

# Wideband Code Division Multiple Accesses: Comparative Performance Analysis of Digital Modulation Techniques for Enhanced Data Capacity

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**Abstract:** This research focused on the comparative performance analysis of Quadrature Amplitude Modulation (QAM) and Quadrature Phase Shift Keying (QPSK) modulation techniques employed in W-CDMA system. Site investigation was conducted and the Received Signal Strength (RSS) measurement taken. From the RSS measurement, the path loss was evaluated and was used to estimate two Quality of Service (QoS) parameters - Signal-to-Noise Ratio (SNR) and the Bit Error Rate (BER) of the modulation techniques under study. These parameters were used to characterize the modulation techniques upon which a comparative analysis was obtained to achieve maximum data throughput consideration. The result of the analysis revealed that as SNR decreases, errors increase. The average estimated SNR of QPSK was slightly greater showing 15.89dB (50.4%) against 15.64dB (49.6%) for QAM, giving rise to why the bit error rate of QAM technique was higher than QPSK. In all, the research revealed that QAM offered higher coding rate which helps to sustain better data capacity and throughput. QPSK on the other hand gave an improved BER performance. From these developments, network designers usually make a tradeoff between spectral efficiency which QAM offers and improved BER performance by QPSK. Modulation scheme implemented therefore in any form of wireless network affects the BER performance which in turn affects the data rate as well as the throughput of the communicating devices.

**Keywords:** QPSK, QAM, throughput, Modulation, BER, WCDMA

## I. INTRODUCTION

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. In the second generation (2G) networks where Gaussian Minimum Shift Keying (GMSK) modulation scheme is widely used in Global System for Mobile communication (GSM), it has been observed that such modulation scheme could only transmit data rate of 1 bit per symbol and so not suitable for the next generation communication system. Also while voice-services have dominated the 2G cellular traffic, data services are predicted to become a major part of global personal mobile communications (PCs). Compared to the 2G narrow-band

systems, the WCDMA radio interface supports higher rate services and offers some other significant improvements. Such improvements include improved coverage and capacity due to higher bandwidth and support for capacity-improving technologies such as dynamic antennas and multiuser detection. Analyzing a third generation – 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, Global System for Mobile communication (GSM) telecommunication systems. Throughput and spectral efficiency are therefore fundamental elements in capacity planning for 3G cellular network deployments. By investigating on the W-CDMA metrics for high throughput performances, network designers are provided a good understanding of very important issues that should be considered in network capacity planning. Based on these developments, this research is aimed at showing the best modulation technique for W-CDMA system that is able to accommodate as much data into the least amount of spectrum possible based on actual network conditions. This is known as spectral efficiency and it measures how much data can be transmitted within a limited bandwidth. This is achieved by a comparative performance analysis of some selected digital modulation techniques i.e Quadrature phase shift keying (QPSK) and Quadrature Amplitude Modulation (QAM). The Bit error rate (BER) of QPSK and QAM digital modulation schemes were compared under additive white gaussian noise (AWGN), and Rayleigh fading channels to identify the best configuration to achieve maximum data throughput which offers better utilization of bandwidth resource. The research was performed using Matlab Simulink for simulation and evaluation of Bit Error Rate (BER) and Signal-to-Noise Ratio (SNR) for W-CDMA system models.

This rest of the paper is structured as follows: Section II presents an overview of wideband code division multiple access, digital modulation and additive white Gaussian noise; Section III describes the method of data collection employed. Data presentation and results are presented in Section IV. Section V concludes the paper by highlighting the main findings of the paper.

## II. LITERATURE REVIEW

### 2.1 Wideband-Code Division Multiple Access (W-CDMA)

Wideband Code Division multiple Access (WCDMA) system, standardized under the 3rd Generation Partnership Project (3GPP), is one of the most widely deployed 3G wireless cellular networks. Recall that CDMA has a bandwidth of 1.25 MHz whereas WCDMA has a bandwidth of 5MHz. Thus it is called Wideband CDMA. WCDMA is a CDMA channel that is four times wider than the current channels that are typically used in 2G networks in North America. It is an air interface standard found in 3G mobile networks. WCDMA is being used by Universal Mobile Telecommunication System (UMTS) as platform of the 3rd generation cellular communication system. It requires a minimum bandwidth allocation of 5MHz, which is an important distinction from the other generation standards. Packet data rates up to 2Mb/s per user in indoor or small-cell outdoor environments and at rates of up to 384 Kbit/s in wide-area coverage is supported by WCDMA. Third generation systems are designed for multimedia communication which can be enhanced with high quality video. Both Frequency Division Duplex (FDD) and Time Division Duplex (TDD) variants are supported.

W-CDMA is a spread-spectrum modulation technique; one which uses channels whose bandwidth is much greater than that of the data to be transferred. Instead of each connection being granted a dedicated frequency band just wide enough to accommodate its envisaged maximum data rate, W-CDMA channels share a much larger band. Information is encoded in each channel in such a way that a decoder, knowing the code, can pick out the wanted signal from other signals using the same band, which simply appear as so much noise (Teasang, et al 2004). WCDMA technology is the most widely used third generation system which is spreading over a wide bandwidth by multiplying the user information with spreading sequence in WCDMA. W-CDMA uses noise-like broadband frequency spectrum as it provides high resistance to multipath fading, which was not present in 2nd generation (2G) communication system. In 2G communication network, Gaussian Minimum Shift Keying (GMSK) modulation scheme is widely used in GSM. This modulation can only transmit data rate of 1 bit per symbol. So this kind of modulation scheme is not suitable for providing higher data rate in the next generation communication system. So there is a need for the performance analysis of suitable new modulation, error correction coding and technology to be used in WCDMA system to improve the system performance in a multipath fading channel.

UMTS uses a core network derived from that of GSM, ensuring backward compatibility of services and allowing seamless handover between GSM access technology and WCDMA (Teasang, et al 2004). Each release of 3GPP specification introduces new technologies and features towards better broadband access in wireless WANs. Release 7

of 3 GPP (HSPA+) provide such new features like; higher order modulation and multiple input and multiple output (MIMO) both on downlink and uplink that enable improved data rate and number of simultaneous user supported, both feature improve the spectrum efficiency, especially for the users in good channel condition.

#### 2.1.1 Features of W-CDMA

WCDMA is a wideband Direct-Sequence Code Division Multiple Access (DS-SS-CDMA) technique. By multiplying the user data with a quasi-random chip sequence, the user information bits are spread over a wide bandwidth. One chip is the minimal time unit in UMTS. Its duration ( $T_c$ ) as denoted by (Yejian, 2006) is given as

$$T_c = 260.42\text{ns} \quad (1)$$

Thus the 3.84Mchip/s chip rate is obtained. Another two time units are UMTS slot and frame. One slot is composed of 2560 chips, and one frame contains 15 slots. The corresponding durations are:  $T_s = 666.67\mu\text{s}$ ,  $T_f = 10\text{ms}$

The slot formats of the dedicated user information bits by applying the Quadrature Phase Shift Keying (QPSK) modulation scheme can support peak bit rate of up to 1920kbit/s. For the dedicated user data, the use of a variable spreading factor and multicode connections are available. In UMTS system, approximately 5MHz carrier bandwidth is required to support the chip rate of 3.84Mchip/s.

In comparison to the traditional DS-SS-CDMA systems with a bandwidth of about 1MHz, such as IS-95, UMTS is thus referred to as wideband CDMA technique. Due to the freedom to choose a suitable variable user bit rate by individual user, the Bandwidth on Demand (BoD) over the complete 5MHz bandwidth is well supported. Chen (2006) puts it that at the mobile terminal, the correlation detection called despreading raises the mean power of the desired user signal by the spreading factor, and maintains the mean power of the noise and interference in the CDMA system, which is termed as processing gain. Processing gain gives CDMA the robustness against self-interference and is given by (Yejian, 2006)

$$G_{(dB)} = 10 \log_{10} \left[ \frac{B}{R} \right] \quad (2)$$

where  $B$  and  $R$  denote the RF bandwidth and the information rate, respectively.

As explained previously, the UMTS system operates with asynchronous base stations, while the IS-95 is synchronous, which needs a global time reference, such as a Global Positioning System (GPS). WCDMA is designed to be deployed in conjunction with GSM. Therefore, handovers between GSM and WCDMA are supported in order to be able to leverage the GSM coverage for the introduction of WCDMA. In Tables 1 and 2, the main differences of the air interfaces for WCDMA, GSM and IS-95 are listed.

Table 1: Characteristics of WCDMA and GSM (Yejian, 2006)

Parameters	W-CDMA	GSM
Carrier spacing	5MHz	200kHz
Frequency re-use factor	1	1-18
Power control frequency	1500Hz	2Hz or lower
Quality control	Radio resource management algorithms	Network planning (frequency planning)
Frequency diversity	5MHz bandwidth gives multipath diversity with Rake receiver	Frequency hopping
Packet data	Load-based packet scheduling	Time slot based scheduling with GPRS
Downlink Transmit diversity	Supported for improving downlink capacity	Not supported by the standard, but can be applied

Table 2: Characteristics of WCDMA and IS-95 Air Interface (Yejian, 2006)

Parameters	W-CDMA	IS-95
Carrier spacing	5MHz	1.25MHz
Chip rate	3.84Mchip/s	1.2288Mchip/s
Power control frequency	1500Hz, both uplink and downlink	Uplink: 800Hz Downlink: slow power control
Base station synchronization	Not needed	Typically obtained via GPS
Inter-frequency handovers	Yes, measurement with slotted mode	Possible, but measurement method not specified
Efficient radio resource management algorithms	Yes, provides required quality of service	Not needed for speech only networks
Packet data	Load-based packet scheduling	Packet data transmitted as short circuit switched calls
Downlink transmit diversity	Supported for improving downlink capacity	Not supported by the standard

The WCDMA air interface has been crafted in such a way that advanced CDMA receiver concepts, such as multiuser detection and smart dynamic antennas, can be deployed by the network operator as an option to increase capacity and/or coverage.

In most 2G systems, no provision has been made for such receiver concepts, and as a result they are either not applicable or can be applied only under severe constraints with limited increases in performance. To understand and compare different modulation format efficiencies, it is important to understand the difference between bit rate and symbol rate. The signal bandwidth for the communications channel depends on the symbol rate or also known as band rate.

$$\text{Symbol rate} = \frac{\text{Bit Rate}}{\text{Number of bits transmitted per symbol}} \quad (3)$$

Where bit rate is the sampling frequency multiplied by the number of bits per sample. For example, a radio with an 8-bit sampler is sampled at 10 kHz for voice. The bit rate, the basic bit stream rate in the radio, would be 8 bits multiplied by 10k samples per second giving 80 kbps. In this example, extra bits required for synchronization, error correction, etc are ignored for simplicity. In GMSK, only one bit can be transmitted for each symbol. Thus, the symbol rate for this modulation technique is 80 kbps. However, high data rate - like 8-PSK

with 3-bits per symbol is shown to have the symbol rate to be 26.7 kbps, if this modulation scheme is employed. This means that the symbol rate for 8-PSK is three times smaller than that of GMSK. In other words, 8-PSK or any high order (M) modulation scheme can transmit same information over a narrower piece of RF spectrum. (Aun and Feng, 2009)

Another parameter is the signal to noise ratio, SNR is defined as the ratio of a signal power to noise power and it is normally expressed in decibel (dB). The mathematical expression of SNR is given by (4)

$$SNR = \frac{10 \log_{10}(\text{signal power}) \text{ dB}}{\text{Noise Power}} \quad (4)$$

Bit error rate, BER is another WCDMA parameter. It is one of the most important parameters employed in measuring the overall quality of a digital communications system. BER shows what fraction of the total bits (transmitted from source to destination) is in error. Schweber, (2009) says that the most important factor in determining BER is the system signal-to-noise ratio (SNR). He revealed that as SNR increases, BER drops dramatically. Most communication systems begin to provide reasonably good BERs when the SNR is above 20 to 30dB (Schweber, 2009).

## 2.2 Digital Modulation

According to Olusanya and Ogunseye, (2014), modulation is defined as the process of putting useful information on a carrier that can be transmitted from one point to another. This information can be voice, data or signaling data. Digital modulation consists of mapping bit sequences into waveforms for transmission over the channel. Many practical modulation techniques and their performances under various channel impairments have been described in literatures. Some of the digital modulation techniques have subtle differences between them. Several factors influence the choice of a digital modulation scheme. A desirable modulation scheme provides low bit error rates at low received signal-to-noise ratios, performs well in multipath and fading conditions, occupies a minimum of bandwidth and is easy and cost-effective to implement. However, since the ultimate goal of a modulation technique is to transport the message signal through a radio channel with the best possible quality while occupying the least amount of radio spectrum. Existing schemes do not simultaneously satisfy all of these requirements (Rappaport, 2006).

Based on the demands of this research, tradeoff between bandwidth utilization and power efficiency is being made in selecting the modulation techniques used for this study. To this end, Quadrature Phase Shift Keying (QPSK) and Quadrature Amplitude Modulation (QAM) modulation techniques have been identified to perform better than other digital modulation techniques based on their ability in making this tradeoff effectively.

### 2.2.1 Digital Modulation Techniques in WCDMA

There are four kind of techniques by which signals can be carried; first is Amplitude Shift Keying (ASK) which involves increasing the amplitude of the carrier wave in step with digital signal. For example low is represented by 0 and high by 1. The second technique is Frequency Shift Keying (FSK) in which digital information is transmitted through discrete frequency changes of a carrier wave. The third technique is Phase Shift Keying (PSK), unlike the other two techniques; PSK conveys data by changing the phase of a reference signal that is the carrier wave. Some of the modulation schemes based on PSK technique include Binary Phase Shift Keying (BPSK) and Quadrature Phase Shift Keying (QPSK). In BPSK, each symbol indicate two different states allowing one bit per symbol, thus 0 degrees represent a digit 0 while 180 degrees digit 1.

Sakshi and Himanshu (2012) put it that BPSK is the simplest form of phase shift keying (PSK). It uses two phases which are separated by 180° and so can also be termed 2-PSK. It does not particularly matter exactly where the constellation points are positioned, and in this figure they are shown on the real axis, at 0° and 180°. This modulation is the most robust of all the PSKs since it takes the highest level of noise or

distortion to make the demodulator reach an incorrect decision. It is, however, only able to modulate at 1 bit/symbol and so is unsuitable for high data-rate applications (Sakshi, et al., 2012)

$$S_{\text{BPSK}} = \sqrt{\frac{2E_b}{T_b}} \cos(2\pi f_c t + \theta_c) \quad 0 \leq t \leq T_b \quad (\text{binary } 0) \quad (5)$$

In QPSK two more phases are added, 90 and 270 degrees. Additions of these two degrees allow QPSK to transmit two bits per symbol in a transmission. Jigna, Maradia, and Gohil, (2012) and Masud, Samsuzzaman, and Rahman (2010) disclosed that the phase carrier takes on one of four equally spaced values, such as 0,  $\pi/2$ ,  $\pi$  and  $3\pi/2$ , where each value of phase corresponds to a unique pair of message bits as shown in figure 1. The basic signal for QPSK can be expressed as

$$S_{\text{QPSK}} = \left\{ \sqrt{E_s} \cos \left[ \left( i - 1 \frac{\pi}{2} \right) \right] \phi_1(t) - \sqrt{E_s} \sin \left[ \left( i - 1 \frac{\pi}{2} \right) \right] \phi_2(t) \right\} \quad i = 1, 2, 3, 4 \quad (6)$$

Ciana, et. al., (2014) disclosed that symbol's phases are compared relative to previous symbols, for example, if there is no phase shift denoted by 0 degree, the bits "00" are represented. When there is a shift of 180 degree, the bits "11" are represented and when there is a shift of 90 or 270 the bits "01" and "10" are represented respectively.

Masud et al., (2010) revealed that special characteristics of QPSK are twice data can be sent in the same bandwidth compared to Binary PSK (BPSK). QPSK also has identical bit error probability to that of BPSK. When QPSK is compared to that of BPSK, QPSK provides twice the spectral efficiency with the same energy efficiency. Furthermore, similar to BPSK, QPSK can be differently encoded to allow non coherent detection. Due to these advantages QPSK has, it has been employed as the modulation technique in UMTS 3G wireless cellular networks where the following data rate can be achieved depending on the channel quality (Aun et al., 2009).

- a) 144 kbps for high mobility.
- b) 384 kbps for low mobility
- c) 2 Mbps for indoor or static environment

Rappaport, (2006) revealed that constellation diagram provides a graphical representation of the complex envelope of each possible Symbol state. The x-axis of the constellation diagram represents the in-phase component of the complex envelope and the y-axis represents the quadrature component of the complex envelope. The distance between the signals on the constellation diagram relates to how different the modulation waveform are, and how well a receiver can differentiate between all possible symbols when random noise is present. The Probability of bit error is proportional to the distance between the closest points in the constellation. This implies 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).

The fourth technique is Quadrature Amplitude Modulation (QAM). It is a modulation technique where its amplitude is allowed to vary with phase. QAM signaling can be viewed as a combination of Amplitude Shift Keying (ASK) as well as Phase Shift Keying (PSK) (Masud et al., 2010). Also, it can be viewed as ASK in two dimension. Rajesh and Rajeshree, (2013) revealed that QAM is a signal in which two carriers shifted in phase by 90 degrees are modulated and the resultant output consists of both amplitude and phase variations. As both amplitude and phase variations are present, it is also considered as a mixture of amplitude and phase modulation. Digital formats of QAM are often referred to as "Quantized QAM" and they are being increasingly used for data communications in radio communications systems. When using QAM, the constellation points are normally arranged in a square grid with equal vertical and horizontal spacing. The most common forms of QAM use a constellation with the number of points equal to a power of 2. By using higher order modulation formats, it is possible to transmit more bits per symbol. As the points are closer together they are therefore more susceptible to noise and data errors. When the states are closer together, a lower level of noise can move the signal to a different decision point. QAM contains an amplitude component hence linearity is necessary. The linear amplifiers are less efficient and consume more power, and this makes them less attractive for mobile applications.

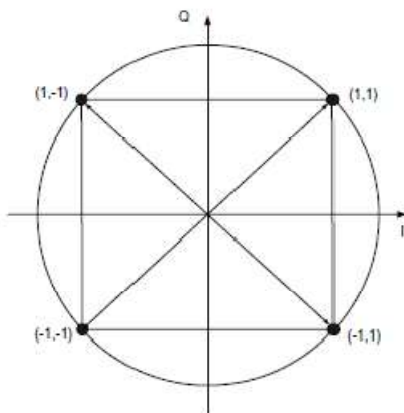


Figure 1: Constellation Diagram of QPSK

Figure 1 shows the constellation diagram of 16-ary QAM (16-QAM). The constellation consists of a square lattice of signal points. The general form of an M-ary QAM can be defined as:

$$S_1(t) = \sqrt{\frac{2E_{min}}{T_s}} a_i \cos(2\pi f_c t) + \sqrt{\frac{2E_{min}}{T_s}} b_i \sin(2\pi f_c t) \quad 0 \leq t \leq T \quad i = 1, 2, \dots, M \quad (7)$$

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.

Theoretically, higher order of M-ary QAM enables data to be transmitted in a much smaller spectrum. However, the symbols are easily subjected to errors due to noise and interference because the symbols are located very closed together in the constellation diagram. Thus such signal has to transmit extra power so that the symbol can be spread out more and this reduces power efficiency as compared to simpler modulation scheme. Also the radio equipment is more complex (Ruchi, Arora, and Akhilesh 2012).

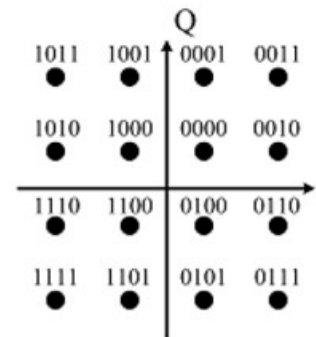


Figure 2: 16-QAM constellation

Figures 1 and 2 shows the constellation diagram of QPSK and 16-QAM systems respectively. Better spectral efficiencies or higher throughput is achieved by different order modulation, sending more bits per symbol. However, to maintain a certain BER, some modulation schemes like 64 QAM need higher SNR.

2.3 Additive White Gaussian Noise (AWGN)

In wireless communication, one of the major problems is thermal noise. The term ‘thermal noise’ refers to unwanted electrical signals that are always present in electrical systems. The term additive means the noise is superimposed or added to the signal where it will limit the receiver ability to make correct symbol decisions and limit the rate of information. Thus, AWGN is the effect of thermal noise generated by thermal motion of electron in all dissipative electrical components i.e. resistors, wires and so on (Aun and Feng 2009). Mathematically, thermal noise is described by a zero-mean Gaussian random process where the random signal is a sum of Gaussian noise random variable and a dc signal that is;

$$z = a + n \quad (8)$$

where ‘a’ is the useful signal while ‘n’ is regarded as the gaussian noise. Also, pdf for Gaussian noise can be represented as follows (Aun et al., 2009).

$$p(z) = \frac{1}{\sigma\sqrt{2\pi}} \exp\left[-\frac{1}{2}\left\{\frac{z-\alpha}{\sigma}\right\}^2\right] \quad (9)$$

Where  $\sigma^2$  is the variance of  $n$

A simple model for thermal noise assumes that its power spectral density  $G_n(f)$  is a flat for all frequencies and is denoted as

$$G_n = N_0/2 \quad (10)$$

Where the factor of 2 is used to indicate that  $G_n(f)$  is a two-sided power spectral density. When noise power has such a uniform spectral density, it is referred as white noise. 'White' refers to noise having constant power spectral density and finally 'Gaussian' means the probability density function of samples of random process is Gaussian. AWGN channel is a model in which there is a linear addition of wideband or white noise that has a constant spectral density and a Gaussian distribution of amplitude. The model does not account for the phenomena of fading, frequency selectivity, interference, non-linearity, or dispersion. AWGN has the effect on the received signal, the power of the noise signal in relation to the power of the desired signal. The ratio of the two is known as the signal-to-noise-ratio (SNR).

Since thermal noise is present in all communication systems and is a prominent noise source for most system, the thermal noise characteristics that are additive, white and Gaussian are most often used to model the noise in communication systems (Aun and Feng, 2009).

#### 2.4 Review of Related Works

The work in Dhruv, Krishnakant, and Rohini (2013) carried out modulation experimentations for high speed downlink packet Access (HSDPA) which is gaining popularity because of its capability of delivering higher data rate transmission with minimum latency than the GSM (global system for mobile communications) and 2.5G General Packet Radio Service (GPRS) systems was carried out to obtain the best data rate for the available channel conditions.

Masud, Samsuzzaman, and Rahman (2010), Similar to Ciana, et al., (2014), carried out a performance analysis of M-ary Quadrature Amplitude modulation (QAM) and Quadrature phase shift keying (QPSK) modulation schemes when the system is subjected to Additive White Gaussian Noise (AWGN) and multipath Rayleigh fading in the channel. Bit Error Rate (BER) and Signal-to-Noise Ratio (SNR) were analysed for W-CDMA system models.

Ifeagwu, Onoh and Obute (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.

Alumona, et al., (2014), showcased that the estimated signal-to-noise ratio of a link is used as a channel metric to decide switching levels. i.e. their studies presented that the channel estimation using two digital modulation techniques (QAM and QPSK) are considered in W-CDMA environment. The study observed that the SNR and path loss depends on the distance and measurement environment.

From the studied literature, multimedia applications need wireless communications service providers to provide service mix traffic (voice, data, and real time audio/video) to the end wireless subscriber. But W-CDMA is shown to be the chosen radio access technology for UMTS/IMT-2000 to support multimedia services. Throughput and spectral efficiency are therefore of fundamental importance in capacity planning for 3G cellular network deployments.

### III. METHODOLOGY

The technique adopted in this research covers field studies which involves measurement and data collation. The data collated is used to characterize the modulation techniques under study. Matlab simulink is used to obtain a useful characterization for any of the modulation scheme adoption for an improved data throughput consideration

#### 3.1 Experimental Measurement Environment

The selection of the base stations sites were done to accommodate the scenarios in and around Owerri, Imo state Nigeria. Figure 3 shows selected base station sites and its environments in map info professional. Each Sector of the base station has PN code and carrier identity that distinguishes it from other base station, with the PN code, the particular base station/Sector reception was made from at each test point was known. This ensures the reference base station was correct. The following parameters were used in this research: Received Signal Strength, distance, frequency, BTS transmit power, Modulation Techniques and BTS antenna height. The parameters are presented in Table 3

Table 3: BTS Parameter Ratings

PARAMETER	BTS 1	BTS 2
Modulation Technique	QPSK	QAM
Site ID	IMO473	IMO410
Transmitted Power	19dBm	44.1dBm
Base station antenna height	30m	30m
Antenna tilt	2°	4°
Frequency	2116.4MHz	2116.4MHz

Source: Ericsson mini-link craft tool

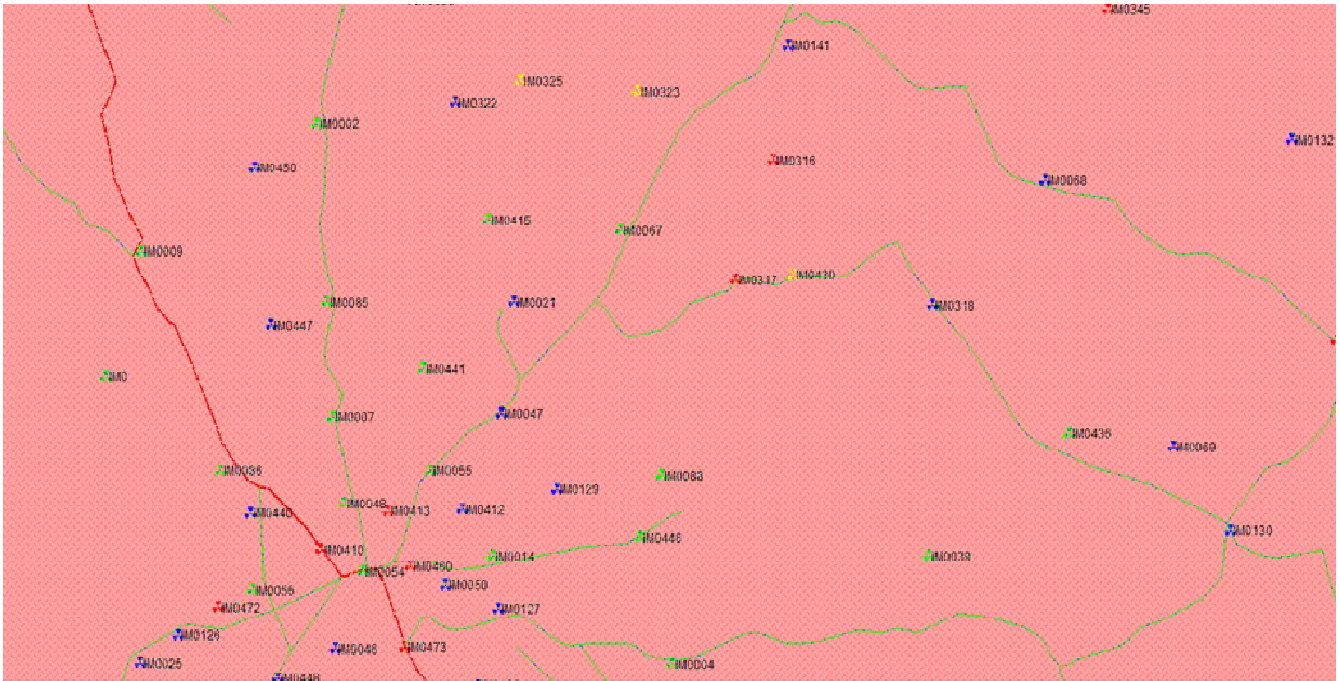


Figure 3: Map showing selected BTS sites in Owerri (Courtesy: Map Info Professional)

### 3.2 Measuring Instruments

The data collation tool consists of test mobile Sony K790 Ericsson phone operated at 95% active mode, Global Positioning System (GPS) receiver set, binocular and digital compass, a laptop equipped with classical node (Ericsson mini-link craft tool) software.

On start up, the software initializes the system by loading a configuration file. This specifies the mode and the frequency of operation. This allows operator independent operation. The equipment used for the azimuths of the antenna was a digital compass and a set of binoculars. All readings were taken using true north. The binoculars were used to get a reasonable distance away from metal structure and still get an accurate azimuth. The tilts were taken using an electronic tilt meter while the height of antenna was measured using tape. Each Sector of the base station has PN code and carrier ID that distinguishes it from the other base station, with the PN code, the base station/Sector reception was made from at each test point was known. This ensures the reference base station was correct. Using the network monitor application of the mobile phone and GPS to determine the distance from base stations, the received signal strength was measured. Readings were taken at intervals of 100m spanning  $0.1\text{km} (100\text{m}) \leq d_i \leq 1.5\text{km} (1500\text{m})$  from each of the base station. Received power were observed to be unstable and fluctuated due to some building obstacles along the line of sight between the BTS and the receiver.

### 3.3 Measurement and Data Collation

Using the network monitor application of the mobile phone and GPS to determine the distance from base stations, the received signal strength measurements were taken. Readings were taken at intervals of 100m from the BTS.

The following procedure for the measurements are enumerated

- i. At the foot of the base station, the GPS was switched on and the point was marked.
- ii. After the four channels of the satellite were launched, the 'Enter' button was pressed.
- iii. The 'page' button was pressed on the map page where the distance is recorded, elevation above sea level and latitude were indicated. At this point, the received signal strength was recorded with the help of the phone.
- iv. Movement was done away from the reference base transceiver station to the next interval (100 meters) for the measurement of its signal strength.
- v. From the BTS and starting from the reference distance of 100m (0.1km), measurements were taken at intervals of 0.1 km for the measurement of its signal strength.
- vi. The above procedure were then repeated up to 1.5 km from the reference BTS

## IV. RESULTS AND ANALYSIS

In this section, the results of the field study carried out are presented. The measured data against their corresponding

transmitter-receiver separation (i.e.  $0.1\text{km} \leq d_i \leq 1.5\text{km}$ ) are presented in Tables 4 and 5 grouped under QPSK and QAM modulation respectively.

Table 4: Measured data from BTS 1 using QPSK`

D (km)	Site ID	Latitude	Longitude	Freq (MHz)	TX power (dBm)	Rx power (dBm)	Antenna Tilt degree ( $^{\circ}$ )	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	-69	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

Table 5: Measured data from BTS 2 using QAM

D (km)	Site ID	Latitude	Longitude	Freq (MHz)	TX power (dBm)	Rx power (dBm)	Antenna Tilt degree ( $^{\circ}$ )	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



From the measured data and considering the distance  $0.1\text{km} \leq d_i \leq 1.5\text{km}$  under study in Tables 4 and 5, it was observed that the received signal strength (Rx Power) decreases as the transmitter to receiver distance increases

4.1 Characterization of QPSK and QAM Modulation Schemes

Tables 4 and 5 show sample data of the measured received signal power obtained using QPSK and QAM modulation techniques respectively along 1.5 km at intervals of 0.1 km (100 meters) from the reference base station.

From the measured data in Tables 4 and 5 above, the signal-to-noise ratio was evaluated using (11) to (13).

4.1.1 Signal-to-Noise Ratio Performance Characterization of QPSK and QAM from Measured Data

Recall that signal-to-noise ratio (SNR) is defined as the ratio of average signal power to average noise power and can be expressed in decibel as (Alumona, 2014).

$$\text{SNR (dB)} = 10\log\text{SNR} \tag{11}$$

Also,

$$\text{SNR} = P_t - L_p(d) - S_r \text{ (Alumona, et al., 2014)} \tag{12}$$

Where  $P_t$  is the transmitted power (hardware capacity) in dBm and  $S_r$  is the receiver sensitivity in dBm (-110dBm)

The operators measure sensitivity, by applying a desired signal and then reduce the signal power until the quality threshold is met.

Schweber, (2009) defines sensitivity specification as indicative of how small a signal the RF stage can accept and still provide a usable signal output.

$L_p$  is the path loss

$L_p = \text{power transmitted } (P_t) - \text{power received } (P_r) \text{ in dBm}$  (Alumona, T. and Nnamani, K. 2015).

$$\text{i.e } L_p \text{ (dBm)} = (P_t) - (P_r) \tag{13}$$

Meanwhile, (13) is used in evaluating the path losses shown in Tables 6 and 7

From Table 6 and for a signal-to-noise ratio estimation of 16.81dB for QPSK modulation for example, it shows the following:

Recall from (12) and (13), i.e

$$\text{SNR} = P_t - L_p(d) - S_r \quad \text{and} \quad L_p = (P_t) - (P_r)$$

It implies

$$\begin{aligned} \text{SNR} &= 19 - 81 - (-110) \\ &= 19 - 81 + 110 \end{aligned}$$

This means,  $\text{SNR(dBm)} = 48\text{dBm}$ .

But from (11),

$$\text{SNR}_{(\text{dB})} = 10\log\text{SNR}$$

$$\text{SNR}_{(\text{dB})} = 10\log(48)$$

$$\text{SNR}_{(\text{dB})} = 16.81\text{dB}$$

Subsequent values of SNRs for specified distances spanning  $0.1\text{km} \leq d_i \leq 1.5\text{km}$  are evaluated using same procedure for QPSK and QAM and presented in Tables 6 and 7 that follows.

Table 6: QPSK Parameters Estimated After SNR Characterization

D (km)	Path Loss (dBm)	Rx power (dBm)	SNR (dBm)	SNR (dB)
0.1	81	-62	48	16.81
0.2	83	-64	46	16.63
0.3	84	-65	45	16.53
0.4	85	-66	44	16.44
0.5	86	-67	43	16.33
0.6	86	-67	43	16.33
0.7	87	-68	42	16.23
0.8	88	-79	41	16.13
0.9	90	-71	39	15.91
1.0	91	-72	38	15.80
1.1	96	-77	33	15.19
1.2	97	-78	32	15.05
1.3	98	-79	31	14.91
1.4	96	-77	33	15.19
1.5	98	-79	31	14.91

Table 7: QAM Parameters estimated after SNR characterization

D (km)	Path Loss (dBm)	Rx power (dBm)	SNR (dBm)	SNR (dB)
0.1	95	-51	59.1	17.72
0.2	97	-53	57.1	17.57
0.3	102	-57	52.1	17.17
0.4	102	-58	52.1	17.17
0.5	109	-65	45.1	16.54
0.6	113	-67	41.1	16.13
0.7	113	-69	41.1	16.13
0.8	114	-70	40.1	16.03
0.9	116	-72	38.1	15.81
1.0	118	-74	36.1	15.58
1.1	123	-79	31.1	14.93
1.2	126	-82	28.1	14.49
1.3	130	-86	24.1	13.80
1.4	132	-88	22.1	13.44
1.5	138	-94	16.1	12.07

From Table 6 and considering the distance  $0.1\text{km} \leq d_i \leq 1.5\text{km}$  under study, the average signal-to-noise ratio for QPSK was given to be the ratio of sum of the SNR values from  $0.1\text{km} \leq d_i \leq 1.5\text{km}$  to the number of times measurement were taken.

$$\text{I.e, Ave. SNR}_{\text{QPSK}} = 238.39/15$$

$$\text{Ave. SNR}_{\text{QPSK}} = 15.89\text{dB.}$$

Also, from Table 7 the average signal to noise ratio for QAM was given to be the ratio of the sum of the SNR values from  $0.1\text{km} \leq d_i \leq 1.5\text{km}$  to the number of times measurement were taken.

$$\text{I.e, Ave. SNR}_{\text{QAM}} = 234.58/15$$

$$\text{Ave. SNR}_{\text{QAM}} = 15.64\text{dB.}$$

Comparing the average SNR values for the two modulation schemes, it was revealed that QPSK offered slightly greater value than QAM for the same distance spanning  $0.1\text{km} \leq d_i \leq 1.5\text{km}$

#### 4.1.2 Bit Error performance Characterization of QPSK

In characterizing the bit error performance of the modulation schemes, their signal to noise ratios were first evaluated. By evaluating the signal-to-noise ratio of QPSK signal for instance, its bit error rate performance in a Guassian channel can be known because the BER performance is a function of the signal to noise ratio estimated from measured data of Table 4

From (14), recall that the bit error performances of QPSK in a Gaussian channel is given as;

$$P_{\text{QPSK\_AWGN}}(\gamma) = Q(\sqrt{\gamma}) \tag{14}$$

But from (12),

$$\text{SNR}(\gamma) = P_t - P_L(d) - S_r$$

Where  $P_t$  is the transmitted power

$P_L$  is the path loss

$S_r$  is the receiver sensitivity

Now given the values of  $P_t$  and  $P_L$  as found in Tables 4 and 6 respectively to be 19dBm and 81dBm, its SNR value can be estimated and put as;

$$\text{SNR} = 19 - 81 + (110\text{dBm})$$

$$48 \text{ dBm}$$

Recall that from (11),

$$\text{SNR}(\text{dB}) = 10\log\text{SNR}$$

$$\text{SNR}(\text{dB}) = 10\log(48)$$

$$\text{SNR}(\text{dB}) = 16.81\text{dB}$$

Having estimated the signal-to-noise ratio, it is then put in the corresponding Matlab equation in (3.8) from which the bit error performance is likewise estimated. Similar procedure was undertaken to also estimate the bit error rate performance of QPSK in a fading channel as shown in Table 8

Table 8: BER Performance Estimation of QPSK in AWGN and Fading Channel

QPSK in AWGN		QPSK in Rayleigh Fading	
D (KM)	BER	D (KM)	BER
0.1	0.000020658	0.1	0.0273
0.2	0.000022713	0.2	0.0276
0.3	0.000023943	0.3	0.0278
0.4	0.000025107	0.4	0.0279
0.5	0.000026607	0.5	0.0281
0.6	0.000026607	0.6	0.0281
0.7	0.000028049	0.7	0.0282
0.8	0.000029570	0.8	0.0284
0.9	0.000033213	0.9	0.0287
1.0	0.000035201	1.0	0.0289
1.1	0.000048608	1.1	0.0300
1.2	0.000052350	1.2	0.0302
1.3	0.000056382	1.3	0.0305
1.4	0.000048608	1.4	0.0300
1.5	0.000056382	1.5	0.0305

#### 4.1.3 Bit Error Performance Characterization of QAM

Also, characterizing the bit error performance of QAM signal, its signal to noise ratios is first evaluated. By evaluating the signal-to-noise ratio, the bit error rate performance in a Guassian channel for instance can be known because the BER performance is a function of the signal to noise ratio estimated from measured data.

From (15), recall that the bit error performances of QAM in a Gaussian channel was given as;

$$P_{\text{QAM}}(\gamma) = \frac{1}{4} Q \left[ \left( \sqrt{\frac{\gamma}{5}} \right) + Q \left( \sqrt[3]{\frac{\gamma}{5}} \right) \right] + \frac{1}{2} Q \left( \frac{\gamma}{5} \right) \tag{15}$$

Also from (12),

$$\text{SNR}(\gamma) = P_t - P_L(d) - S_r$$

Where  $P_t$  is the transmitted power

$P_L$  is the path loss model

$S_r$  is the receiver sensitivity = (-110dBm)

Now given the values of  $P_t$  and  $P_L$  as found in Tables 5 and 7 to be 44.1dBm and 95dBm respectively, its SNR value can be estimated and put as;

$$SNR = 44.1 - 95 - (-110\text{dBm})$$

$$59.10\text{dBm}$$

Recall that from (11),

$$SNR(\text{dB}) = 10\log SNR$$

$$SNR(\text{dB}) = 10\log(59.10)$$

$$SNR(\text{dB}) = 17.72\text{dB}$$

Having estimated the signal-to-noise ratio, it is then put in the corresponding Matlab equation in (3.9) from which the bit error performance is likewise estimated. Similar procedure was undertaken to also estimate the bit error rate performance of QAM in a fading channel as shown in Table 9

Table 9: BER Performance Estimation of QAM in AWGN and Fading Channel

QAM in AWGN		QAM in Rayleigh Fading	
D (KM)	BER	D (KM)	BER
0.1	0.0066	0.1	0.2854
0.2	0.0067	0.2	0.2856
0.3	0.0070	0.3	0.2861
0.4	0.0070	0.4	0.2861

0.5	0.0076	0.5	0.2869
0.6	0.0081	0.6	0.2875
0.7	0.0081	0.7	0.2875
0.8	0.0082	0.8	0.2876
0.9	0.0084	0.9	0.2879
1.0	0.0087	1.0	0.2883
1.1	0.0096	1.1	0.2892
1.2	0.0103	1.2	0.2899
1.3	0.0116	1.3	0.2910
1.4	0.0124	1.4	0.2916
1.5	0.0165	1.5	0.2941

#### 4.1.4 Performance Evaluation of the Modulation Schemes from Field Study

From the field study, the final characterization of the modulation techniques in this case resulted in Table 10. The Table shows estimated bit error performances that were obtained by varying the average path loss obtained using QPSK and QAM modulation techniques as shown in the measured data in Tables 6 and 7 respectively. From these Tables (i.e. 6 and 7), it was observed that as the distance from the base station increased, attenuation increased and the path loss also increased while the received signal strength drops.

Table 10: Bit Error Performances of the Modulation Schemes Studied

QPSK in AWGN		QAM in AWGN		QPSK in Rayleigh Fading		QAM in Rayleigh Fading	
D (KM)	BER	D (KM)	BER	D (KM)	BER	D (KM)	BER
0.1	0.000020658	0.1	0.0066	0.1	0.0273	0.1	0.2854
0.2	0.000022713	0.2	0.0067	0.2	0.0276	0.2	0.2856
0.3	0.000023943	0.3	0.0070	0.3	0.0278	0.3	0.2861
0.4	0.000025107	0.4	0.0070	0.4	0.0279	0.4	0.2861
0.5	0.000026607	0.5	0.0076	0.5	0.0281	0.5	0.2869
0.6	0.000026607	0.6	0.0081	0.6	0.0281	0.6	0.2875
0.7	0.000028049	0.7	0.0081	0.7	0.0282	0.7	0.2875
0.8	0.000029570	0.8	0.0082	0.8	0.0284	0.8	0.2876
0.9	0.000033213	0.9	0.0084	0.9	0.0287	0.9	0.2879
1.0	0.000035201	1.0	0.0087	1.0	0.0289	1.0	0.2883
1.1	0.000048608	1.1	0.0096	1.1	0.0300	1.1	0.2892
1.2	0.000052350	1.2	0.0103	1.2	0.0302	1.2	0.2899
1.3	0.000056382	1.3	0.0116	1.3	0.0305	1.3	0.2910
1.4	0.000048608	1.4	0.0124	1.4	0.0300	1.4	0.2916
1.5	0.000056382	1.5	0.0165	1.5	0.0305	1.5	0.2941

The performance results were obtained by using Matlab simulink for simulation of the bit error performance values (from Table 10) and the estimated SNR values for the two modulation techniques.

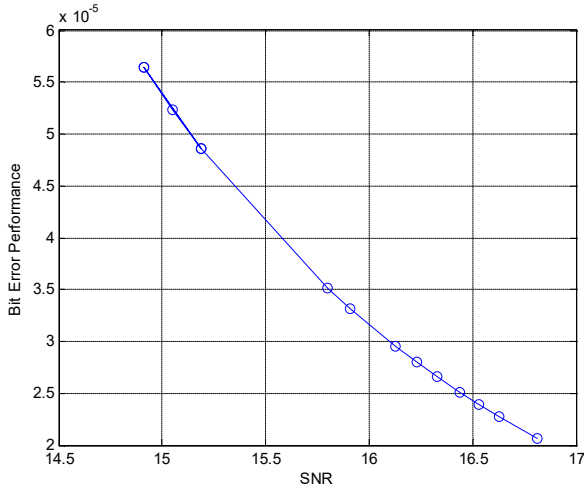


Figure 4: System BER Performance for QPSK under AWGN

Figure 4 shows the System BER Performance for QPSK under AWGN. Here, there is an inverse relationship between the BER and the SNR. It is observed that as the SNR increases, probability of bit error reduces making it less vulnerable to errors under this environment. This behaviour is therefore suited for applications that require higher precision in the reception of data but the available bandwidth is however not utilized because the data rate as well as the throughput reduces.

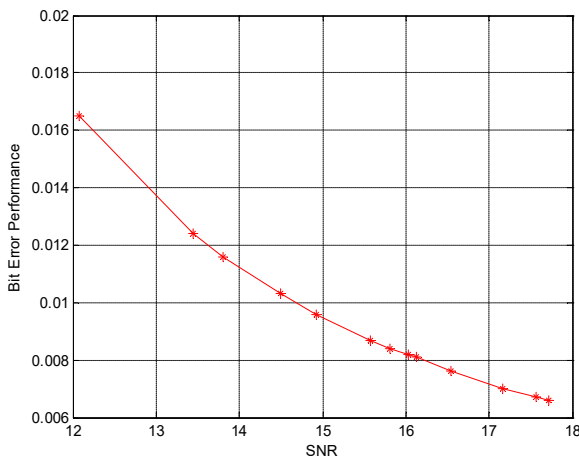


Figure 5: System BER Performance for QAM under AWGN

Also in figure 5, the errors reduce as the SNR increases but there is a considerable reduction in bit errors for figure 4 than in 5. Considering the same distance spanning 0.1 km to 1.5 km, the average SNR for QAM was slightly lesser. This

resulted in an increase in the BER performance when compared to QPSK in figure 4.

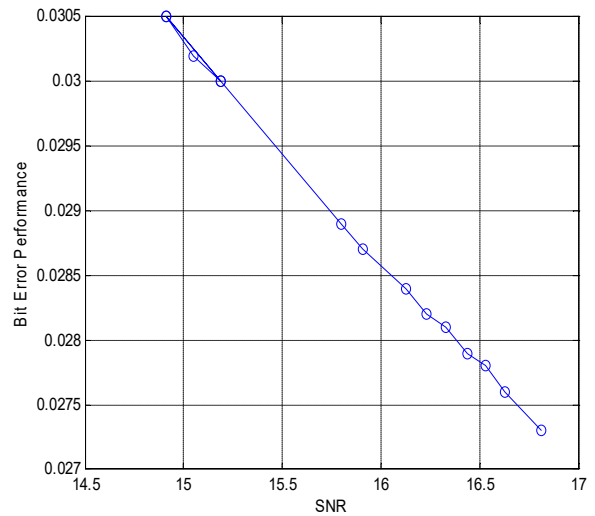


Figure 6: System BER Performance for QPSK under Rayleigh fading

Figure 6 depicts the System BER Performance for QPSK under Rayleigh fading. From the graph, it shows QPSK modulation to be a little unstable under fading. However, errors were found to reduce as the SNR increases.

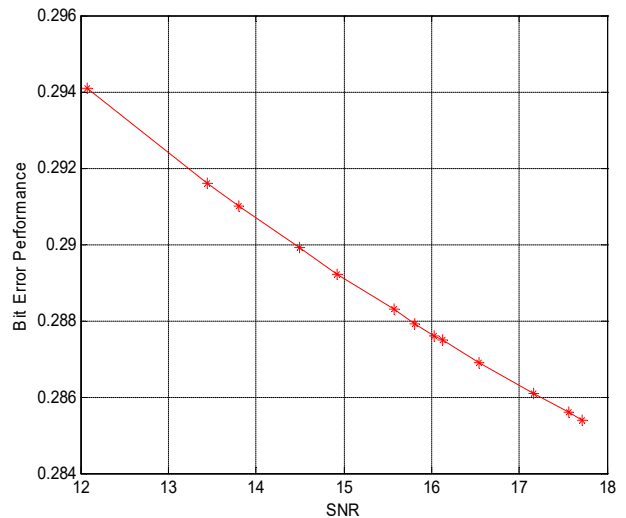


Figure 7: System BER Performance for QAM under Rayleigh fading.

Figure 7 show the bit error performance of QAM modulation under fading and appendix D was used in plotting the graph. It shows a SNR ranging from 12.07dB to 17.72dB. Also, errors reduced as the SNR values increased. However, there was considerable reduction in errors for figure 6 than for figure 7. This can be seen in the combined graph of figures 6 and 7 as shown in figure 8

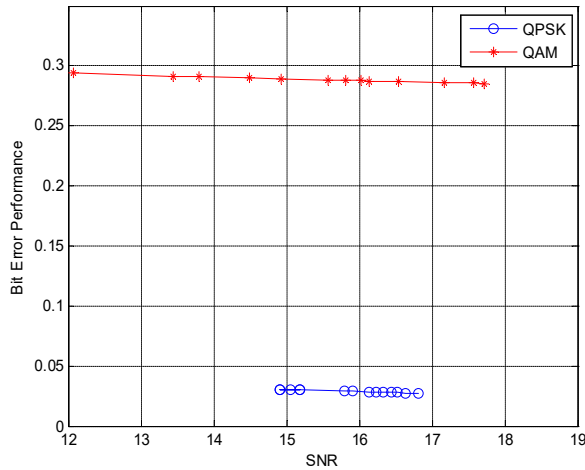


Figure 8: System BER performance of QPSK and QAM under Rayleigh fading

Figure 8 compares the performance of the two modulation schemes under fading and appendix F was used in generating the plots. 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 greater showing its robustness over QAM.

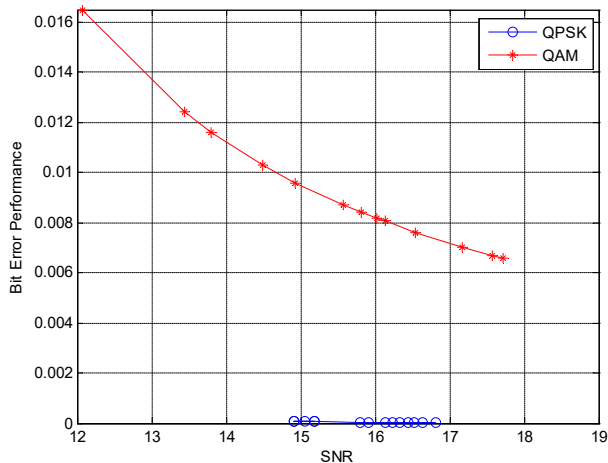


Figure 9: System BER performance of QPSK and QAM under AWGN

Here, figures 4 and 5 were observed closely to obtain the resultant graph in figure 10. The upper graph shows the performance of QAM under 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 that of 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.

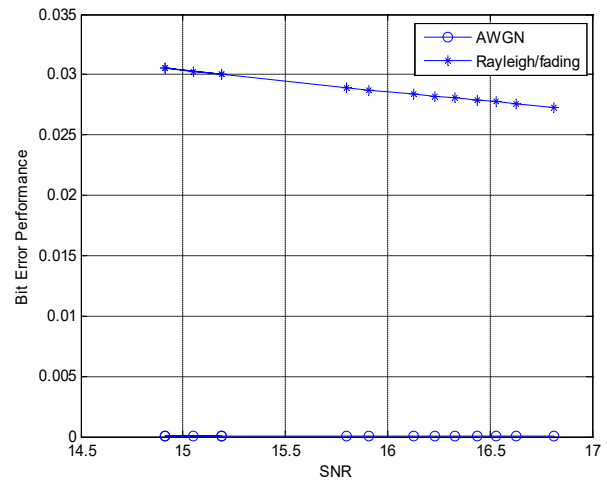


Figure 10: System BER performance of QPSK under AWGN and Rayleigh fading

Figure 10 shows the performance of QPSK modulation under fading in the presence of noise. From this figure 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. Also, comparing the performance of QPSK under AWGN channel and fading channel in figures 5 and 7 respectively, it is seen that the bit error probability in AWGN decreases exponentially with increasing SNR. However, in fading the bit error probability decreases just linearly with increasing SNR. This means 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.

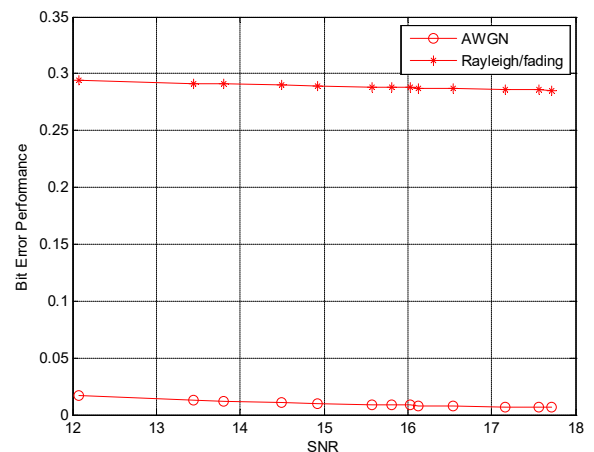


Figure 11: System BER performance of QAM under AWGN and Rayleigh fading

From the result obtained from figure 11, the bit error performance behavior 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.

## V. CONCLUSION

Fundamentally, the study has dealt with the performance evaluation of two modulation techniques: QPSK and QAM to show the one with best data rate capability. The study revealed that modulation scheme implemented in any form of wireless network (W-CDMA inclusive) was found to affect the BER performance which in turn affects the data rate as well as the throughput of the communicating devices. While QAM technique was able to offer much higher and faster data rates because of its lower spectral leakage and pulse width, QPSK gave an improved bit error performance because it had higher SNR values. Also, comparing the performance of both modulation schemes under AWGN channel and fading channel, it is seen that the bit error probability in AWGN decreases exponentially with increasing SNR. However, in fading the bit error probability decreases just linearly with increasing SNR. This means 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.

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