK modulation technique have steady envelope but discontinuous phase transitions from symbol to symbol. DPSK, QPSK and MSK are the derivatives modulation schemes of the Phase Shift Keying. A better digital modulation scheme is to be contemplated over by the designer which has an ability of exploiting the existing transmitted power and the bandwidth to its full coverage [48]. In paper [15], author have presented the characteristics of modulation techniques and determined the figure of merit for each particular modulation. The comparative study of Digital Modulation schemes that can used in OFDM which is main part of WI-MAX model is presented in [16]. The designs of BASK, BFSK and BPSK modulators using Field Programmable Gate Arrays employs the minimum number of

block necessary for their implementation [17]. Binary Phase Shift keying (BPSK), Quadrature Phase Shift keying (QPSK), Eight- Phase Shift keying (8-PSK) and Sixteen- Phase Shift keying (16-PSK) are the types of M-ary modulation schemes [18]. The BPSK, QPSK, 16-QAM and 64-QAM modulation schemes has been investigated for performance according to their BER values in [19]. The energy efficient schemes such as BPSK or QPSK are used when channel conditions are poor whereas when the channel quality improves, 16-QAM or 64-QAM is to be used [20]. The BPSK, QPSK and QAM has been analyzed to reduce the error performance of the signal and to compare which scheme is better through Rayleigh Fading Channel in the presence of Additive White Gaussian Noise [21]. Performance evaluation of an wi-max system under different combinations of BPSK, QPSK, 4-QAM, 16-QAM digital modulation and different communication channels AWGN and fading channels is presented in [22]. The BER performance of wi-max physical layer with the implementation of different concatenated channel coding schemes under QAM and 16-QAM digital modulations over realistic channel conditions is discussed in [23]. The performance of various modulation schemes in AWGN channel is investigated in [24]. The paper given in [25] is based on Wi-Max physical layer to understand the effect of various modulation techniques, coding rates, cyclic prefix factors and OFDM symbol on the system performance.

Modulation Scheme	Application
BPSK	Cable modems, Deep space telemetry
FSK, GFSK	Paging, land mobile, public safety
MSK, GMSK	Global System for Mobile
QPSK, $\pi/4$ QPSK	Satellite, CDMA, cable modems, TSTS
OQPSK	CDMA, Satellite
8-PSK	Satellite, aircraft, telemetry pilots for monitoring broadband video systems
16-QAM	Modems, Microwave digital radio
32-QAM	Terrestrial microwave
64-QAM	Broadband set top boxes, Modems, MMDS
256-QAM	Modems, Digital Video (US)

Table1. Typical applications of different modulation schemes [8]

The Table-1 describes the typical applications of the commonly employed digital modulation techniques in diverse fields. The Table -2 given in the last of paper, presented the comparison of various digital modulation schemes on the basis of no. of symbols, types of envelope, no. of message points, information capacity and symbol shaping.

Binary Amplitude Shift Keying (BASK)

The Binary Amplitude Shift Keying is obtained by changing the amplitude of the carrier wave [48]. The BASK is a coherent modulation scheme hence the concept of the co-relation between the signals , number of basis functions, the I and Q components and the symbol shaping are not applicable here.

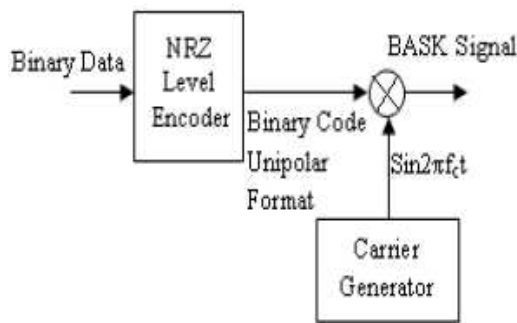


Fig.2 BASK modulation block diagram

In the block diagram of BASK modulator, the output of multiplier is modulated by binary code. The input binary sequence is converted into suitable format for product modulator by the NRZ level encoder.

The bandwidth efficiency is very poor in BASK. The implementation of the BASK is simple but it is highly vulnerable to noise and the performance is good only in the linear region which does not make it suitable for mobile or wireless applications. QAM and M-ary ASK which have much significant applications with improved parameters can be obtained by combining BASK with PSK. The FPGA based modulator is presented for BASK and BPSK modulation techniques in [26].

Binary Frequency Shift Keying (BFSK)

In the BFSK, the two different frequencies mark and space are used to represent the two different symbols [27]. Depending upon the separation between the two carrier frequencies, BFSK can be categorized as wideband or a narrowband digital modulation technique. FSK has a poorer error performance than PSK or QAM and thus is seldom used for high performance digital modulation systems [28]. Because of the separation in the carrier frequencies, it is not a bandwidth efficient scheme and generally not used because of the receiver design complexities.

Binary Phase Shift Keying (BPSK)

The BPSK digital modulation technique is referred as the simplest form of phase modulation and in this scheme the carrier phase represent only two phase states.

A Coherent BPSK system is characterized by having a one dimensional signal space with a constellation diagram consisting of two message points.

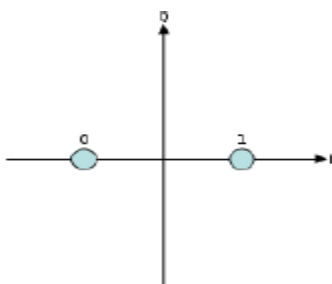


Fig.3 Constellation diagram of BPSK

The two phases which are separated by 180° and can also be termed as 2-PSK. In BPSK, a single carrier is modulated by controlling its polarity according to the binary data signal to be transmitted. The magnitude of the modulated BPSK signal is kept constant, thus increasing the maximum power to be delivered.

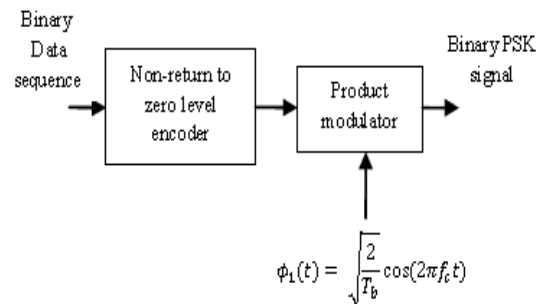


Fig.4 BPSK modulator

To produce a BPSK signal, the binary sequence in polar form with symbol 1 and 0 are represented by fixed magnitude levels of $+(E_b)^{1/2}$ and $-(E_b)^{1/2}$ respectively. The resulting binary wave in polar form and a sinusoidal carrier $\phi_1(t)$, whose frequency is given by $f_c = (n/T_b)$ for some fixed integer n_c are applied to the product modulator. The carrier and timing pulses used to obtain the binary wave are generally extracted from a common master clock. At the output of modulator the desired PSK waveform can be obtained.

The BPSK modulator is basically a two positional switch, controlled by the data stream [29]. The high level in data allows 0° phase and the low level in data permits the 180° phase introduced in the output. The prime advantage of Binary Phase Shift Keying is that it provides a suitable modulation format for downlink data transmission in inductive biomedical telemetry systems, because it achieves high data rates and power efficiencies. BPSK modulation is simple to design and less complex when compared to QPSK, which is almost double the complexity of BPSK design [30]. The BPSK digital modulation technique is generally used in the application of high speed data transfer. It is simple in implementation and gives a 3dB power improvement as compared to BASK modulation technique. The BPSK modulation consists of a phase modulation with two possible states of the intermediate frequency by a serialized numerical signal [31]. The Bit error rate (BER) of BPSK in AWGN channel can be estimated as in [32].

$$P_b = \frac{1}{2} \operatorname{erfc} \left(\sqrt{\frac{E_b}{N_0}} \right)$$

(1)

As the transmitted signal per energy bit, E_b is increased for a particular noise spectral density N_0 , then the message points corresponding to symbols 1 and 0 move further apart and the average probability of error will be reduced.

There is only one bit per symbol in BPSK, this is also termed as symbol error rate. The BER is the number of bit errors divided by the total number of transmitted bits during an observed time interval [33]. The BER is a unitless quantity and is often expressed in percentage. The BER measurement is a standard figure of merit in high speed digital systems [34]. The figure shown below explain the process of BPSK demodulation.

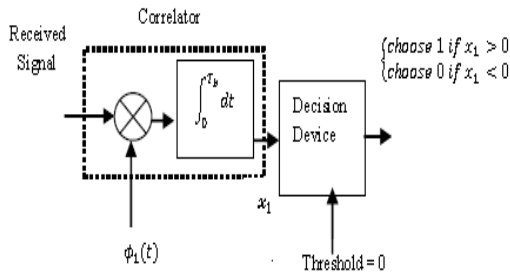


Fig.5 BPSK demodulator

To demodulate the original binary sequence of 1s and 0s, the noisy PSK signal $x(t)$ is applied to a correlator, which is also supplied with a locally produced coherent reference signal $\phi_1(t)$. The correlator output x_1 is compared with a threshold of zero volts. If $x_1 > 0$, the receiver output will be symbol 1. On the other hand, If $x_1 < 0$, the receiver decides in favor of symbol 0. If $x_1 = 0$, then the receiver makes a random decision in favor of 0 or 1.

Differential Phase Shift Keying (DPSK)

For the demodulation of a phase modulated signal, it become noticeable that the receiver needs a coherent reference signal but if differential encoding and phase shift keying are combined together at the transmitter station then the resulting modulating technique is termed as Differential Phase Shift Keying [6]. In this, the phase is unchanged for the transmission of the symbol 1, whereas the phase of the signal is advanced by 180° for the transmission of symbol 0. The track of the phase change information which becomes mandatory in determining the relative phase change between the transmitted symbols. The complete process is based on the assumption that the alteration of the phase is very slow to an extent that it can be considered to be almost constant over two bit intervals [35].

Quadrature Amplitude Modulation (QAM)

The QAM is a modulation scheme where its amplitude is allowed to vary with phase [36]. This technique can be viewed as a combination of ASK as well as PSK [37].

QAM is widely used in many digital data communication applications, where data rates beyond 8-PSK are needed by a radio communication system then QAM modulation scheme is extensively used because QAM achieves a greater distance between adjacent points in the I-Q plane by distributing the points are more distinct and data errors are reduced [38]. The QAM modulation is more useful and efficient than the others and is almost applicable for all the progressive modems [39].

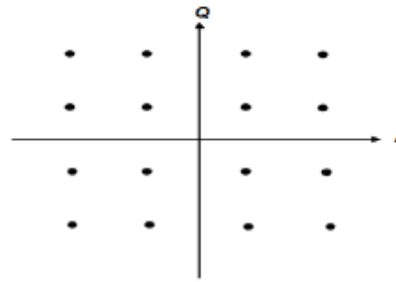


Fig.6 Constellation diagram of 16-QAM

In the 16-QAM, the four different magnitude levels are used. The combined stream would be of $4 \times 4 = 16$ states. In this scheme, each symbol represents four bits.

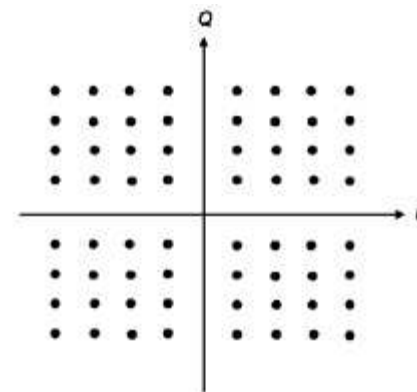


Fig.7 Constellation diagram for 64-QAM

This is same as 16-QAM except that it has 64 states where each symbol represents six bits. It is a complex modulation technique but with a greater efficiency. The mobile Wi-Max technology uses this higher modulation technique when the link condition is high.

Quadrature Phase Shift Keying (QPSK)

In QPSK digital modulation scheme, the division of the phase of the carrier signal designed by allotting four equally spaced values for the phase angle as $\pi/4$, $3\pi/4$, $5\pi/4$ and $7\pi/4$, thus providing a major advantage over BPSK by having the information capacity double to it.

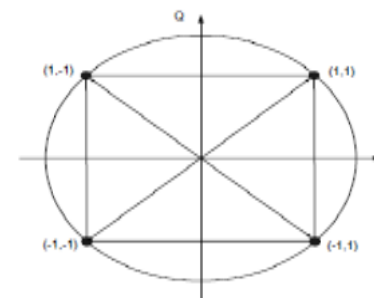


Fig. 8 Constellation diagram of QPSK system [21]

The QPSK becomes a highly bandwidth efficient digital modulation technique because in its constellation diagram, there are four message points. In QPSK the data bits to be transmitted are combined into symbol, each containing two bits each symbol can take on one of four possible values which are 00, 01, 10 or 11 [40]. In QPSK the bandwidth requisite and power requirement is less because more data can be transmitted using different phases and single carrier [41]. QPSK technique may be used either to double the data rate compared to a BPSK modulation system while maintaining the bandwidth of the signal or to maintain the data rate of BPSK but half the bandwidth requirement [42]. The performance of QPSK system in the presence of system impairments may be determined by its bit error rate or symbol error rate [43].

Offset Quadrature Phase Shift Keying (OQPSK)

By offsetting the I and Q modulations by $T_s/2$, then there is an assurance that a_{I_n} and a_{Q_n} can not change polarity at the same time [44]. The maximum fluctuation in instantaneous amplitude is now restricted to that corresponding to a 90° phase reversal. The resulting modulation is termed as Offset- Quadrature Phase Shift Keying.

The OQPSK is also called Staggered Quadrature Phase Shift Keying. This modulation technique is a variant of phase shift keying using four different values of the phase to transmit. The fluctuations in amplitude in the OQPSK are lower as compared to fluctuations in the Non-OQPSK because OQPSK limits the phase shift to no more than 90° at a time. The OQPSK signal does not regenerate the high frequency side-lobes as that of in QPSK modulation scheme. It provides the reduced spectral occupancy and thus allowing more efficient RF amplification. The OQPSK modulation scheme is extensively used for satellite and CDMA applications.

Minimum Shift Keying (MSK)

MSK is a modulation scheme having characteristics of performing well in Gaussian channels and Fading channels [45]. It is an updated form of continuous phase FSK. For keeping the two frequency states orthogonal, the minimum spacing between the two carrier frequencies should be equal to half of the bit rate. The information capacity of an MSK signal is equal to that of QPSK signal but bandwidth requisite is lesser than that needed by QPSK due to the $1/2$ cosine pulse shaping. An MSK signal can be obtained from either an OQPSK signal by substituting a square pulse by $1/2$ co-sinusoidal pulse or from an FSK signal alternatively. An MSK technique is spectrally more efficient than the QPSK technique because an MSK has lower out of band power. The demerits of this modulation technique are that it comes in the category of linear modulation and resulted spectrum is not enough compact to realize data rate approximating RF channel bandwidth.

Gaussian Minimum Shift Keying (GMSK)

GMSK modulation technique is used in variety of digital radio communication systems. This modulation is based on MSK, which is itself a form of continuous-phase frequency shift keying [46]. An MSK signal is obtained by applying a half sinusoidal pulse instead of the square pulse. If a Gaussian pulse shape is applied instead then the resulted digital modulation scheme is an enhanced version of the MSK modulation technique in the terms of bandwidth and spectral efficiency and is known as GMSK.

This technique can be seen as frequency or phase modulation scheme, even though the rate of change of phase is restricted by the Gaussian response but the phase carrier can still advance up to 90° over the track of the bit period. The sternness in pulse shaping lies on the bandwidth time product because obtained phase change over a bit period may fall short by $\pi/2$ which will have a scrupulous impact on bit error rate [47] but it still provides improved bandwidth efficiency over MSK. The relationship between the pre-modulation filter bandwidth B and the bit period T_b gives the bandwidth of a GMSK system [48]. The linear approximated GMSK is presented in Software Defined Radio environment because it provides a common I/Q modulator that can be used for all second generation systems [49]. The GMSK permits class-C non-linear amplifiers to be used, however even with a low BT value its bandwidth competency is less than the filtered QPSK [50]. In GMSK, the side lobe levels of the spectrum introduced in MSK are further reduced by passing the modulating NRZ data waveform through a pre-modulation Gaussian pulse-shaping filter [51]. The performance of GMSK can be enhanced by using optimum filters, Viterbi-adaptive equalization and soft decision Viterbi decoding.

III. Conclusion

A literature survey on the digital modulation techniques presented in this paper reveals that the selection of digital modulation technique is exclusively dependent on the type of specific application, as one application may need higher precision in reception of data, where as the other application requirement may be available bandwidth or power. The quality of service provided by wireless communication system can be greatly enhanced with the help of correct selection of modulation scheme. Thus, increased radio coverage and reduced power consumption can be obtained by the proper selection of digital modulation technique. The some of the technique involve lesser complexities in the modulation and demodulation system design and prove cost-effective like the BASK, BFSK, BPSK and DPSK modulation schemes and can be visualized for the systems which actually does not need high amount of precisions or when financial budget is the foremost aspect and the BER performances can be tolerated. The QAM techniques are exclusively used for Microwave Digital radio, Digital video, Broadband set top boxes and in Modems. In the area of mobile communication, GMSK has proved its performance over the QPSK and MSK because of the better spectral efficiency. But the search for a better modulation scheme doesn't end here as the criterion for higher data rate communication is taking the lead role in almost every field of communication and thus the Inter Symbol Interference and Bit Error Rate calculation become very crucial and important aspect for any ultramodern digital modulation scheme.

REFERENCES

- [1] J.T. Haitham, M.F.M Salleh, Multi-carrier Transmission Techniques for Wireless Communication Systems: A Survey, WSEAS Transactions on Communications, ISSN: 1109-2742, Vol.8, Issue 5, May 2009.
- [2] B.W. Hiroshi, W.M. Ramjee, Digital Communication, Artech House, London, 2005, pp 5-8.
- [3] G. Tharakanatha, S.K. Mahaboob, V.B. Chanda, I. Hemalatha, Implementation and Bit Error Rate analysis of BPSK

Modulation and Demodulation Technique using MATLAB, IJETT, Volume 4, Issue 9, Sep-2013.

[4] V.Chauhan, M. Arora, R.S. Chauhan, Comparative BER Performance of PSK based Modulation Techniques under Multipath Fading , Advances in Applied Science Research , 2011, 2(4): 521-524.

[5] J. Bagga, N. Tripathi, Study and Comparison of Various Modulation Classification Techniques under Noisy Channel Conditions ,IJETAE, ISSN: 2250-2459, Vol.-2, Issue-4, April 2012.

[6] R. Pandey, K. Pandey, An Introduction of Analog and Digital Modulation Techniques in Communication System, Journal of Innovative Trends in Science Pharmacy & Technology, Vol. 1 2014.

[7] Digital Modulation in Communications Systems- An Introduction, Agilent Technologies, Application Note-1298.

[8] R. R.Bhambare, R.D. Raut., A Survey on Digital Modulation Techniques for Software Defined Radio Applications, IRACST, ISSN: 2250-3501 Vol.3, No.3, June 2013.

[9] R. Mongre, M. Kapoor, Compative Analysis of Digital modulation Techniques on the Basis of Their Bit Error Rate in VHDL, IJETR, ISSN : 2277-5668, Volume-2, Issue-6 2013.

[10] K. Hamid, I. Khider, A. Babiker, Performance Evaluation of Digital Modulation Techniques on DS-WCDMA, IJCA (0975-8887), Vol. 74, No. 8, July 2013.

[11] J.D. Oetting, A Comparison of Modulation Techniques for Digital Radio , IEEE Transactions on Communications, Vol. COM-27, No. 12, Dec. 1979, pp 1752-1762.

[12] B.Sklar, P.K.Ray, Digital Communications, Fundamentals and Applications, second edition, Pearson Education, Inc., 2001.

[13] T.Schilling, Principles of Communications Systems, second edition, Tata McGraw-Hill publishing Company Limited, New Delhi.

[14] M.Tao, "Principles of Communications, Chapter-8: Digital Modulation Techniques," Shanghai Jiao Tong University.

[15] A.Tarniceriu, B. Iordache, An Analysis on Digital Modulation Techniques for Software Defined Radio Applications, Semiconductor Conference-2007, International CAS, Vol. 2, Oct. 2007, pp. 571-574.

[16] U. Sharma, Comparative Study of Digital Modulation Techniques in Wi-Max, IJEIT, Volume-2 Issue-2, August 2012.

[17] N.P.Shrirao, A. P.Thakare, Design of Digital Modulators: BASK, BPSK and BFSK using VHDL, IJARCSSE, Volume 3, Issue 1, January 2013.

[18] O. A. Adeleke and R.O. Abolade, Modulation Methods Employed in Digital Communication : An Analysis, IJECS-IJENS, Vol. 12 , No. 03, June 2012.

[19] R. Singh, MIMO System using Space-Time Block Code with Digital Modulation Techniques, IJEER, Vol.-1, Issue-1, Oct. -Dec. 2013, pp ; 26-31.

[20] A.Rehman, T.Khan, S.K.Chaudhry, Study of Wi-Max Physical Layer under Adaptive Modulation Technique using Simulink , IJSRET, ISSN: 2278-0882, Vol. 1, Issue 5, Aug. 2012, pp 05-11.

[21] S. Gupta, H.Sharma, Performance Investigation for Different Modulation Techniques in WCDMA with Multipath Fading Channels, IJARCSSE, Volume-2, Issue-7 July 2012.

[22] A. Islam, Z. Hasan, Performance Evaluation of Wi-Max Physical Layer under Adaptive Modulation Techniques and Communication Channels, IJCSIS, Vol.5, No. 1, 2009.

[23] A.Islam, A.Z.M.Touhidul Islam, Performance of Wi-Max Physical Layer with Variations in Channel Coding and Digital Modulation under Realistic Channel Conditions, IJIST, Vol.2, No. 4, July 2012.

[24] S.A.Oyetunji, A.A.Akinninranye, Performance Evaluation of Digital Modulation Techniques in AWGN Communication Channel, IJERT, ISSN: 2278-0181, Vol. 2, Issue 5, May 2013.

[25] V.Tilwari, A.S.Kushwah, Performance Analysis of Wi-Max 802.16e Physical Layer using Digital Modulation Techniques and Code Rates , IJERA, ISSN: 2248-9622, Vol. 3, Issue 4, July-Aug. 2013, pp 1449-1454.

[26] S.Dowrla, K.J. Rani, VLSI Implementation and Design of Digital Modulation using Xi-link , IJRCT, ISSN 2278-5841, Vol. 2, Issue 9, Sept. 2013.

[27] P.Vinoth, P.Jayakumar, A Survey on Modulation Schemes used for Link Adaption in Wi-Max Networks , IJCA (0975-8887), Vol.-73, No.4, July 2013.

[28] Geetu, H. Singh, M. Singh, Optimization Method for Analysis of Bit Error Rate with BPSK Modulation Technique, IJSER, ISSN: 2229-5518, Vol.3, Issue 6, June 2012.

[29] J.P.Agrawal, O.Farook, C.R.Sekhar, Simulink Laboratory Exercises in Communication Technology, American Society for Engineering Education, Annual Conference and Exposition, session:2247, 2005.

[30] G.Tharaka Natha, V.B.Chanda, I. Hemalatha, Implementation of a Suitable Modulation Technique for the Detection of a Fast Moving Object, IJECT, Vol. 5, Issue SPL-3, Jan-March 2014.

[31] P.Dondon, J.M.Micouleau, J.Legall, P.Kadionik, Design of a Low Cost BPSK Modulator/Demodulator for a practical teaching of Digital Modulation Techniques, Engineering Education, Agios Nicholaos: Greece, 2007.

[32] T.K.Roy, Comparative BER Performance Analysis of OFDM System using BPSK Modulation Technique over AWGN and Rayleigh Fading, IJAR-CSIT, ISSN: 1839-8480, Vol.-1, Issue-3, July 2012.

[33] S.Sharma, V.Walia, Performance Evaluation of Digital Modulation Techniques for WCDMA Radio over Fiber using BER and Fiber Length , IJECT, ISSN: 2230-7109, Vol.-3, Issue-1, Jan-March 2012.

[34] G.M.Foster, T.Waschura, Beyond Bit Error Rate- Gain New Insight from Studying Error Distributions, Agilent Technologies.

[35] P.Aulin, W.C.Sundberg, Continuous Phase Modulation Part-1: Full Response Signaling, IEEE Transactions on Communications, Vol. COM-29, No. 3, 1981, pp 196-209.

[36] S.Haykin, M. Moher, Introduction to Analog and Digital Communications, John Wiley & Sons, Inc., 2007.

[37] M.A.Masud, M.Samsuzzaman, M.A.Rahman, Bit Error Rate Performance Analysis on Modulation Techniques of Wideband Code Division Multiple Access, Journal of Telecommunications, Vol.1, Issue 2, March 2010.

[38] G.Arulampalam, V.Ramakona, A.Bouzerdoum and D.Habibi, Classification of Digital Modulation Schemes using Neural Networks, Proceeding of ISSPA , 99, August 1999, pp.649-652.

[39] J.Bagga, N.Tripathi, Analysis of Digitally Modulated Signals using Instantaneous and Stochastic Features for Classification, IJSCE, ISSN: 2231-2307, Vol.-1, Issue-2, May 2011.

[40] K.Mounica, S.M.Das, P.U. Kumar, A Verilog design in FPGA implementation of Quadrature Phase Shift Keying Digital Modulator, IJESRT, ISSN : 2277-9655, July 2013.

- [41] R.Taware, T.D.Biradar, BER Performance Analysis of SSB-QPSK over AWGN and Rayleigh Channel, IJCA (0975-8887), International Conference on Communication Technology, 2013.
- [42] B.K.Mishra, S.K.Singh, M.Sharma, Enhancing quality of service using OFDM technique for Next Generation Network, ICWET, 2011.
- [43] A.H.Aghvami, Digital Modulation Techniques for Mobile and Personal Communication Systems, Electronics and Communication Engineering, June 1993.
- [44] M.K.Simon, Bandwidth Efficient Digital Modulation with application to Deep-Space Communications, Deep-Space Communications and Navigation series-Monograph 3.
- [45] D.K.Rout, L.Samantaray, R.Panda, A Novel Modulation Technique for High Data Rate Body Area Network, IETE Journal of Research, Vol. 58, Issue 5, Sept.-Oct. 2012.
- [46] S.Chatterjee, S.Sen, Various Effects of Modulation Schemes on Wi-Fi Network of Urban Scenarios using QUALNET Simulator, IJSER, (ISSN: 2229-5518), Vol.-3, Issue 5, May 2012.
- [47] K.Murota, K.Hirade, GMSK Modulation for Digital Mobile Telephony, IEEE Transactions on Communications, Vol. COM-29, No. 7, 1981, pp 1044-1050.
- [48] D.K.Sharma, A.Mishra and R.Saxena, Analog and Digital Modulation Techniques : An Overview, TECHNIA-IJCSCT, ISSN 0974-3375, VOL. 3, NO. 1, July 2010.
- [49] J.Gurugubelli, C.Indrajit, Design and Implementation of Generalised Parametrizable Modulator for a Reconfigurable Radio, TENCON 2009, IEEE Region 10 Conference, pp. 1-6, sept. 2009.
- [50] M.Fitton, Principles of Digital Modulation, Telecommunications Research Lab., Toshiba Research Europe Limited.
- [51] D.Devi, A.Sharma, BER Performance of GMSK using MATLAB, IJARCET, Vol. 2, Issue 4, April 2013.

Digital Modulation Scheme	No. of Symbols	Types of Envelope	No. of message Points	Information Capacity	Symbol Shaping
BASK	01	Not Constant	01	Poor	Not Required
BFSK	01	Constant	01	Better than BASK	Not Required
BPSK	02	Constant	02	Double to BFSK	Not Required
DPSK	02	Constant	01	Same as BPSK	Not Required
QPSK	04	Constant	04 Expressed in terms of symbol Energy/Symbol	Double of BPSK	Required Rectangular Pulse
MSK	04	Constant	04 Expressed in terms of signal Energy/Bit	Same as QPSK	Required Half Co-sinusoidal Pulse
GMSK	04	Constant	04	Same as MSK	Required Gaussian Pulse
16-QAM	16	Not Constant	16	Higher than above	Better than Above schemes
64-QAM	64	Not Constant	64		

Table 2. Parametric Study of Digital Modulation Schemes [48]