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Bit Error Rate Performance Analysis of a Wideband Code Division Multiple Access System Model in an Indoor Environment using Convolution Coding over Additive White Gaussian Channel

Filbert Ombongi, Philip Kibet, Stephen Musyoki
Department of Telecommunication and Information Engineering, Jomo Kenyatta University of Agriculture and Technology, Nairobi, Kenya
Email: onkundifilo@yahoo.com, kibetlp@gmail.com, smusyoki@eng.jkuat.ac.ke,

ABSTRACT

The research entails the development of a WCDMA system model in an indoor environment that transmits data over an Additive White Gaussian Noise channel. In this environment the data rate is taken as 2Mbps. The performance of this model is enhanced by employing convolution coding scheme which reduced the error rate encountered in the system. The results show that the performance of the system improves when convolution coding is implemented. The performance of QPSK is found to be better that that of 16-QAM which means that QPSK is an efficient modulation scheme but its throughput is less that of 16-QAM. Therefore, there must be a trade-off between the modulation format to be applied in a given system and the error rate generates at the receiver by that format. The convolution coding improves the power efficiency of the system when it is incorporated into the system.

Keywords: *Additive White Gaussian Noise (AWGN), bit Error rate (BER), Convolution Coding, Quadrature Phase Shift Keying, Quadrature Amplitude Modulation (QAM)*

1. INTRODUCTION

The WCDMA is a Third Generation (3G) air interface whose specifications were developed by the 3G Partnership Project (3GPP). These specifications were developed in 2000 and the technology is a standard of the International Telecommunication Union (ITU) derived from the CDMA referred to as International Mobile Telecommunication of 2000 (IMT-2000) direct spread spectrum. This technology has received wide adoption all over the world with bandwidths allocated of 5MHz, 10MHz and 20MHz and are used to offer flexibility of operation. The technology is based on direct sequence spread transmission and therefore a wideband transmission scheme. The DS-CDMA is the form used for the air interface in the UMTS known as WCDMA with a chip rate of 3.84Mcps. The variable spreading and multicode connection are used in WCDMA to make the system support high data rates up to 2Mbps. The chip rate of the pseudo-random sequence is used to lead a carrier of 5MHz bandwidth [1], [2] and [3]. The performance of a given digital communication system is normally determined by its Bit Error Rate (BER). This parameter can be determined from the receiver end by dividing the number of bit errors that are found in the received bits of a data stream at the receiver over a communication channel and the total number of bits that were transmitted from the source. The BER is normally defined in terms of the probability of error which can be determined from three variables are namely; error function, energy in one bit, E_b ,and the noise power spectral density, N_o. Different modulation types have their own value for the error function because each of them performs differently when it encounters noise in the channel [4], [5], [6] and [7]. This implies that the higher order modulation schemes such as 64-QAM can support higher data rates but are not robust when they encounter noise in the channel. This is so due to the amplitude variations which are associated the QAM modulation technique. Therefore, the modulation formats that are of low order such as BPSK and QPSK offer lower data rates when they are used in digital communication systems since they are more robust and do not have the amplitude variations which are prone to noise.

This paper focuses on the improvement of performance in a WCDMA system model in an indoor environment by determining the magnitude of the BER at the receiver for a data rate of 2Mbps over the AWGN channel with or without convolution coding.

2. Additive White Gaussian Noise

This noise is generated through the thermal motion of electrons in all dissipative electrical elements. It is modeled as a zero-mean Gaussian random process where the random signal is the summation of the random noise variable and a direct current signal as shown in Equation 1[8], [9] and [10].

$$z = a + n \quad (1)$$

The probability distribution function for this Gaussian noise can be represented as;

$$p(z) = \frac{1}{\sigma\sqrt{2\pi}}\exp[-\frac{1}{2}(\frac{z-a}{\sigma})^2 \quad (2)$$

The model of this noise assumes a power spectral density $G_n(f)$ which is flat for all the frequencies denoted as;

$$G_n(f) = \frac{N_o}{2} \quad (3)$$

The factor 2 indicates that the power spectral density is a two-sided spectrum. This type of noise is present in all communication systems and is the major noise source for most systems with characteristics of additive, white and Gaussian. It is mostly used to model noise in communication systems

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which are simulated to determine their performance. This noise is normally used to model digital communication systems which can be replaced with other interference schemes.

3. Signal Modulation and Pulse Shape Filtering

The WCDMA system model designed in his case employs a bandwidth saving modulation technique called Quadrature Phase Shift Keying (QPSK). In this modulation format, the information transmitted is contained in the phase of the carrier and occupies any of the four equally spaced phases of π/4, 3π/4, 5π/4 and 7π/4 in gray coding. There is no amplitude variation in this modulation which makes it immune from noise that creates amplitude distortions. The equation for QPSK from [11] is given as;

$$s_{qpsk}(t) = a\text{-}b \quad (4)$$

The expressions for a and b are given as;

$$a = \sqrt{E_s}cos[(2i-1)\frac{\pi}{4}\emptyset_1(t) \quad (5)$$

$$b = \sqrt{E_s}\sin(2i-1)\frac{\pi}{4})\emptyset_2(t)] \quad (6)$$

$$1 \leq i \leq 4$$

The expressions of $\emptyset_1(t)$ and $\emptyset_2(t)$ are given as;

$$\emptyset_1(t) = \sqrt{\frac{2}{T_s}}\cos 2\pi f_c t \quad (7)$$

$$\emptyset_2(t) = \sqrt{\frac{2}{T_s}}\sin 2\pi f_c t \quad (8)$$

The WCDMA technology employs the spectral spreading of the transmitted signal. If the transmitted signal has large envelope variations, it will create large envelope fluctuations as it propagates through the transmitter. These envelope variations can be eliminated by using the pulse shaping filter placed at the transmitter and receiver part of the system.

This filter is important in modern wireless communication to spectrally shape the transmitted signals which reduces the spectral bandwidth. The filter can also reduce the adjacent channel interference also known as inter-symbol interference. When this filter is applied the portion of the out of band power is reduced which results in a low cost, reliable, power and spectrally efficient mobile radio communication system.

In most cases, the square root raised cosine filter is used in the transmitter and receiver part of the system so that the overall response resembles that of a raised cosine filter. The impulse or time domain response of the raised cosine filter and the square root raised cosine filter in [12] are given by Equations;

$$h_{RC}(t) = \frac{Sin\,(\frac{\pi t}{T})}{\frac{\pi t}{T}}\frac{Cos\,(\frac{\pi\alpha t}{T})}{1-(\frac{2\alpha t}{T})^2} \quad (9)$$

This expression can be simplified further by introducing the sinc function (sinc x= $\frac{Sin\,x}{x}$)

$$h_{RC}(t) = sinc\,(\frac{\pi t}{T})\,\frac{Cos\,(\frac{\pi\alpha t}{T})}{1-(\frac{2\alpha t}{T})^2} \quad (10)$$

The sinc function in the response of the filter ensures that the signal is band-limited. The time domain or impulse response of the square root raised cosine filter is given as;

$$h_{RRC}(t) = \frac{\sin[\pi(1-\alpha)t]+4\alpha(\frac{t}{T})\cos[\pi(1+\alpha)\frac{t}{T}]}{\frac{\pi t}{T}[1-(\frac{4\alpha t}{T})^2]} \quad (11)$$

The overall response of the system is given as;

$$h_{RC}(t) = h_{RRC}(t)h_{RRC}(t) \quad (12)$$

4. Probability of Error in QPSK Modulation

The QPSK signal constellation has four decision zones. All the four signal points are equidistant from the origin. If it is assumed that all the symbols are equally likely and one symbol was transmitted, then the received signal at the receiver will be from [13] and [14] given as;

$$r(t) = S_{qpsk}(t) + n(t) = \sqrt{E_b} + n(t) \quad (13)$$

In this case $n(t)$ represents the additive white Gaussian noise which has a mean of zero and a variance of$\sigma_n^2 = \frac{1}{2}N_o$.

The received vector $\bar{r}(t)$ of the QPSK modulated signal components are given as;

$$r_1 = \int_0^{T_s} r(t)\varphi_1 dt = \sqrt{E_b}cos[(2i-1)\frac{\pi}{4} + n_1 \quad (14)$$

$$r_2 = \int_0^{T_s} r(t)\varphi_1 dt = -\sqrt{E_b}\sin[(2i-1)\frac{\pi}{4} + n_2$$

These signal components r_1 and r_2 are sample values of independent Gaussian random variables. The receiver will make a decision on the received signal following a given correlation metric which determines which of the M signals was transmitted from the source;

$$C(r.s_m) = 2r.s_m - |s_m|^2 \quad (15)$$

The product $r.s_m$ is a projection of the received signal vector onto each of the M possible transmitted signal vectors and the value of M in QPSK modulation is taken as 4. Its value gives a measure of the correlation between the received vector and the m^{th} signal ($m = 1,2, \ldots. M$). The received signal $r(t)$ is compared with the threshold of zero by this correlation metric. The decision is made in favour of symbol $s_1(t)$ with co-ordinates (1, 0) when $r > 0$, and the decision is made for $s_2(t)$ with co-ordinates (0, 0) when $r < 0$. Assuming a symbol $s_4(t)$ with co-ordinates (1, 1) was transmitted and signal received as$r(t)$. Then the probability of a correct decision when any of the symbols is transmitted can be determined. From the transmission of this symbol, the means of $r_1$and r_2 are given as;

$$r_1 = \sqrt{E_s}\cos\left(\frac{7\pi}{4}\right) = \sqrt{\frac{E_s}{2}} \quad (16)$$

$$r_2 = -\sqrt{E_s}\cos\left(\frac{7\pi}{4}\right) = \sqrt{\frac{E_s}{2}} \quad (17)$$

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Then the probability of a correct decision P_c when this symbol is transmitted can be determined as;

$$\frac{1}{\sqrt{\pi N_o}}\int_0^\infty \exp[\frac{-\left(r_1-\sqrt{\frac{E_S}{2}}\right)^2}{N_o}]\,dr_1 \times \frac{1}{\sqrt{\pi N_o}}\int_0^\infty \exp[\frac{-\left(r_2-\sqrt{\frac{E_S}{2}}\right)^2}{N_o}]\,dr_2$$

The probability P_c represents the joint probability for an event in the regions $r_1 > 0$ and $r_2 > 0$. Since the received signal components r_1 and r_2 are statistically independent, then the expression $\frac{r_j-\sqrt{\frac{E_b}{2}}}{\sqrt{N_o}}$ can be denoted by y and j=1, 2.

$$P_c = \frac{1}{\sqrt{\pi}}\int_{-\sqrt{\frac{E_b}{N_o}}}^{\infty} \exp[-y^2]\,dy \qquad (18)$$

But the integral $\frac{1}{\sqrt{\pi}}\int_{-d}^{\infty} e^{-x^2}dx = 1 - erfc(d)$ .Then;

$$P_c = \left[1 - erfc\sqrt{\frac{E_s}{2N_o}}\right]^2 \qquad (19)$$

The probability of the decision error will be given as;

$$P_e = 1 - P_c = erfc\sqrt{\frac{E_s}{2N_o}} - \frac{1}{4}erfc^2\sqrt{\frac{E_s}{2N_o}} \qquad (20)$$

The probability of error when any of the four equally spaced symbols is transmitted is the same i.e.

$$P_e(s_1) = P_e(s_2) = P_e(s_3) = P_e(s_4) \qquad (21)$$

Since all the symbols are equally likely, the average probability of symbol error is given as;

$$P_e = 4 \times \frac{1}{4}\left[erfc\sqrt{\frac{E_s}{2N_o}} - \frac{1}{4}erfc^2\sqrt{\frac{E_s}{2N_o}}\right] \qquad (22)$$

The value of the error function $erfc(d)$ decreases rapidly with an increase in its argument. This implies that for large values of the bit energy to noise spectral density ratio, E_b/N_o the second term of Equation 18 may be neglected to obtain the average probability of symbol error, P_e as;

$$P_e \cong erfc\sqrt{\frac{E_s}{2N_o}} = erfc\sqrt{\frac{E_b}{N_o}}, \; E_b = \frac{E_s}{2} \qquad (23)$$

From the relation of the number of bits and symbols where the total number of bits transmitted over an instant is twice the number of transmitted symbols. Therefore, the average bit error probability for QPSK modulation is given as;

$$Average\ BER = \frac{1}{2}\lim_{N_{Tot}} \frac{Number\ of\ bits\ received\ in\ error}{Total\ number\ of\ bits(N_{Tot})}$$

$$= \frac{1}{2}\lim_{N_s} \frac{Number\ of\ symbols\ received\ in\ error}{Total\ number\ of\ symbols(N_s)} = \frac{1}{2} \times P_e$$

$$= \frac{1}{2}erfc\sqrt{\frac{E_b}{N_o}} \qquad (24)$$

It is then observed that the probability of error depends only on the bit energy to noise spectral density ratio E_b/N_o and not on other characteristics of the signal and noise. During the BER simulation of system model in MATLAB the BER is determined by varying the ratio E_b/N_o at any data transmission rate. In this case the data rate is taken as 2Mbps.

5. Simulation of WCDMA System Model

The computer simulation tool, MATLAB is used to develop and simulate the digital communication system model that has the capability of transmitting information at a data rate of 2Mbps. The Communication and Simulink block sets are used to develop the model shown in Figure 1;

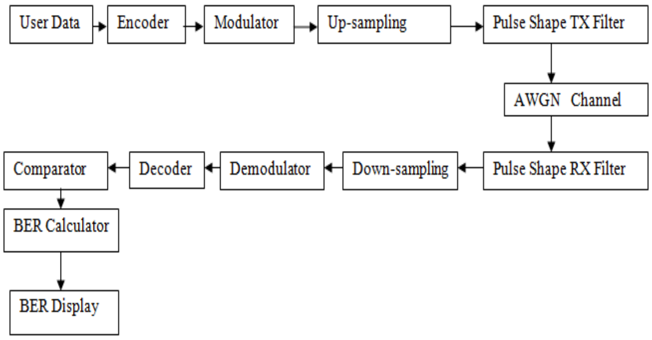

Fig 1: Digital Communication System Model

The Bernoulli binary generator which uses the Bernoulli distribution generates random binary numbers. The distribution produces zero when the probability is p, a one when the probability is 1-p. This distribution has a mean value of 1-p and the variance of p× (1-p). The user data rate, R_b is set in this block using its sampling time parameter which is given as;

Sampling time=$\frac{1}{R_b}$ where R_b is the data rate

The data rate, R_b was taken as 2Mbps during the simulation of the BER. The differential encoder does the encoding of the binary input signal generated and the output is the logical difference between the present input and the previous output. In this block the initial condition is set at zero (0).

The modulation of the user information is done by the QPSK modulator whose output is a baseband representation of the modulated signal. The QPSK demodulator is also used in receiver side to demodulate the signal. The input to the demodulator must be a discrete-time complex signal which can be either a scalar or a frame-based column vector. The square root raised cosine filter is used in the transmitter part to up-sample and filter the input signal. The same filter is used in the receiver section where demodulation of the signal is done. The parameters which are set for the filter includes the roll off factor (α), group delay (D), up-sampling factor (N), length of the filter's impulse response (2×N×D+1) and gain of the filter which is set as 'normalized' for automatic scaling to be done.

The bits received are compared to the transmitted bits by the Error Rate Calculator to determine the bit error rate (BER). The error rate is calculated as a running statistic by dividing the total number of bits that are received in error by the total number of bits generated from the source of information.
This block can also be used to determine the symbol or bit error rate. If the inputs are bits, then the block computes the bit error rate and if the inputs are symbols, then it computes the symbol error rate. The errors are then displayed using the Display Block in Simulink.

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6. SIMULATION RESULTS

The figure below show the simulated results of a WCDMA system at a data rate of 2mbps with or without convolution coding. The modulation formats are QPSK and 16-QAM over an AWGN channel.

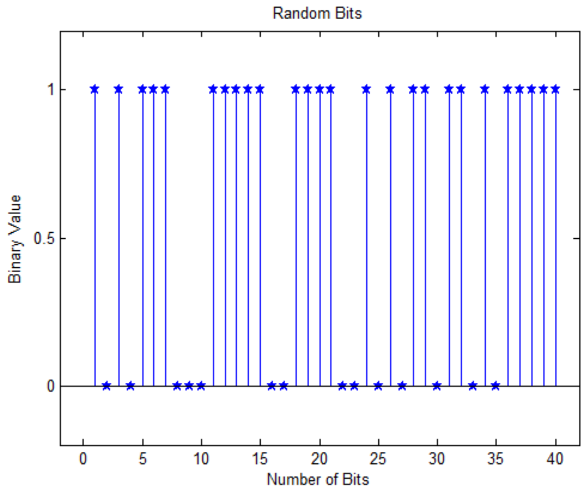

Fig 2: A plot of the first 40 random bits

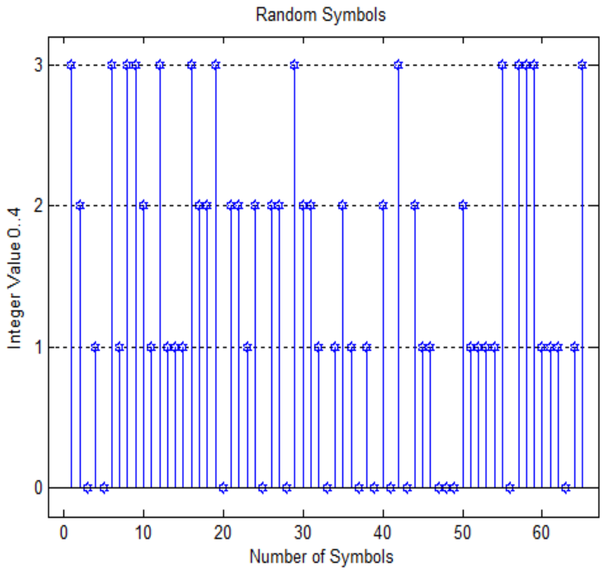

Fig 3: Plotting the first 60 random symbols

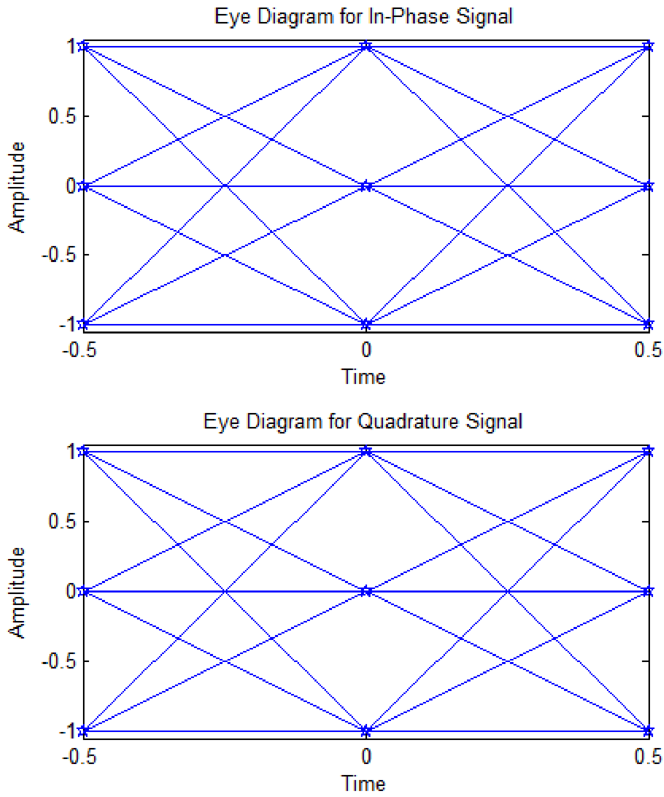

Fig 4: The eye diagram of the I and Q signals

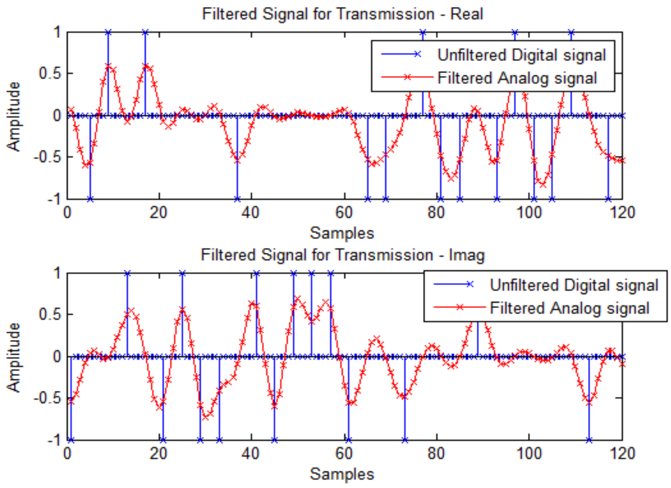

Fig 5: Comparison of filtered and unfiltered transmitted signal

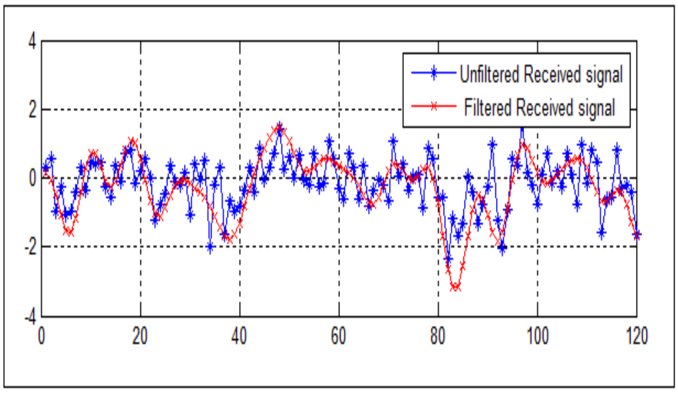

Fig 6: Comparison of filtered and unfiltered received signals

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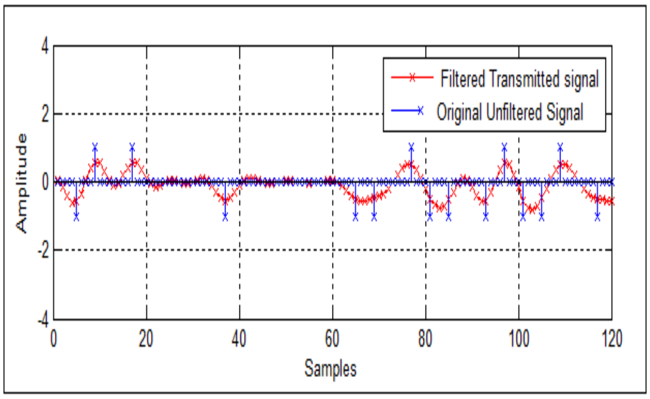

Fig 7: Comparison of filtered transmitted and original signal

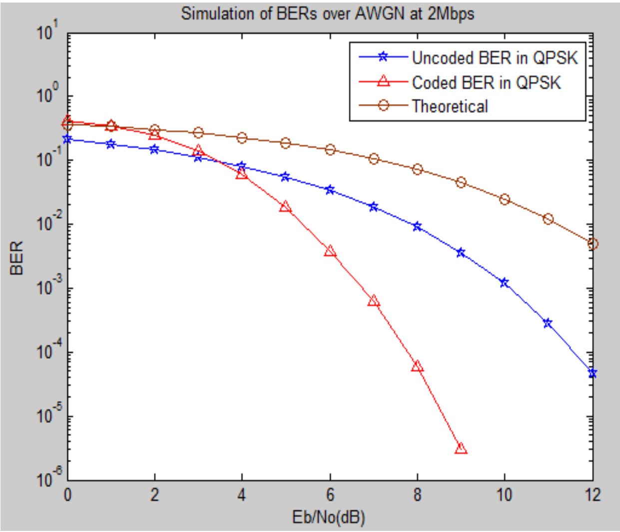

Fig 8: BER simulation for QPSK modulation

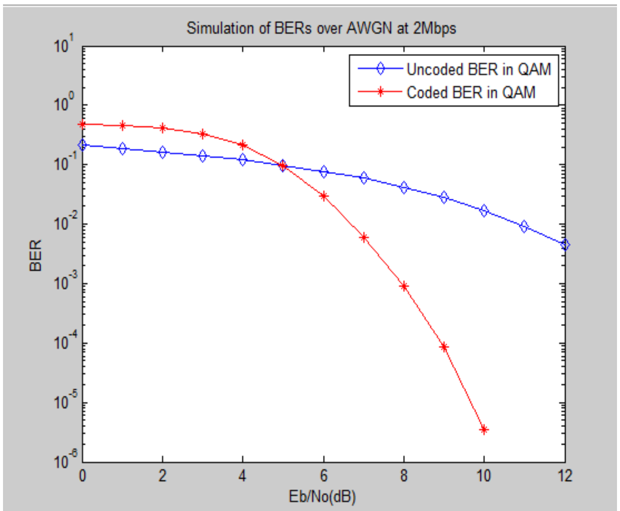

Fig 9: BER simulation for 16-QAM modulation

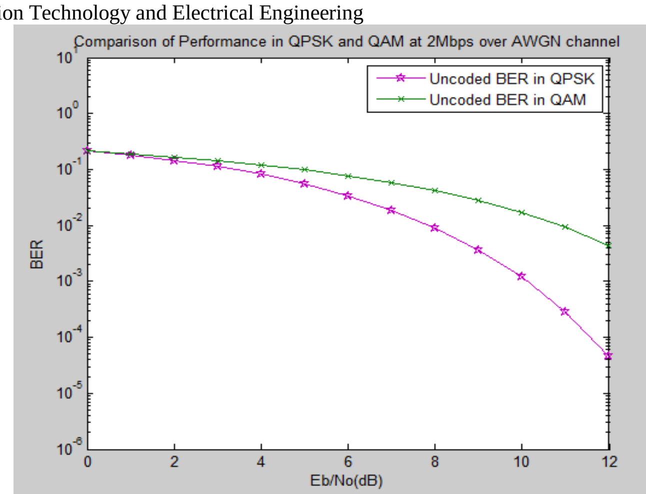

Fig 10: Comparison of BERs in QPSK and 16-QAM modulation without convolutional coding

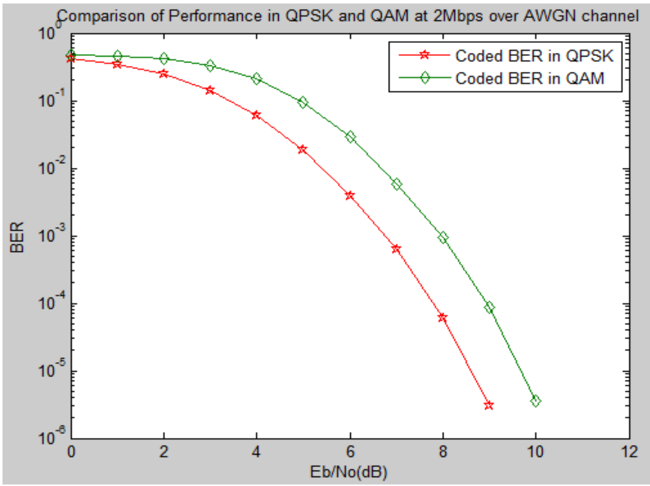

Fig 11: Comparison of QPSK and 16-QAM modulation with convolutional coding

7. Discussion of Results

The WCDMA system model has been simulated at a data rate of 2mbps over AWGN channel with or without convolution coding. The signal was modulated by QPSK and 16-QAM modulation formats. From Fig. 8 and 9, it can be shown that the system performs poorly at lower values of E_b/N_o. The performance improved when convolution coding is incorporated.

When the two modulation schemes were compared, it is found out that the QPSK modulation scheme performs better that 16-QAM with or without convolution coding. This can be attributed to the fact that 16-QAM has the amplitude variations which are prone to noise which normally affects the amplitude and not the phase or frequency of the signal as shown in Fig. 10 and 11. The E_b/N_o that is required to obtain an error rate of 10-3 is around 6dB for QPSK modulation and 8dB in 16-QAM with error correction. This shows that the error correction scheme improves the power efficiency of the system.

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Conclusion

The BER performance has been simulated for a WCDMA system at a data rate of 2Mbps where the error rate depends on the modulation format used, the ratio E_b/N_o and the channel conditions. This paper has analyzed the performance of this system for QPSK and 16-QAM when the data rate is 2mbps over the AWGN channel. The BER performance was shown to be better in QPSK modulation than 16-QAM. This implies that QPSK is an efficient modulation scheme at this data rate of 2Mbps. Furthermore, the convolution coding improves the BER performance of the WCDMA system when it is incorporated into it. The study is beneficial for an implementation of a wireless communication system to deliver services at a data of 2Mbps and beyond. It can also be extended to Wi-Fi, Wi-MAX networks that employ OFDM transmission.

References

[1] Tero Ojanpera and Ramjee Prasad, *Wideband CDMA for Third Genaration Mobile communications*. Boston, London: Artech House, 1998.

[2] Keiji Tachikwa, *WCDMA Mobile Communication Systems*.: Wiley Publications, 2002.

[3] Jeffey Bannister, *Convergence Technologies for 3G Networks IP, UMTS, EGPRS and ATM*. West Sussex, England: John Wiley & Sons, 2004.

[4] M.A Masud, "Bit Error Rate Performance Analysis on Modulation Techniques of Wideband Code Division Multiple Access," *Journal of Telecommunications*, vol. 1, no. 2, March 2010.

[5] A. Goldsmith, *Wireless Communications*. Cambridge, UK: Cambridge University Press, 2005.

[6] Harjot Kaur, "Comparative Performance Analysis of M-ary PSK Modulation Schemes using Simulink," *International Journal of Electronics and Communication Technology*, 2011.

[7] Jagat Dhiman, "Determination and Analysis of Bit Error Rate using Theoretical, Semianalytic and Monte-Carlo Simulation Method," *International Journal of Advanced Research in Computer Science and Software Engineering*, 2013.

[8] Benard Sklar, *Digital Communications: Fundamentals and Applications*, 2nd ed. New Jersey, Carlifonia: Prentice Hall.

[9] John G. Proakis and Masoud Salehi, *Contemporary Communication Systems using MATLAB*. Boston, USA: PWS Publishing Company, 1998.

[10] M. Samsuzzannan and M. A Rahman M. A Masud, "Bit Error Rate Performance Analysis on Modulation Techniques of Wideband Code Division Multiple Access," *Journal of Telecommunications*, vol. 1, no. 2, pp. 22-29, March 2010.

[11] A. Ravish Khan, "Performance Evaluation of DS-CDMA System using MATLAB," *International Journal of Advances in Engineering and Technology*, January 2012.

[12] J.A Crawford, *Advanced Phase Lock Techniques*. London: Artech House,Boston, 2008.

[13] John G. Proakis and M. Salehi, *Digital Commuincations, 5th Edition*. New York, USA: McGraw-Hill, 2008.

[14] John G. Proakis, *Digital Communications, 4th Edition*. New York, USA: McGraw-Hill, 2001.