PERFORMANCE EVALUATION OF WIDEBAND CODE DIVISION MULTIPLE ACCESS (WCDMA) OVER THE ADDITIVE WHITE GAUSSIAN NOISE CHANNEL

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Abstract
Mobile operators have rolled out 4G networks, which have more benefits compared to the third, second and first generation networks. This is because they can support voice, data and multimedia applications. The signal transmitted over these mobile systems suffers from interference due to thermal noise, propagation loss in space and distortion of bit sequence for higher bit rate applications. Thus, this research focuses on performance evaluation of Wideband Code Division Multiple Access (WCDMA) system over the Additive White Gaussian Noise (AWGN) channel. The Wideband Code Division Multiple Access (WCDMA model was simulated for a data rate of 2Mbps with and without convolutional coding scheme and using QPSK, 16-PSK, 16-QAM and 64-QAM modulation techniques to modulate the signal at the transmitter. WCDMA system model was developed and simulated using computer simulation tool MATLAB 7.8 for different digital modulation techniques applied in turns and variation of filter roll off factor from 0.1 to 0.9. The results show that QPSK modulation format had better performance, with and without convolutional coding, when comparison was made with other modulation schemes making it an efficient modulation scheme at 2Mbps data rate. Therefore, it can be applied only for a system with poor channel conditions and other modulation schemes applied in systems with better channel conditions.

Keywords: WCDMA, AWGN, QPSK, 16-PSK, 16-QAM and 64-QAM

Introduction
Wireless mobile communication allows voice and multimedia data transmission from a computer or a mobile device without a physical fixed link connection. Most consumers have acquired devices which can receive services from various evolutions of mobile communication. This has resulted in mobile communication technologies that have made businesses conduct their operations faster and efficiently which in turn raises the standards of living. The mobile technologies have evolved from the first generation (1G) in 1970 to the fifth generation (5G) which started implementation in some countries in 2015 (Tachikwa, 2018). These technologies are based on different security standards and transmission protocols.

In the recent times, there has been a rising demand for mobile radio services that integrate voice, data and multimedia applications which is made possible by WCDMA technology. This implies that the number of users accessing the network has gone up which give rise to interference among the users referred to as inter-channel interference.

During propagation, the signal follows multiple paths from the transmitter to the receiver, a phenomenon known as multipath fading. At the receiver, the symbols received will be having errors due to inter-symbol interference since symbols arrive at different times at the receiver. There is also noise in the path of propagation of a signal from the transmitter to the receiver and noise due to the motion of electrons in the internal circuitry of the transmitter and receiver known as thermal noise which can be modelled as additive white Gaussian noise (Annamalai, *et al.*, 2019).

The increase of data rate in a WCDMA system accounts for the errors generated during signal transmission which calls for increase of the bandwidth as the pulse width of digital symbols decreases. The BER is related to user data rate because the bit error probability depends on the energy per bit (E_b). When the data rate increases, energy per bit increases which requires that the transmission power be increased for reduced Bit Error Rate (BER) to be obtained. If the transmission power is not increased due to the high cost of power amplifiers, then the number of errors in the receiver goes up. These calls for incorporation of channel coding in the system to reduce errors at the receiver and at the same time improve power efficiency (Aun, 2019).

Since the bandwidth in a wireless communication system is fixed, the bits are transmitted in the limited bandwidth with collisions between the bits resulting in distortion of the bit sequence which introduces errors in the bit stream that is received. The collisions of packets occur when two or more nodes are transmitting a packet across the network at the same time. This also occurs when the receiver is within the communication range of two senders that are transmitting simultaneously which make some frames to interfere with each other. In wireless communication, the received power of each packet is dependent on the position of the access terminal and the condition of the communication channel. The packet with the largest power is received and the others are discarded which makes the bits to be received in error. The higher data rate also requires that the transmission power be increased to raise the power per bit for reliable communication in this system.

The WCDMA technology employs Direct Sequence Spread Spectrum (DSSS) technique where the information signal is multiplied by a pseudo-random noise code which gives rise to spread delay when the transmission is serial. This time delay is supposed to be smaller compared to the symbol period in the information signal. This condition cannot be met in high data rate transmissions in WCDMA which makes this time delay to be greater than the information signal symbol period that is transmitted. This spread delay causes inter-symbol interference (ISI) since in WCDMA the signal undergoes serial transmission (Farooq *et al.*, 2018).

For better transmission quality and delivery of quality services to the consumers there is need to develop systems that meet the spectral requirements of mobile communications with an improved performance at higher data rates and in the presence of these interferences. Therefore, the current study focuses on the Wideband Code Division Multiple Access (WCDMA) which can offer augmented bandwidth capability, multiple mobile applications and clarity of the digital signals transmitted across its network infrastructure. The technology can also allow transmission of packet switched data economically at a better and increased bandwidth giving more advanced services to mobile users. In addition, many multimedia applications can be transmitted with a better spectral efficiency realized.

Since transmission is done at a higher data rate in WCDMA which requires an increase in the transmission power, the channel coding scheme (convolution coding) is incorporated in the system to improve the power efficiency of the system instead of increasing the transmission power. In addition, the convolution coding scheme compensates for errors in the signal received which improves the overall performance and quality of communication in the system model (Wijanto, 2018).

Overview of WCDMA System

The growth of wireless communication technologies has been on the rise for the last one decade which has resulted in the increase of subscribers and traffic and applications which require new bandwidths. These applications include gaming, music downloading and video streaming which at the same time demands more capacity on the system. This led to the development of a new technology and spectrum which can provide a solution to these new requirements imposed on the system referred to as WCDMA (Wang, 2018). This technology was to create a standard for real time multimedia services that can support international roaming and the spectrum allocated around 2GHz. The WCDMA provided more benefits such as efficient spectrum utilisation and variable user data rates. The system performance can be improved by utilizing multipath signals as a diversity scheme (Hanzo & Steele, 2019).

Performance of WCDMA Wireless Communication System

The performance of a given digital communication system is normally determined by its 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. This parameter is normally defined in terms of the probability of error which can be determined from the error function, energy in one bit, *Eb* and the noise power spectral density, *No*. The signal that is transmitted in a digital transmission system undergoes modulation using different modulation techniques. The various modulation techniques used in digital communication systems have their own values of error function because each of them performs differently when it encounters noise in the channel (Holma & Toskala, 2017).

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 occurs normally due to the amplitude variations which are associated with 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 have a lower value of the modulation order. However, they offer better performance in wireless communication systems as they are more robust and do not have the amplitude variations which are prone to noise (Milstein, 2019). Therefore, the system designer will have to make a choice between the throughput required and the BER performance of the designed system depending on each modulation format used and the filter parameters which optimize the performance of the filter and the wireless system.

Materials and Method

a. Development of WCDMA System Model

This study develops a WCDMA system model that can transmit data at 2Mbps over an AWGN channel using MATLAB 7.8 simulation software as a tool. The information signal at this rate is spread by the pseudo-random noise signal which is generated at a chip rate of 3.84Mcps. The Simulink Library which has communication and signal processing blocks are used to implement the block diagram of the WCDMA system in Figure 1.

The model should be capable of transmitting data in the range of 64kbps-2Mbps which are used for voice, data and multimedia applications. The convolution channel coding scheme is implemented at a data rate of 2Mbps to perform error detection and correction. The model uses QPSK modulation technique and pulse shaping filter.

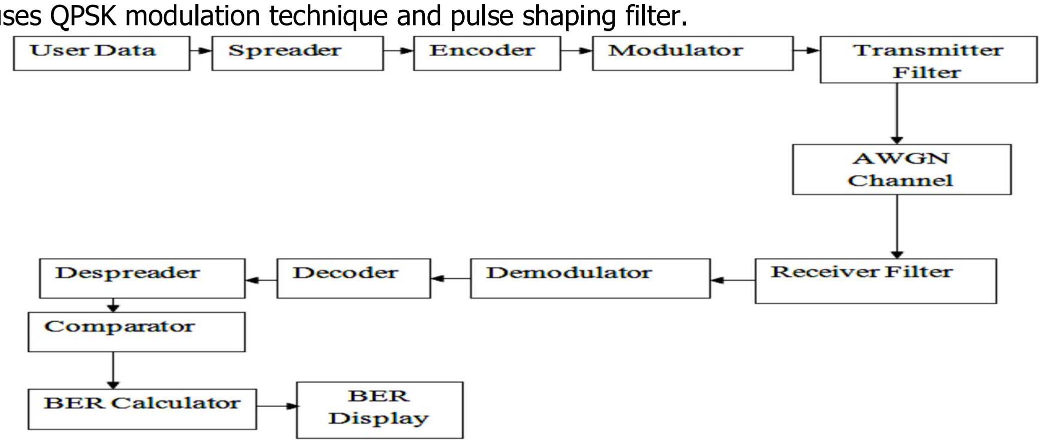

Figure 1: Block diagram of a WCDMA system used for simulation

Transmitter Design

The transmitter section has the data generator, PN sequence generator, spreader, encoder, modulator and square root raised cosine filter. The data generator used is the Bernoulli binary generator.

(i) Bernoulli Binary Generator

The Bernoulli binary generator is used to generate random binary numbers. The distribution has a parameter p (probability) which produces a zero (0) and one (1) when the probability is 1-p. The mean value of this type of distribution is 1-p and the variance is given as p*(1-p). When p is specified by a probability of a zero parameter, there can be any real number between zero and one produced. The user data rate is set in this block in the sampling time parameter.

The MATLAB simulation software has the Bernoulli binary, random integer and Poisson integer generators which are used as sources of data. The Bernoulli binary generator gives an output which is binary while the other two generators give an output which is non-negative integers. When the random integer and Poisson integer generators are applied, the output needs to be converted to binary before spreading which might add some delay in this conversion process. Therefore, the Bernoulli binary generator is used as it gives out a binary data which can be fed directly and be multiplied by the spreading code without any conversion, (Mogal, 2020).

(ii) PN Sequence Generator

The generator produces a PN sequence that is used for spreading the transmitted signal. This sequence has a frequency which is much higher than that of the user signal.

(iii) Differential Encoder

The differential encoder encodes the binary input signal and its output is the logical difference between the present input and the previous output. In this block, the initial condition is set at zero (0).

(iv) Convolutional Encoder

It encodes a sequence of binary input vectors to produce a sequence of binary output vectors and processes multiple symbols at any given time.

(v) QPSK Modulator Baseband

This modulator modulates the modulation of the signal by utilizing quaternary phase shift keying technique whose output is a baseband representation of the modulated signal. The QPSK demodulator block is placed at the receiver to demodulate the signal that is modulated with QPSK modulation method in the transmitter section. The input to the demodulator must be a discrete-time complex signal and can be either a scalar or a frame-based column vector. The QPSK modulator is replaced by MQAM modulator (M=16 and 64) for 16-QAM or 64-QAM modulation and MPSK modulator with M=16 for 16-PSK modulation.

(vi) Raised Cosine Transmit Filter

It up-samples and filters the input signal using a normal raised cosine FIR filter or a square root raised cosine FIR filter. The following parameters are set in the raised cosine transmit filter block;

(i) The type of the filter is set as square root
(ii) The roll off factor (α) as 0.22.

(iii) The group delay (*D*) which is the number of symbol periods between the start of the filter's response and the peak of the filter's response is set as 5. The up-sampling factor, N, is 4 and the length of the filter's impulse response can be determined from the expression $2 \times N \times D + 1$. Therefore, the length of this filter is 21.

(iv) The gain of the filter which indicates how the block will normalize the filter coefficients is also selected between '*user specified*' and '*normalized*'. This study uses normalized so that the block uses an automatic scaling.

Transmission Channel

The level of noise in the transmission channel is described by the quantities;

(i) The value of signal to noise ratio (*SNR*) which is normally the actual parameter of the AWGN channel

(ii) The ratio of bit energy to noise power spectral density (*Eb/No*) and the ratio signal energy to noise power spectral density (*Es/No*).

The ratio between (*Eb/No*)/ (*Es/No*) is given by;

$(Es/No)(\text{dB}) = (Eb/No)(\text{dB}) + 10\log K$................................(1)

The value of (*Es/No*) is influenced by the modulation technique and the code rate of the error control coding used. When the control coding scheme is implemented its value is given by the equation;

$(Es/No)(\text{dB}) = (Eb/No)(\text{dB}) + 10\log K - 10\log[\text{code rate}]$.........................(2)

Where k is the number of bits per symbol and the code rate was taken as ½.

(iii) Differential Decoder

It does the reverse process of the differential encoder that is on the transmitter section.

(iv) Viterbi Decoder

It decodes the user information that was convolutionally encoded at the transmitter end. It can process multiple input symbols at any given time for a faster performance of the system. The decoder is also specified by the trellis structure parameter, decision type, trace-back depth and operation mode. For this study the Trellis structure is *poly2trellis (7, [171 133]),* trace-back depth as 34 and operation mode as continuous.

(v) Error Rate Calculator

The error rate calculator is used 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.

The block can determine the symbol error rate or bit error rate. This is where the number of bits received in error and the total numbers of bits sent from the source are counted to determine the symbol or bit error rate. If the inputs are bits, then the block computes the bit error rate. If the inputs are symbols, then it computes the symbol error rate.

(vi) Display Block

This block displays the bit error rate which is determined by the error rate calculator. It displays the number of errors that are introduced in the signal transmitted by the channel noise.

Receiver Design

(i) Raised Cosine Receive Filter

The parameters of this filter are the same as those set on the raised cosine filter used in the transmitter.

(ii) Demodulator
The demodulator used in this case is the same modulation format as the modulator used in the transmitter section but does the reverse process of the modulator.

Table1 shows the parameters used for simulating the CDMA model

Table 1: Parameters used in the simulated model

Component	Parameters
Bernoulli Data generator	Sample rate=2Mbps, Generator sample time =1/sample rate
Convolutional encoder	Code length=7, code rate=1/2, code generator polynomial=(177, 133) in octal number form
Modulator	M-PSK (M=4, 16), M-QAM(M=16, 64)
Pulse Shaping filter	Square root raised cosine filter parameters: Group delay=5, roll-off factor=0.22, oversampling factor=4
Channel	AWGN channel
Demodulator	M-PSK (M=4, 16), M-QAM(M=16, 64)
Viterbi Decoder	Trace back length=34, hard decision decoding, operation mode=continuous, Code length=7, code generator polynomial=(177 133) in octal

Simulation Results and Discussion

The simulation results of a WCDMA system over the AWGN channel are given and discussed when there is variation of a modulation technique and the roll- off factor of the pulse-shaping filter. The simulation of wireless systems provides a powerful tool for analysis of these networks without the actual implementation of the real world systems. The WCDMA system model was simulated in MATLAB 7.8 (R2009a). The performance of the model developed was tested through different modulation techniques which were: QPSK, 16-PSK, 16-QAM and 64-QAM over the AWGN channel with and without channel coding.

For validation of the implemented functions and simulation results, a comparison was made to the theoretical models without channel coding. The simulated results for the modulation schemes applied in the WCDMA system simulation were compared with the theoretical results. Then channel coding was applied to reduce the power efficiency difference between the two curves. The mapping of *Eb/No* ratio and the BER for QPSK modulation scheme is presented in Fig. 2.

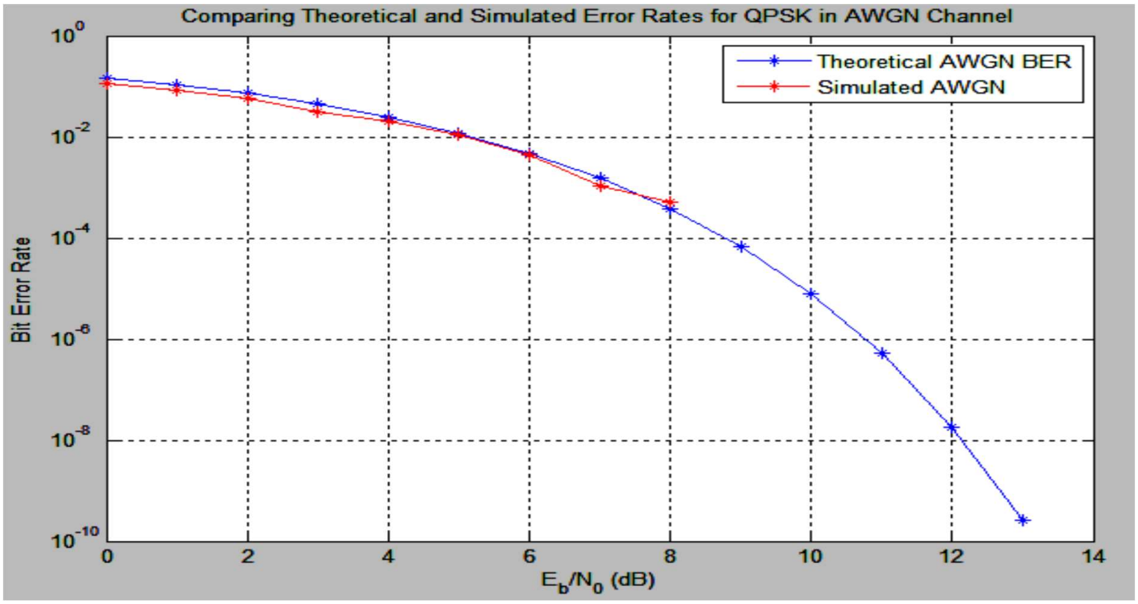

Figure 2: Comparison of BER in QPSK Modulation

From Fig. 2, it can be seen that the simulated results are very close to the theoretical plot of BER for QPSK modulation over the AWGN channel. The BER mapping for the 16-QAM modulation technique is presented in Fig. 3.

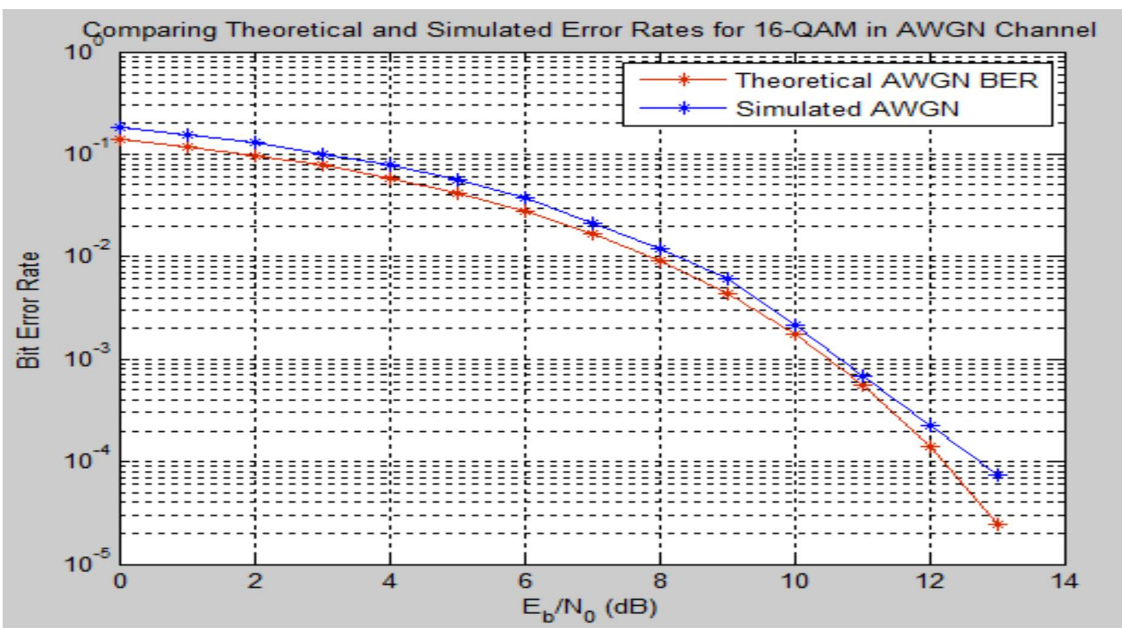

Figure 3: Comparison of BERs for 16-QAM modulation

From Fig. 3, it can be seen that the simulated BERs are slightly higher when compared to the theoretical results. The same relationship was observed in 64-QAM presented in Fig. 4 but with a greater margin of increase of BER than in 16-QAM. Therefore, it can be said that the modulation formats that were applied in WCDMA simulation have been validated.

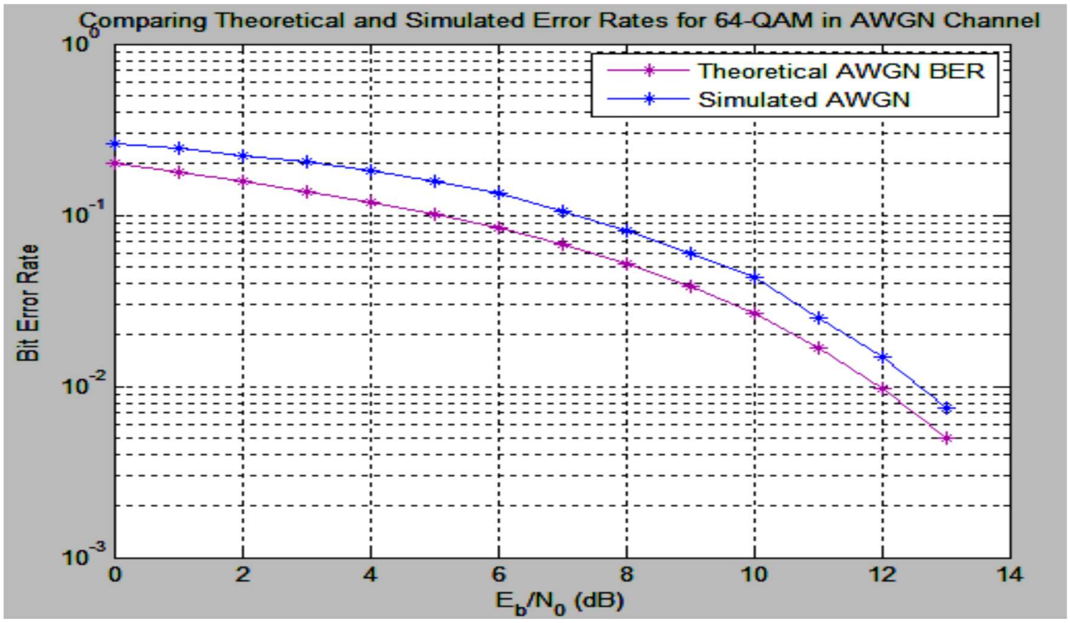

Figure 4: Comparison of BERs in 64-QAM modulation

The results for different simulation set ups were also verified for the modulation techniques by comparison with the results that are known under the AWGN environment and they were found to be consistent with those presented in (Bhalerao *et al.*, 2013).

Variation of the Modulation Formats

The simulated results of a WCDMA system at a data rate of 2Mbps with and without convolution coding due to the variation of modulation techniques are presented in Table 2. The modulation techniques used were QPSK, 16-PSK, 16-QAM and 64-QAM over an AWGN channel.

Table 2: Simulated BERs over AWGN channel

Eb/No	**Modulation Technique QPSK**		**16-PSK**		**6-QAM**		**64-QAM**	
	No Coding	***Coding***	***No Coding***	***Coding***	***No Coding***	***Coding***	***No Coding***	***Coding***
0	0.2130	0.4144	0.2830	0.4916	0.2123	0.4817	0.2689	0.4977
1	0.1793	0.3466	0.2613	0.4842	0.1874	0.4602	0.2500	0.4946
2	0.1454	0.2501	0.2387	0.4744	0.1643	0.4160	0.2310	0.49
3	0.1118	0.1432	0.2145	0.455	0.1414	0.3316	0.2116	0.4806
4	0.0817	0.0605	0.1904	0.4231	0.1194	0.2120	0.1919	0.4608
5	0.0550	0.0186	0.1668	0.3721	0.0980	0.0968	0.1727	0.4271
6	0.0339	0.0038	0.1444	0.2981	0.0777	0.0296	0.1529	0.3674
7	0.0189	6.3e-4	0.1234	0.2071	0.0588	0.0063	0.1340	0.2808
8	0.0090	6.0e-5	0.104	0.1223	0.0420	0.000856	0.1146	0.181
9	0.0036	3e-6	0.0855	0.0591	0.0281	0.000079	0.0956	0.0914
10	0.0012	0	0.068	0.0237	0.0170	0.000005	0.0772	0.0366
11	0.000286	0	0.052	0.0079	0.0093	0	0.06	0.0118
12	4.73e-5	0	0.0376	0.0024	0.0045	0	0.0443	0.003
13	6.75e-6	0	0.0257	0.00052	0.0018	0	0.0304	6.2678e-4
14	0	0	0.0157	1.03e-4	5.708e-4	0	0.0195	9.5456e-5
15	0	0	0.0089	0.000014	1.418e-4	0	0.0112	8.586e-06
16	0	0	0.0043	1.5e-6	2.55e-5	0	0.0057	1.010e-06
17	0	0	0.0019	0	2.5e-6	0	0.0025	0
18	0	0	5.883e-4	0	0	0	0.00091389	0
19	0	0	0.000156	0	0	0	0.0002452	0
20	0	0	0.000034	0	0	0	5.6818e-5	0

This can be observed by plotting the BER curves for QPSK and 16-QAM modulation techniques with and without channel coding as shown in Fig. 5 and 6.

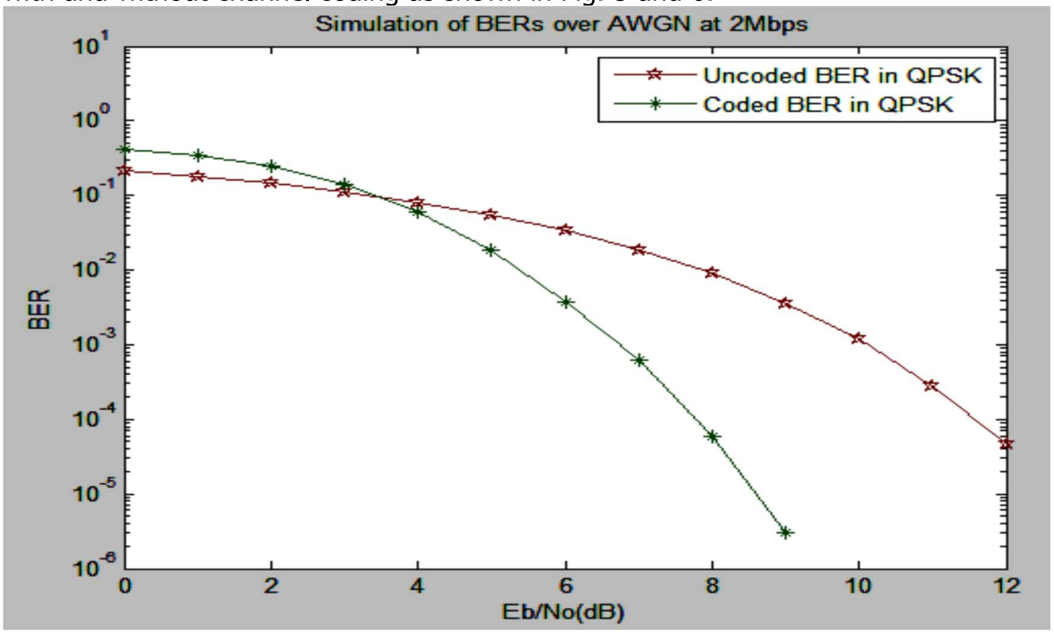

Figure 5.: Performance improvement in QPSK modulation

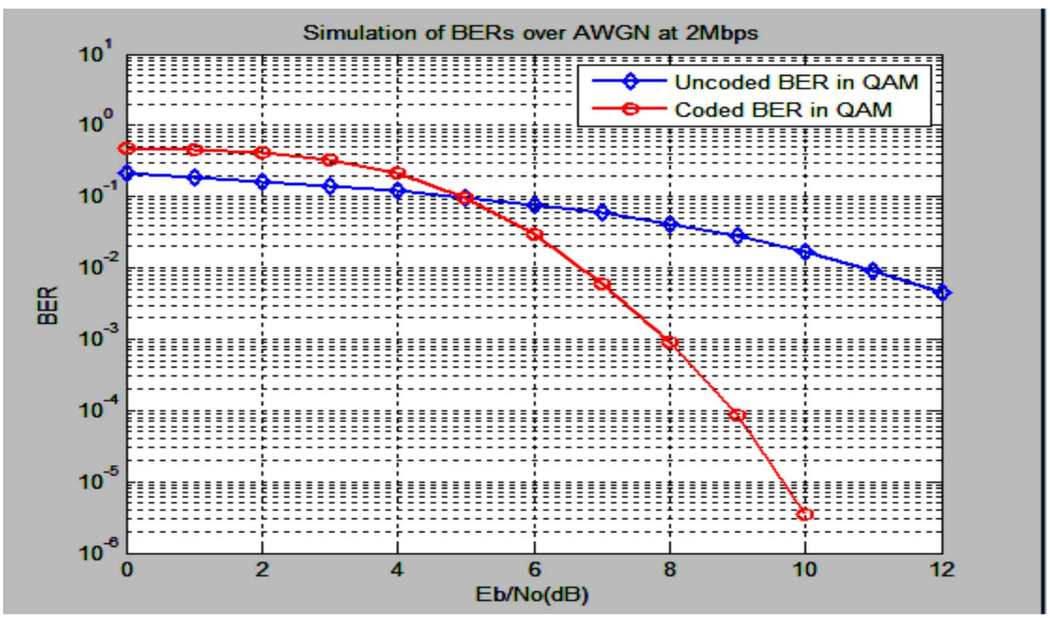

Figure 6: Performance improvement in 16-QAM modulation

From Fig.5 and 6, it can be seen that the application of error correction coding reduced the *Eb/No* required for a particular BER level. For example, a BER 10-6 is obtained at a ratio of *Eb/No* of around 17dB without coding which is reduced to around 10dB when coding is done for 16-QAM modulation. The BER of 10-6 for QPSK modulation is obtained at around 13dB without coding which reduces to 9dB with error correction coding. This means that error correction coding has improved the performance in terms of power efficiency for the system. This reduces the transmitter or antenna cost which will have been incurred because the transmit power is not increased for better BER to be obtained.

The trend that can be observed with the comparison of modulation techniques performance can be validated by simulating the theoretical error rates by the *bertool* in MATLAB with and without convolution coding over the AWGN channel. The bertool plotted the theoretical BERs for the modulation schemes that were used in the simulation for the 2Mbps system as in Fig. 7 and Fig. 8 without and with channel coding (for hard decision) respectively. The simulated error rates of a WCDMA model transmitting at a rate of 2Mbps was done using the m-files created in MATLAB for a case where the modulation formats were varied.

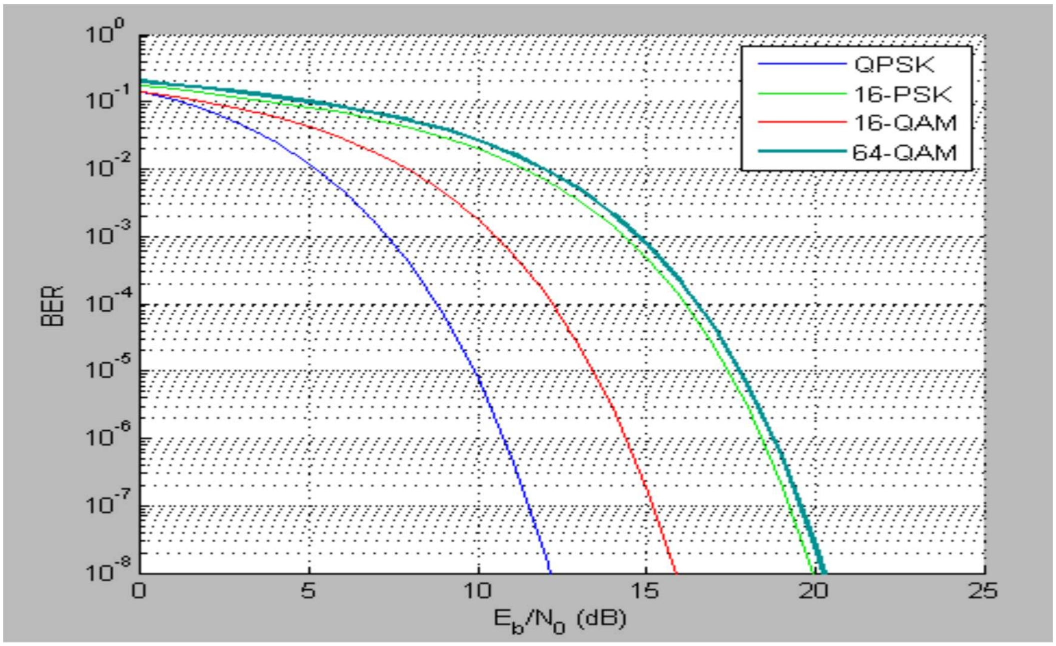

Figure 7: Theoretical BERs without convolution coding

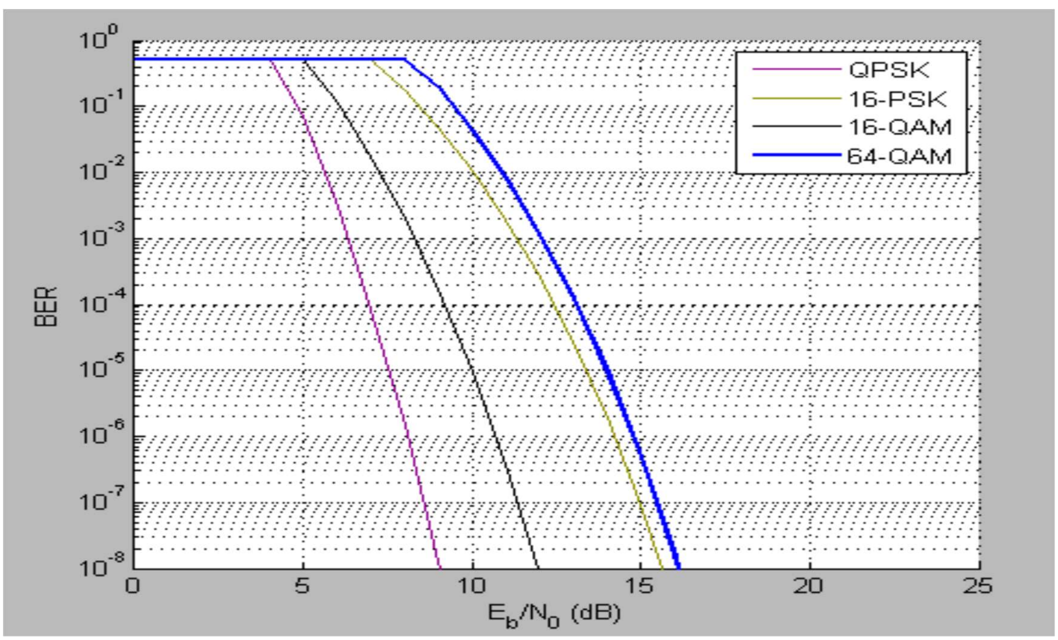

Figure 8: Theoretical BERs convolution coding for hard decision decoding

The comparison of the simulated BERs at 2Mbps data rate over AWGN channel was done by plotting the results given in Table 2 in Fig.9 and Fig.10 respectively.

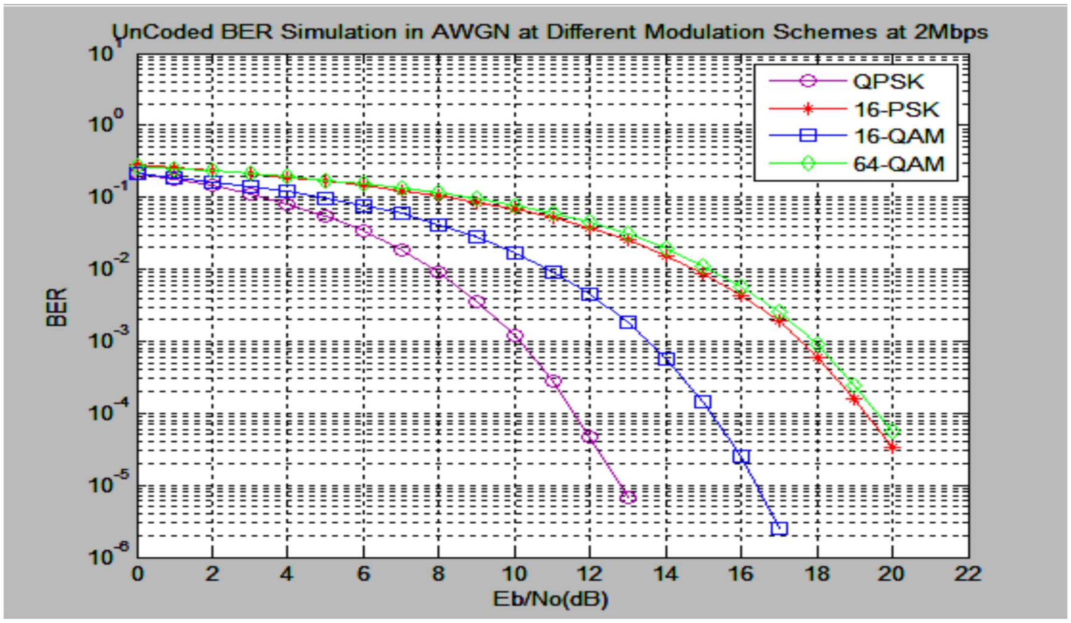

Figure 9: Comparison of BERs at 2Mbps without convolutional coding

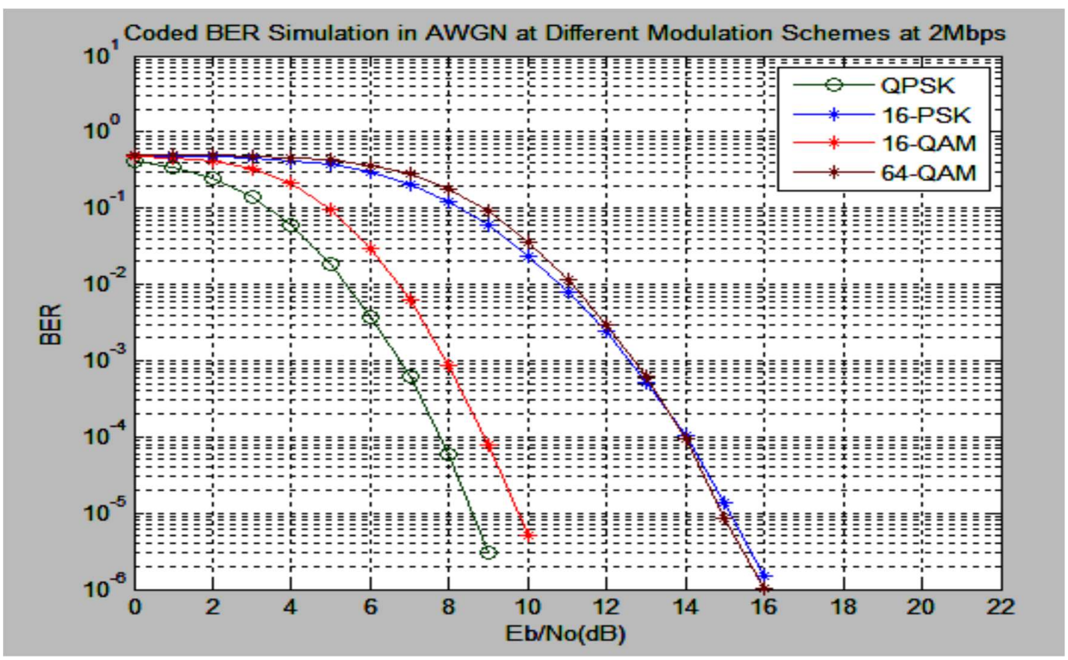

Figure 10: Comparison of BERs at 2Mbps with convolutional coding

The performance was analyzed by considering the BER and the power efficiency at the receiver. The Figures 7 and Figure 8 show the theoretical error rates when the modulation formats were varied without channel coding. Fig. 9 and Fig. 10 show the simulated error rates for different modulation schemes without and with channel coding respectively. From Fig. 9 and 10, it can be seen that the power efficiency to obtain an error rate of 10-3 is 6.8dB, 12dB, 8dB and 12.4dB for QPSK, 16-PSK, 16-QAM and 64-QAM respectively with convolutional coding. The power efficiency is 10dB, 17dB, 13dB and 17dB for QPSK, 16-PSK, 16-QAM and 64-QAM respectively without convolutional coding. This reduces the transmitter cost and permits increased data rates for the same transmitter power and antenna size. Therefore, it can be said that the performance in terms of power efficiency of a WCDMA system transmitting data at 2Mbps has improved with the application of error correction coding.

In addition, to implement an error free communication at a data rate of 2Mbps with channel coding the power efficiency is 10dB, 17dB, 11dB and 17dB for QPSK, 16-PSK, 16-QAM and 64-QAM respectively. When all the modulation schemes are compared, QPSK gives the best result at this data rate followed by 16-QAM, 64-QAM and 16-PSK in that order up to around 13dB with convolutional coding present. The 16-PSK performs better than 64-QAM after 13dB with channel coding but 64-QAM gives better performance than 16-PSK when there is no coding for all values of Eb/No.

The 64-QAM and 16-QAM modulation schemes have a higher throughput at the expense of the BER while QPSK performs well over AWGN channel but has a lower throughput. Therefore, this study was important as it gives information that can be used as a guide by the designer of wireless communication systems to make a choice between modulation formats in terms of throughput required, BER level and the average signal to noise power spectral density ratio.

Conclusion

The WCDMA system model has been simulated at 2Mbps with or without convolutional coding over an AWGN channel. It has been found that when the error correction scheme is implemented the power efficiency of the system improves and the bit error rate (BER) reduced allowing for reliable and quality communication. The error rate depends on the modulation format used, ratio of bit energy to noise power spectral density, Eb/No and the channel conditions. The performance of this system was analysed for a data rate of 2Mbps by considering the variation of the modulation format used and the variation of the filter roll off factor with the ratio of bit energy to noise power spectral density kept constant.

The modulation formats whose performance was compared were QPSK, 16-PSK, 16-QAM and 64-QAM with and without convolutional coding. The performance was found to be better in QPSK than other modulation formats which made QPSK an efficient modulation scheme at this data rate (2Mbps) to deliver quality services. This means that QPSK can only be applied in systems with poor channel conditions and other modulation schemes in systems with better channel conditions. The QPSK modulation scheme offers a better performance because it only has the phase variations which are not prone to noise but the QAM modulation formats have the amplitude variations which are prone to noise which increases the BER. During the simulation of this system, the phase variations which might have affected the BER were minimized by compensating for the delays in the system and use of coherent detection at the receiver which minimized the phase errors.

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