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Comparative Performance Analysis of Modulation Techniques of Wideband Code Division Multiple Access (W-CDMA) System for Maximum Data Throughput

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Abstract

The performance of W-CDMA as a platform of the third generation (3G) technology can be greatly improved by the choice of a modulation technique used. With the explosion in the usage of mobile telephone, internet, high speed data and multimedia traffic, active researches into higher order modulation techniques becomes relevant. This paper focused on the comparative performance analysis of two digital modulation techniques - Quadrature Amplitude Modulation (QAM) and Quadrature Phase Shift Keying (QPSK) employed in W-CDMA system. Site investigation was conducted and the Received Signal Strength (RSS) measurement taken. From the RSS, the pathloss was evaluated and was used to estimate two Quality of Service (QoS) parameters - the signal-to-Noise ratio (SNR) as well as the Bit Error Rate (BER) of the modulation techniques under study. These parameters were used to characterize the modulation techniques upon which a comparative performance analysis was obtained to achieve maximum data throughput. The result of the analysis revealed that as SNR decreases, errors increase. The average estimated SNR of QPSK was slightly greater than that of QAM, showing 15.89dB (50.4%) against 15.64dB (49.6%) for QAM. Given that errors will increase as SNR does decrease, the BER of QAM technique was observed to be higher than QPSK. This means the signal states of QAM are closer together and so contain more bits per symbol. This makes a lower level of noise enough to move the signal to a different decision point than in QPSK. Therefore modulation scheme implemented in any form of wireless network affects the error performance which in turn affects the data rate as well as the throughput of the communicating devices.

Keywords: Bit error rate, Signal-to-noise ratio, Quadrature amplitude modulation, Quadrature phase shift keying, Throughput

1. Introduction

Multimedia applications expect wireless communications service providers to provide service mix traffic (voice, data, and real time audio/video) to the subscriber. Wideband Code Division Multiple Access (W-CDMA) has been chosen as a basic radio access technology for Universal Mobile Telecommunications System/International Mobile Telecommunication 2000 (UMTS/IMT-2000) to support multimedia services. Throughput alongside spectral efficiency is basic parameters to be considered in capacity planning for 3G cellular network roll outs. (Matalgah, et., al 2003). The Universal Mobile Telecommunications System (UMTS) is one of the new emerging third generation (3G) cellular standards for global wireless data telecommunications. Unlike the second generation narrow-band CDMA, the wideband CDMA radio interface supports higher data rate services and offers other improvements in coverage and capacity. (Matalgah, et. al 2003). Whereas voice-services have dominated the second-generation (2G) cellular traffic, data services are predicted to become a major part of global personal mobile communications (PCs). An essential element of any commercial deployment for 3G network is the network capacity. By investigating the W-CDMA metrics for high throughput performances, this provides designers a good understanding of very important issues that should be considered in network capacity planning.

Analyzing a 3G Wideband Code Division Multiple Access (WCDMA) System for maximum data throughput is a research initiative resulting from the demand for improvement in the existing CDMA and GSM telecommunication systems. This 3G system offers so many benefits compared with the 1G and 2G standards.

1.1 W-CDMA System Parameters

a) Signal-to-Noise Ratio (SNR)

SNR is defined as the ratio of signal power to noise power and it is normally expressed in decibel (dB). The mathematical expression of SNR is

$$SNR = 10\log_{10}\left[{(signal\ power)_{dB}}/{Noise\ power}\right] \quad (1)$$

The SNR is extremely important in determining how well the (WCDMA) system will operate and how successfully the system can recover a weak signal. The SNR shows how much stronger (or weaker) the desired signal is, compared with the unwanted noise (Schweber, 2004).

b) Bit Error Rate (BER)

The bit error rate is a parameter that measures what fraction of the transmitted bits arrives its destination in error. It is one of the most important parameters employed in measuring the overall quality of a digital communications system. Also, the most important factor in determining the BER is the system SNR. BER shows what fraction of the total bits (transmitted from source to destination) is in error (Schweber, 2004).

1.2 Modulation Schemes

a) Quadrature Phase Shift Keying (QPSK)

Quadrature phase shift keying is a modulation technique which involves the transmission of two bits for every symbol. The phase carrier takes on one of four equally spaced values, such as 0, π/2, π and 3π/2. According to Masud e.t al, (2010) each value of phase corresponds to a unique pair of message bits as it is shown in figure 1.

The implementation of QPSK is more general than that of BPSK and also indicates the implementation of higher-order PSK. Writing the symbols in the constellation diagram in terms of the sine and cosine waves used to transmit them gives (Sakshi et. al, 2012).

$$S_{QPSK} = \left\{ {E_s}^{\frac{1}{2}} \cos\left[\left(i - 1\frac{\pi}{2}\right)\right] \emptyset_1(t) - \sqrt{Es}\, \sin\left[\left(i - 1\frac{\pi}{2}\right)\right] \emptyset_2(t) \right\} \quad i = 1,2,3,4 \quad (2)$$

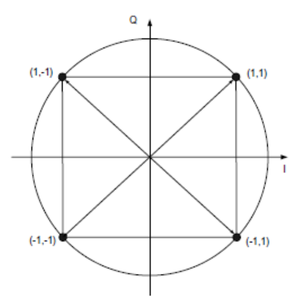

Figure 1: Constellation diagram of a QPSK system

b) Quadrature Amplitude Modulation (QAM)

When carrier waves vary in amplitude and phase, it is referred to as quadrature amplitude modulation, QAM. In QAM, the two carrier waves, usually sinusoids, are out of phase with each other by 90° and are thus called quadrature carriers or quadrature components (Sakshi et. al, 2012). The modulated waves are summed, and the resulting QAM signal can be viewed as a combination of Amplitude Shift Keying (ASK) as well as Phase Shift Keying (PSK) (Masud et. al, 2010) and (Sakshi et. al, 2012).

Figure 2 shows the constellation diagram of 16-ary QAM. The general form of an M-ary signal can be defined as (Masud et. al, 2010) and (Sakshi et. al, 2012).

$$S_1(t) = \left(\frac{2E_{min}}{T_s}\right)^{\frac{1}{2}} a_i \cos(2\pi f_c t) + \left(\frac{2E_{min}}{T_s}\right)^{\frac{1}{2}} b_i \sin(2\pi f_c t) \qquad 0 \le t \le T \qquad i = 1,2 \ldots, M \quad (3)$$

where E_{min} is the energy of the signal with the lowest amplitude and a_i and b_i are a pair of independent integers chosen according to the location of the particular signal point.

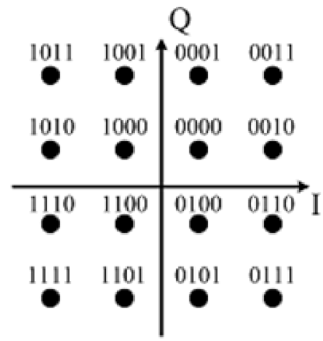

Figure 2: 16-QAM Constellation diagram

In a constellation diagram, the distance between the signal points indicates how modulation waveforms differ. It also indicates if a receiver can distinguish between all possible symbols when random noise is present. The probability that a bit will be in error is proportional to the distance between nearest signal points in the constellation arrangement. This means that a modulation scheme with a constellation that is densely packed is less energy efficient than a modulation scheme that has sparse constellation (Rappaport, 2006).

1.3 Throughput

Throughput, defined as the data rate successfully received, is also a key measure of performance for wireless data transmission systems. Several factors affects throughput. They include the distance between the transmitter and the receiver, channel characteristics as well as the noise and interference amplitude characteristics. It is also influenced by the choice of design parameters like symbol rate, modulation and coding, constellation size, power level, multiple access schemes, and many others (Teasang et. al, 2006). For example, at low symbol rates, most packets arrive without error. However, if the symbol rate is too high packet error probability increases and throughput is limited by frequent retransmission. Thus, it is expected that an optimum symbol rate will give a moderate error rate and high throughput. The same holds for the selection of a packet length.

2.0 Related Work

The work of Akl, et. al (2004) examined some of the variables affecting throughput and they include; packet size, transmission rate, received signal power, etc. The authors looked at how the transmission rate and packet size can optimize the throughput jointly. The work did not take any particular wireless system into account. It was also found that the key to maximization of the throughput rate is maintaining the signal-to-noise ratio at an optimal level. According to Sklar, (2001), the work presented a mathematical technique for determining the optimum transmission. Trade-offs between the throughput and the operation range are observed, and equations derived for the optimal choice of the design variables. These parameters are SNR dependent and can be adapted dynamically in response to the mobility of a wireless data terminal. The work also looked at the joint optimization problem involving all the design parameters together. It was found that not all the three parameters (data rate 'b', SNR, Length of packet) need to be adapted simultaneously

Estimated SNR of the link is used as a channel metric to decide switching levels (Alumona, et. al 2014). The channel estimation using two digital modulation techniques (QAM and QPSK) are considered in WCDMA environment. The work also observed that the SNR and path loss depend on the distance and measurement environment. For the work in Alumona et. al (2015), there is a systemic study on the increase in spectral efficiency obtained by optimally varying combinations of the modulation formats for a real radio environment is provided. The work noticed that adaptive modulation schemes improve the performance of the system by meeting a BER constraint over a range of SNR. The authors in Ifeagwu, et. al (2014) carried out a comparative evaluation of CDMA 20001X and GSM networks that use CDMA and TDMA technologies respectively. The comparison proved that CDMA technology offered more advantages over TDMA in terms of the system capacity, spectral efficiency, flexibility coverage and quality of service. This paper seeks to obtain a useful characterization for modulation technique selection which will enhance throughput capacity in W-CDMA system.

3.0 Material and methods

3.1: Experimental Measurement Environment

The selection of the base station sites was done to cover the suburban terrain conditions in and around Owerri, Imo state Nigeria where measurements were taken. This was characterized majorly of bungalows and sparsely located storey buildings of about 2 to 3 floors, with low density traffic. The base station antenna height was 30 meters.

3.2: Measurements and Data Collection

The measurements were taken using test mobile Sony K790 Ericsson phone operated at 95% active mode, alongside a Global Positioning System (GPS) receiver. The GPS was used to determine the distance from base stations at which positions the received signal strength (RSS) measurements were taken. Readings were taken at intervals of 100m spanning 0.1km (100m) ≤ d_i ≤ 1.5km (1500m) from each of the base station. Tables 1 and 2 show sample data of the recorded received signal strength or power along respective distances including useful parameters measured using QPSK and QAM modulation techniques respectively

Table1: Measured data from BTS 1 using QPSK

Distance (km)	Site ID	Latitude	Longitude	Freq (MHz)	TX power (dBm)	Rx power-RSS (dBm)	Antenna Tilt degree (^{0})	BTS Antenna Height (m)
0.1	IMO473	7.32006	5.45109	2116.4	19	-62	2	30
0.2	IMO473	7.32672	5.46606	2116.4	19	-64	2	30
0.3	IMO473	7.25217	5.45244	2116.4	19	-65	2	30
0.4	IMO473	7.27684	5.43247	2116.4	19	-66	2	30
0.5	IMO473	7.24378	5.43256	2116.4	19	-67	2	30
0.6	IMO473	7.11419	5.32464	2116.4	19	-67	2	30
0.7	IMO473	7.17894	5.33116	2116.4	19	-68	2	30
0.8	IMO473	7.12684	5.58244	2116.4	19	-79	2	30
0.9	IMO473	7.11753	5.55553	2116.4	19	-71	2	30
1.0	IMO473	7.16613	5.54977	2116.4	19	-72	2	30
1.1	IMO473	7.04823	5.59538	2116.4	19	-77	2	30
1.2	IMO473	7.09344	5.59775	2116.4	19	-78	2	30
1.3	IMO473	7.09883	5.61931	2116.4	19	-79	2	30
1.4	IMO473	7.06436	5.60014	2116.4	19	-77	2	30
1.5	IMO473	7.07995	5.64786	2116.4	19	-79	2	30

3.3: Quality of Service Estimation from Measured Data
(a) Signal to Noise Ratio (SNR)

Table 3 contains estimated signal-to-noise ratios obtained by varying the average path loss obtained using QPSK and QAM modulation techniques.
Thus, from Alumona et. al, (2014)

$$SNR = P_t - P_L - S_r \quad (4)$$

Where P_t is the transmitted power in dBm

P_L is the path loss model (Alumona et. al, 2015).

Here L_p = power transmitted (P_t) – power received (P_r) in dBm.

i.e L_p (dBm) = (P_t) – (P_r)

and S_r is the receiver sensitivity in dBm.

Equation 4 is therefore used to estimate the SNRs for the two modulation techniques under study. The estimated SNR results show that QPSK offered slightly greater SNR values when compared to QAM. Its average SNR valued for the distance under study stood at 15.89dB as against 15.64dB for QAM.

Table 2: Measured data from BTS 2 using QAM

Distance (km)	Site ID	Latitude	Longitude	Freq (MHz)	TX power (dBm)	Rx power-RSS (dBm)	Antenna Tilt degree (^{0})	BTS Antenna Height(m)
0.1	IMO410	7.32006	5.45109	2116.4	44.1	-51	4	30
0.2	IMO410	7.32672	5.46606	2116.4	44.1	-53	4	30
0.3	IMO410	7.25217	5.45244	2116.4	44.1	-57	4	30
0.4	IMO410	7.27684	5.43247	2116.4	44.1	-58	4	30
0.5	IMO410	7.24378	5.43256	2116.4	44.1	-65	4	30
0.6	IMO410	7.11419	5.32464	2116.4	44.1	-67	4	30
0.7	IMO410	7.17894	5.33116	2116.4	44.1	-69	4	30
0.8	IMO410	7.12684	5.58244	2116.4	44.1	-70	4	30
0.9	IMO410	7.11753	5.55553	2116.4	44.1	-72	4	30
1.0	IMO410	7.16613	5.54977	2116.4	44.1	-74	4	30
1.1	IMO410	7.04823	5.59538	2116.4	44.1	-79	4	30
1.2	IMO410	7.09344	5.59775	2116.4	44.1	-82	4	30
1.3	IMO410	7.09883	5.61931	2116.4	44.1	-86	4	30
1.4	IMO410	7.06436	5.60014	2116.4	44.1	-88	4	30
1.5	IMO410	7.07995	5.64786	2116.4	44.1	-94	4	30

(b) Bit Error Rate (BER)

Table 3 below also show estimated bit error performances realized by varying the SNRs (in equation 4) by means of using the average path loss.

The performance of M-ary phase shift keying (PSK), M-ary quadrature amplitude modulation (QAM) and M-ary frequency shift keying (FSK) for a considered wireless communication system are evaluated in terms of bit error probability. The mathematical expression used to obtain the bit error performances of QPSK and QAM as shown in Table 3 are respectively put as (Alumona, et. al 2014).

$$P_{QPSK}(\gamma) = Q\left(\gamma^{1/2}\right) \quad (5)$$

and

$$P_{QAM}(\gamma) = \frac{1}{4}\, Q\left[\left(\gamma/5\right)^{\frac{1}{2}} + Q\left(\gamma/5\right)^{\frac{1}{3}}\right] + \frac{1}{2} Q\left(\frac{\gamma}{5}\right) \quad (6)$$

Equations (5) and (6) are the mathematical expressions used to obtain the bit error performances of QPSK and QAM respectively assuming perfect clock and carrier recovery for a Gaussian channel (Alumona, et. al 2014).
Also, from Table 3, the mathematical expressions used in obtaining the bit error performances of QPSK and QAM for a Rayleigh fading channel are respectively given as (Alumona, et. al 2014).

$$P_{QPSK}(\gamma) = \frac{1}{2}\left\{1 - \left(\frac{\gamma}{(2+\gamma)}\right)^{\frac{1}{2}}\right\} \quad (7)$$

And

$$P_{QAM}(\gamma) = \frac{1}{4}\left[\left\{1 - \left(\frac{\gamma}{(10+\gamma)}\right)^{\frac{1}{2}}\right\} + \left\{\frac{9\gamma}{10+9}\right\}\right] \quad (8)$$

Where (γ) is the SNR, and

Q = Q-function defined as $Q(x) = \frac{1}{(2\pi)^{\frac{1}{2}}}\int_{x}^{\infty} e\left\{-\frac{x^2}{2}\right\} dx$

Similarly, Equations (7) and (8) are the mathematical expressions used to obtain the bit error performances of QPSK and QAM respectively over a rayleigh fading channel are given in (Alumona, et. al 2014).
From the expressions in equations (5) to (8), the bit error performances of QPSK and QAM are evaluated in terms of its the estimated signal to noise ratio values thus giving rise to table 3.

Table 3. Performances Evaluated of QPSK and QAM modulation techniques

	QPSK in AWGN		QAM in AWGN		QPSK in Rayleigh Fading		QAM in Rayleigh Fading	
Distance (km)	**SNR (dB)**	**BER**	**SNR (dB)**	**BER**	**SNR (dB)**	**BER**	**SNR (dB)**	**BER**
0.1	16.81	0.000020658	17.72	0.0066	16.81	0.0273	17.72	0.2854
0.2	16.63	0.000022713	17.57	0.0067	16.63	0.0276	17.57	0.2856
0.3	16.53	0.000023943	17.17	0.0070	16.53	0.0278	17.17	0.2861
0.4	16.44	0.000025107	17.17	0.0070	16.44	0.0279	17.17	0.2861
0.5	16.33	0.000026607	16.54	0.0076	16.33	0.0281	16.54	0.2869
0.6	16.33	0.000026607	16.13	0.0081	16.33	0.0281	16.13	0.2875
0.7	16.23	0.000028049	16.13	0.0081	16.23	0.0282	16.13	0.2875
0.8	16.13	0.000029570	16.03	0.0082	16.13	0.0284	16.03	0.2876
0.9	15.91	0.000033213	15.81	0.0084	15.91	0.0287	15.81	0.2879
1.0	15.80	0.000035201	15.58	0.0087	15.80	0.0289	15.58	0.2883
1.1	15.19	0.000048608	14.93	0.0096	15.19	0.0300	14.93	0.2892
1.2	15.05	0.000052350	14.49	0.0103	15.05	0.0302	14.49	0.2899
1.3	14.91	0.000056382	13.80	0.0116	14.91	0.0305	13.80	0.2910
1.4	15.19	0.000048608	13.44	0.0124	15.19	0.0300	13.44	0.2916
1.5	14.91	0.000056382	12.07	0.0165	14.91	0.0305	12.07	0.2941

4.0 Results and Discussions

With the help of Matlab Simulink, the performance results obtained was plotted using the estimated bit error performance values against the computed SNR values for the two modulation techniques.
From figure 3 to figure 6, the performance of W-CDMA system has been analyzed for two modulation techniques QPSK and QAM by considering their bit error performances and comparing which modulation technique gives a better result.

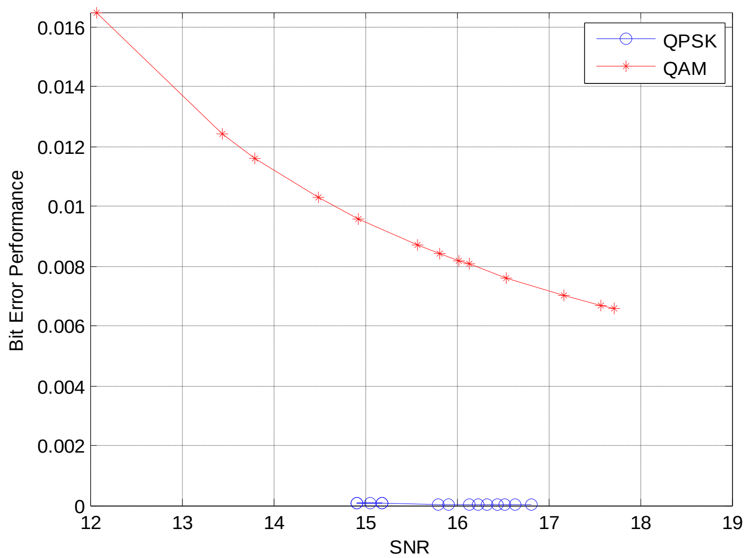

Figure 3: system BER performance of QPSK and QAM under Additive White Guassian Noise Channel

The upper graph in figure 3 shows the performance of QAM under Additive White Guassian Noise (AWGN) while the lower graph shows the performance of QPSK modulation under same environment. From their BER values, it can be observed that there is a considerable reduction in errors for QPSK than for QAM. This implies QAM becomes more susceptible to noise because the signal states of QAM are closer together and so contain more bits per symbol but this makes a lower level of noise enough to move the signal to a different decision point than in QPSK.

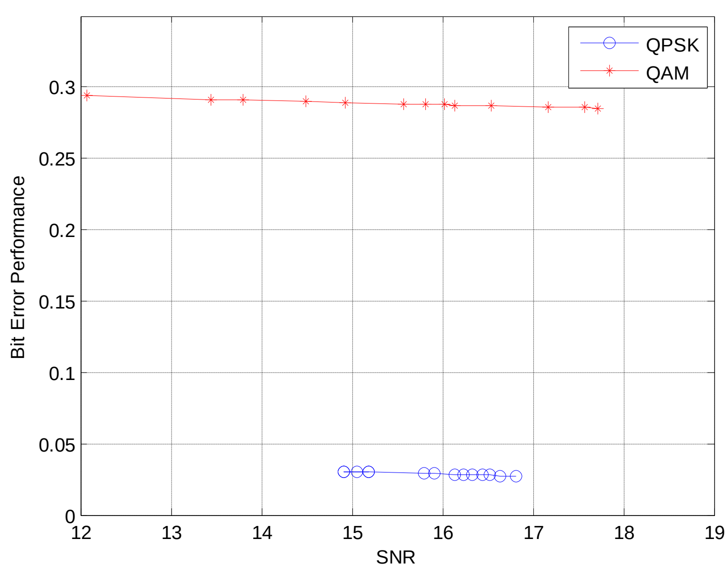

Figure 4: System BER performance of QPSK and QAM under Rayleigh Fading

Figure 4 compares the performance of the two modulation schemes under channel. The figure shows that QPSK modulation outperforms QAM under fading because it offered less bit errors. This is because for the same range of distance (spanning 0.1 km to 1.5 km) under study, the SNR of QPSK was slightly greater showing its robustness over QAM.

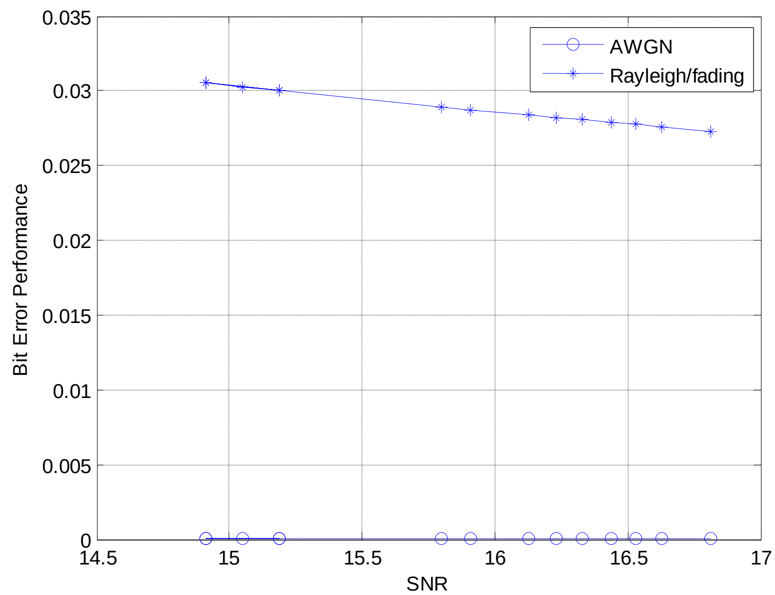

Figure 5: System BER performance of QPSK under Additive White Guassian Noise Channel and Rayleigh Fading

From figure 5, QPSK modulation was seen to perform better under noise than under fading. This is because in the noisy channel, QPSK offered minimal bit error rates. This implies that the power necessary to maintain a given probability of error, particularly for small values, is much higher in fading channels than in AWGN channels.

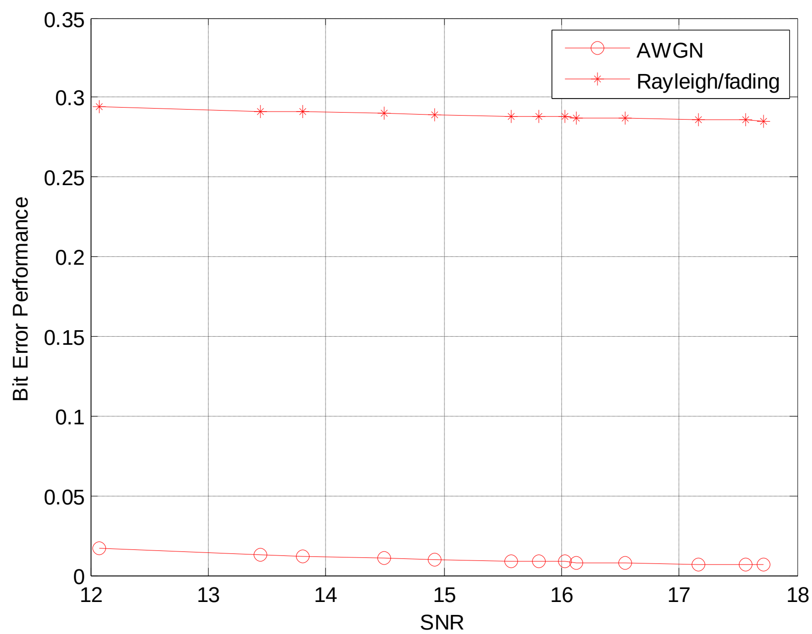

Figure 6: System BER performance of QAM under Additive White Guassian Noise Channel and Rayleigh Fading

From the result obtained from figure 6, the bit error performance behaviour for the two modulation schemes under study was better all through in an AWGN channel than when compared to the performance in a fading channel. This means that the noisy channel is more power efficient compared to the fading channel as seen from the simulation results. However, if the same BER is desired, network planners therefore will have to increase the transmitted power under the fading environment.

5.0. Conclusion and Recommendation

5.1 Conclusion

In this paper, the general trend in the displayed plots show that QPSK with higher SNR show improved bit error rating. However, as signal to noise ratio decreases as was the case in QAM, errors increased. This will slow throughput if error correction mechanism is considered since the data in error would be re-sent. The result also revealed that for the same measurement distance under study, the average estimated SNR of QPSK was slightly greater showing 15.89dB (50.4%) against 15.64dB (49.6%) for QAM. This gave rise to why the bit error rate of QAM technique was observed to be higher than QPSK. The signal states of QAM are therefore closer together and so contain more bits per symbol. This makes a lower level of noise enough to move the signal to a different decision point than in QPSK In other words, any modulation scheme implemented in any form of wireless network (W-CDMA inclusive) affects the BER performance which in turn affects the data rate as well as the throughput of the communicating devices.

5.2 Recommendation

From this paper, advanced WCDMA systems can be developed using the recommendations below.

1. Advanced error correction coding should be implemented since higher order modulation schemes like QAM are vulnerable to errors to ensure higher chances of signal survivability especially in multipath Rayleigh channel to enhance the performance of the W-CDMA system.
2. Rician fading could also be included in the channel in addition of AWGN and multipath Rayleigh fading channel. Then, comparison can be made between these channels.

References

Akl, R and Parvez, A. 2004. “Impact of Interference Model on Capacity in CDMA Cellular Networks”, Proceedings of SCI 04, Communication and Network Systems, Technologies and Applications, 3:404-408

Alumona, T. L., Onoh, G. N, Ezeagwu, C. O, Okeoma, S. C. 2015. “Adaptive Modulation Techniques for Capacity Improvement of BER in W-CDMA”, International Journal of Advanced Research in Computer Engineering and Technology, Volume 4 (9) pg 3537-3542

Alumona, T. L. and Nnamani K. N. 2015. “Path Loss Prediction of Wireless Mobile Communication for Urban Areas of Imo State, South-East Region of Nigeria at 910 MHz”, Journal of Academia and Industrial Research (JAIR), Volume 3 (9) pg 397-400

Alumona, T. L., Onoh, G. N, Mbanugo, P. C. Ugwuoke, O. O. 2014. “Signal to Noise Ratio Estimation of QAM and QPSK Modulation Technique at 910MHz and 2116.4MHz Using Measured Data”, International Journal of Advanced Research in Computer Engineering and Technology, Volume 3 (10) pg 3572-3576

Ifeagwu E. N, Onoh G. N., Obute K. C. 2014. “Comparative Evaluation of CDMA 20001X and GSM Networks”, International Journal of Electrical and Telecommunication System Research, Volume 6 (6)

Masud, M. A., Samsuzzaman, M., Rahman, M.A. 2010. “Bit Error Rate Performance Analysis on Modulation Techniques of Wideband Code Division Multiple Access”, Journal of Telecommunications, Volume 1(2), Pp 22-29.

Matalgah, M., Qaddour, J., Sharma, K. 2003. “Throughput and Spectral Efficiency Analysis in 3G Frequency-Division Duplex WCDMA Cellular Systems”, Paper Published at the IEEE Global Telecommunications Conference (Volume: 6). doi: 10.1109/GLOCOM.2003.1258870

Rappaport, T.S. 2006. “Wireless Communications: Principles and Practice”, New Delhi, India: Prentice Hall of India

Sakshi, G., Himanshu, S. 2012. “Performance Investigation for Different Techniques in WCDMA with Multipath Fading Channels”, International Journal of Advanced Research in Computer Science and Software Engineering, Volume 2(7)

Schweber, W. 2009. “Electronic Communication Systems: A Complete Course”, New Delhi, India: PHI learning

Sklar, B. 2001. “Digital Communications: Fundamentals and applications”, New Delhi, India: Prentice-Hall of India

TaesangYoo, Richard J. L., Andrea G., David J.G. 2006. “Throughput Optimization Using Adaptive Techniques”, In Proceedings of the IEEE International Conference on Communications.