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EFFECTS OF MULTI-LEVEL QAM SCHEME ON CELLULAR RADIO COMMUNICATION SYSTEMS

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Abstract – *Cellular radio transmissions over radio channels are subject to error bursts owing to the presence of deep fades resulting in the distortion, degradation of service quality and outages of cellular radio signals thereby limiting cellular network capacity, bandwidth requirements, and spectral efficiency. Simulation was carried out with randomly generated and uniformly distributed data in the range [0, M-1]. An Adaptive Modulation Scheme with receiver algorithm technique were employed for the estimation of channel variations which automatically selects the modulation levels according to the integrity of the estimated received signal and thereby computes the Bit Error Rate (BER). Simulation results reveal a general trend in BER improvement as the Multi-level (M) increases in value. More so, Multi-level Quadrature Amplitude Modulation (M-QAM) function best at low Energy-to-Noise Ratio (Eb/No), when signal quality degrades and at high Eb/No, when signal quality exceeds or operates at critical limits, implying the effectiveness of the M-QAM scheme to handle Mobile communication signals during deep fades.*

Keywords – Adaptive Modulation, Bit Error Rate, Eb/No, Spectral Efficiency, TDMA.

I. INTRODUCTION

The need to provide communication facilities for the teeming Nigerian populace has motivated the Nigerian Communication Commission (NCC) to issue licenses to several wireless and GSM operators in a bid to secure and empower the telecom industry for the future generation. Some of these operators have made giant strides in a bit to cover as much of the country as their capital and time have allowed them. The wireless and GSM networks are still expanding in Nigeria. More so, the demand for higher data rate services is anticipated to expand steadily and projections indicate that annual budgets will exceed hundreds of billion of dollars (Hethorn, 2000). As a result, the need to meet the challenges posed by this demands in terms of system capacity, quality and performance becomes very necessary. Advancement in cellular system is brought about by the exploration of modulation schemes in wireless systems. Much of the success of wireless standards is due to the contribution of modulation schemes that allow power efficient mobiles that require minimal bandwidth and battery size and provide crisper voice technology (Ali et al, 1999). Cellular radio channels vary rapidly with time owing to the high mobility of users in cellular network systems. Cellular signals take different paths to reach the receiver and by this process experience different speeds of amplitude and phase variations owing to the effects of Doppler spread and tropospheric conditions on the received signals. These time varying channels characterized by multipath fading at times have very good signal-to noise ratio (SNR) and at other times very bad (Chatterjee et al, 2003). Using fixed modulation technique for the system would mean introducing power control whereby the constellation transmitted is unchanged but the transmission level is adapted according to the channel integrity. However, the system power requirements and co-channel interference will both increase and thereby severely curtail system capacity and spectrally insufficient to handle high order modulation format during fades.

Almost all the radio communication operators in Nigeria employ fixed level modulation/demodulation schemes which are not adaptive, and therefore may not always handle the fluctuating signal amplitudes and phases due to unsteady nature of the wireless channels and multiple reflections, which most of the time results in deep fades. To enhance the spectral efficiency of these networks, an adaptive modulation is proposed. The idea is to adaptively change the digital modulation format depending on the channel condition. In this paper, adaptive modulation technique used in a Time Division Multiple Access (TDMA) system for second generation communication networks is investigated. Adaptive modulation based M-QAM, Phase Shift Keying (PSK) and Gaussian Minimum Shift Keying (GMSK) system applied to a communication system in a Rayleigh fading channel environment have been investigated and the BER performance have been compared.

The rest of the paper is organized as follows: Section II describes the system model and the system specifications adopted for the simulation while section III illustrates selection approach for the channel estimation/constellation size. This is followed by the simulation results and discussion in section IV and finally concluded this paper with section V.

II. SYSTEM MODEL

Figure 1 represents the block diagram of an adaptive communication system. The input signal is a randomly generated and uniformly distributed data in the range [0, M-1], where M is the M-ary number defined in the system. The binary data is first encoded using differential encoding to produce low bit-rate streams. Each stream is then modulated using M-QAM modulation technique depending on the receiver's information provided by the channel estimate. These modulated streams are then transmitted through the system transmission channel. The receiver system performs a reverse operation by demodulating and decoding the original information. At the channel estimator, the present estimate which is made up of two parts; the first part is the prediction based on the previous best estimate, and the second part as a correction which depends on the difference between the currently available input and the previous estimate. By this, the channel estimator estimates the quality of the channel and informs the transmitter via the constellation size selector through the feedback loop. The transmitter then decides the modulation format to be employed for the next transmission. In this way the communication system is made to adapt according to the channel integrity. This is to say that the modulation levels are selected automatically by the receiver algorithm system according to the integrity of the channel, so that when the receiver is not in fade the receiver algorithm increase the number of constellation points and as the receiver is in a fade the constellation point is decreased to a value which provide an acceptable BER.

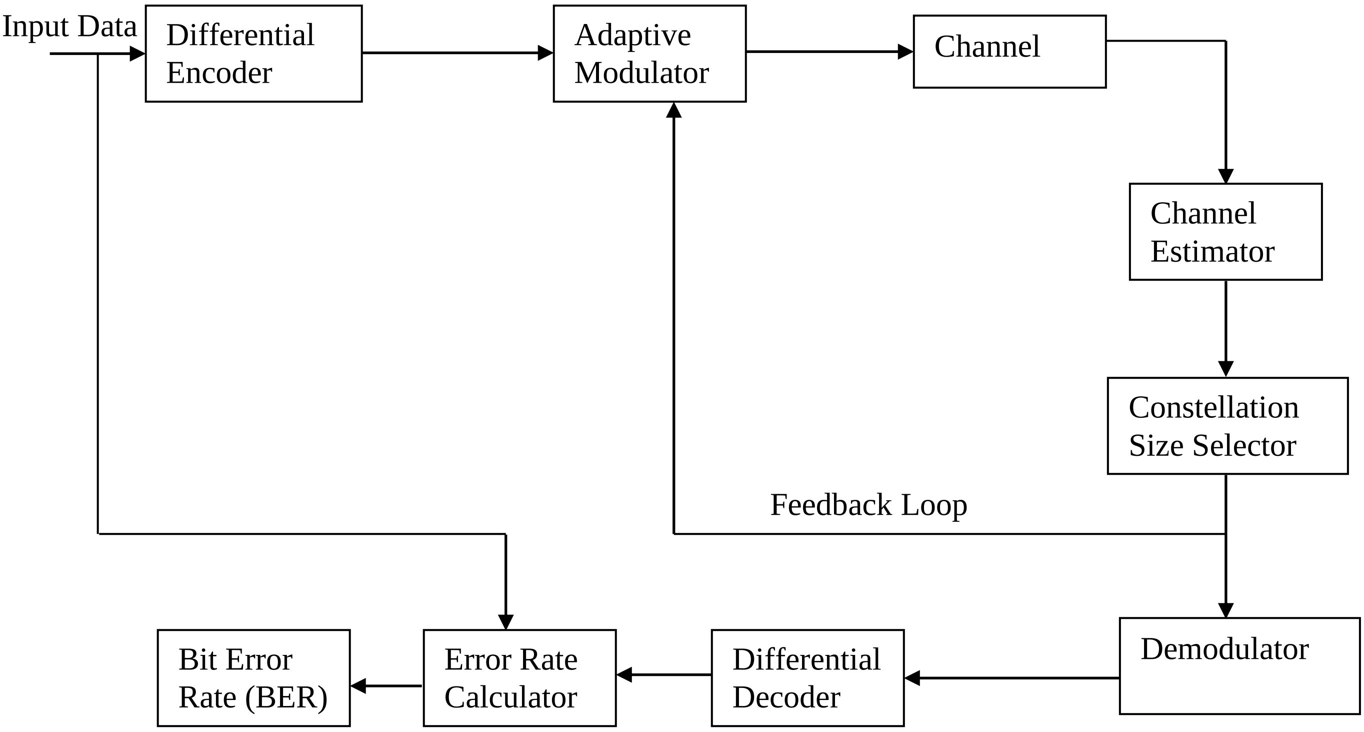

Figure 1: Adaptive Communication System

The system specifications are as tabulated below

TABLE 1: SYSTEM SPECIFICATIONS

Symbol set size	8,16, 32, 64, 256
Symbol period	0.2 s
Sample period	0.01 s
Eb/No (dB)	Steps of 3 dB

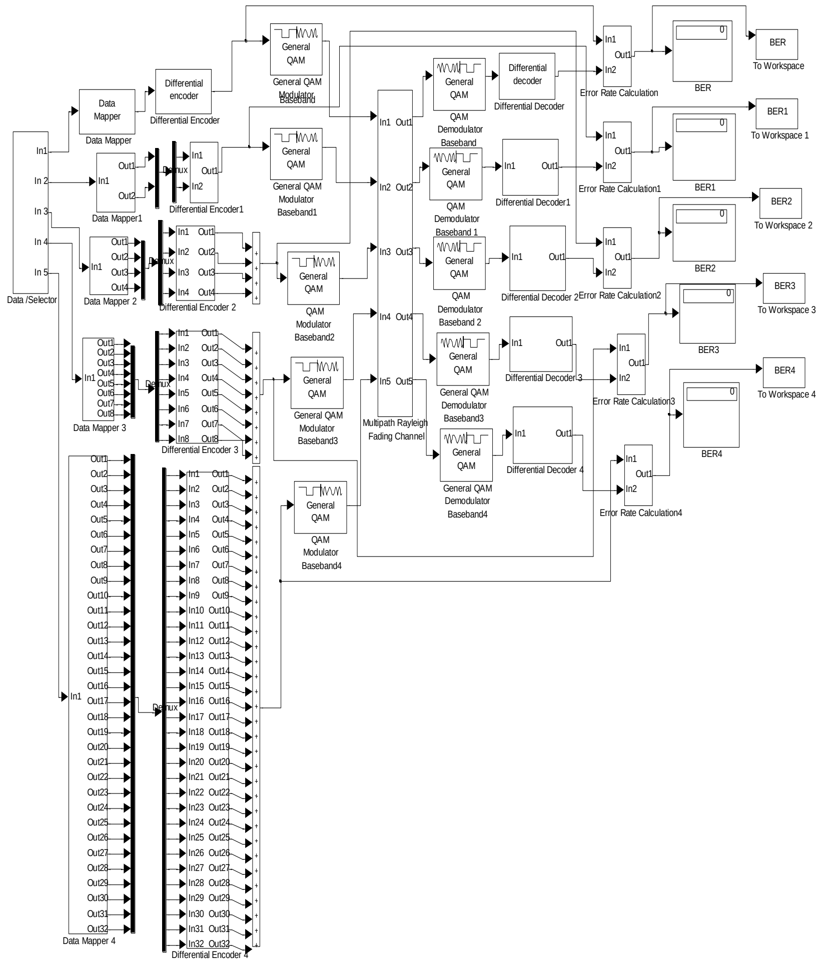

Fig 2 Multi-level Star QAM Communication Model 1

From figure 2, QAM scheme have different BER at higher values of M. The Random-Integer Generator (embedded in the Data/selector block) serves as the source, producing a sequence of integers cascaded with a multiport selector that selects integer according to defined order. The data mapper block maps the received input in the order 0, 1, 3, 7, 5, 4, 6, 2 radially to the next block. The differential encoder encodes the mapped data. The M-QAM Modulator Baseband block modulates the data in complex envelope format, using a Gray-coded constellation ordering. The transmission channel block multiplies the modulated input signal with samples of Rayleigh distributed complex random processes. The M-QAM Demodulator Based and block demodulates the corrupted data. The differential encoder is employed to convert each binary representation to a corresponding integer. The Error Rate Calculation block (labeled Error Rate

Calculation 1 to 4 in this model) compares the demodulated integer which is converted to bit with the original source data also converted to bit, yielding bit error statistics.

III. SELECTION APPROACH FOR THE CHANNEL ESTIMATION/CONSTELLATION SIZE

A Finite State Machine (FSM) which is a representation of an event-driven system is used to implement the decision loop embedded in the constellation size selector block (see figures 1 and 3). In an event-driven system, the system transits from one state (mode) to another prescribed state, provided that the condition defining the change is true. The behaviour of the system is modeled by describing it in terms of transitions among states. The state that is active is determined based on the occurrence of events under certain conditions.

When we simulate this model, the generation of the input event, will cause the activity of the states between Decision Dec_one and Dec_two and then through to Dec_five in figure 4. By default, the loop enters Dec_one and outputs Constellation size 16 abbreviated Const 16. By examining the received estimated signal, if the received r_est. is greater than the th_hold, then it selects Dec_two and outputs Const 32. But if the received r_est is less than the th_hold, then it selects Dec_three and outputs Const 64. However, if the received r_est further degrades so that its value equals th_hold2 due to fading, then Dec_four is selected and outputs const 128. And when the received r_est becomes greater than th_hold2, it selects Dec_five and outputs const 256 but when it is less than th_hold2, it attempts to reset the system by repeating the process and then going round the loop searching for a suitable Dec_ and outputting the appropriate constellation size and in situation where it becomes intolerable for appropriate th_hold, the loop terminates causing communication service failure or signal loss.

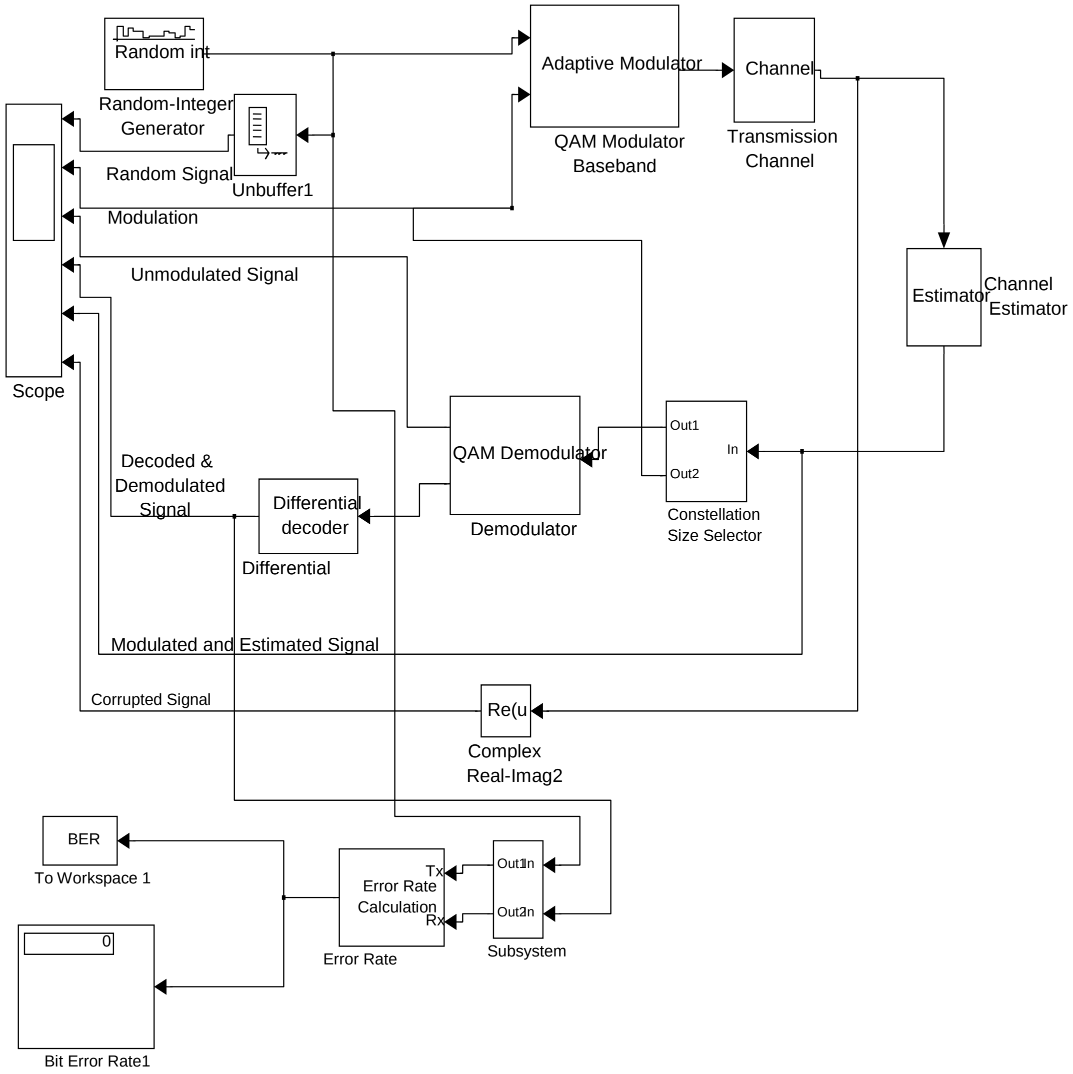

Figure 3: Adaptive Communication Model 2

Model 2 as shown in figure 3, is an adaptive communication system using variable – rate M-QAM scheme. Data flows through this model in same sequence as in figure 2. The Transmission Channel block multiplies the modulated input signal with samples of Rayleigh distributed complex random processes. Channel estimation block uses Kalman tracking filter to track the time-varying received signal. The M-QAM Demodulator Based block demodulates the corrupted data. The Differential encoder is employed to convert each binary representation to a corresponding integer. One Multi-input Scope displays graphical results of the system performance at designated points for comparism with real situation. The Error Rate Calculation block (labeled Error Rate Calculation1 and 2 in this model) compares the demodulated integer data with the original source data, yielding symbol error statistics. Another copy of the Error Rate Calculation library block (labeled Error Rate Calculation2 in this model) compares the demodulated binary data with the binary representations of the source data, yielding bit error statistics.

The algorithm for constellation size selector block in figure 3 is given below;

```
If [r_est = th_hold] {
        Const = 16
        If [re_est > th_hold] {
                Const = 32
                } elseif [r_est < th_hold] {
                        const = 64
                        elseif [r_est = th_hold2]
                                const = 128
                } elseif [r-est > th_hold2]{
                        const = 256
        elseif [r_est < th_hold2]{
                const = 16
                }
        }
 }
```

The decision loop representing the programme structure algorithm is shown above. The decision points in the system (see figure 4) decides the constellation size to select according to the integrity of the estimated received signal. In this figure the connective junction is used as a decision segment that transit to the next states. See figure 4, the Flow Chart for the simulation details illustrating the communication model 2 of figure 3.

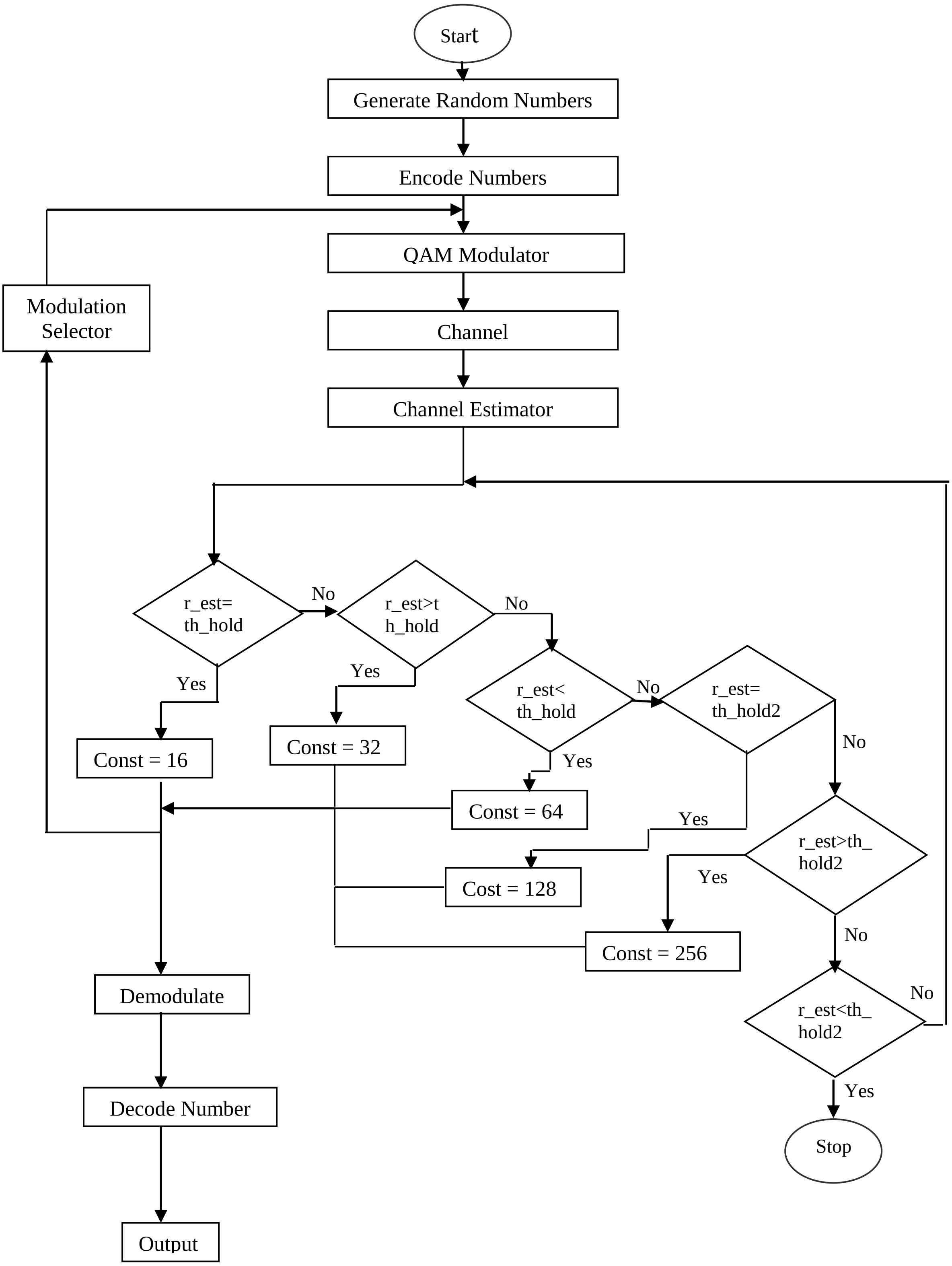

Figure 4: Flow Chart for the Simulation

IV. SIMULATION RESULTS AND DISCUSION

The simulation of the Adaptive communication system in Rayleigh fast fading channel has been carried out for various M-ary QAM schemes, that is 8,16,32,64 and 256 schemes and also for 16-QAM, PSK and GMSK schemes respectively. It considers Eb/No values in the range of 0 dB to 45 dB, in steps of 3 dB.

Figure 5 shows how the BER performance varies under varying Eb/No values (channel conditions) for a number of Star M-QAM schemes. A general BER improvement is seen from the curves as M increases in value and in constellation. 256-QAM scheme show best performance and followed subsequently by 64, 32, 16 and 8 in that order. Comparing with the theoretical Star 16 QAM system, we find that at low Eb/No, the simulation values outperform the theoretical values and at higher values of Eb/No, they all deteriorate but follow similar convergence.

Figure 6 shows the performance of the theoretical and simulated star 16QAM, GMSK and PSK systems in a Rayleigh Multipath Fading Channel. The performance of the theoretical Star 16QAM over the simulated Star 16QAM system at 10^{-1} BER is about 12dB. At 10^{-2} BER, it is about 10dB and at 10^{-3} BER it is zero, that is, it attained the same Eb/No value. Also, as the Eb/No increases, the simulated value improves in BER performance until at 45dB; its performance equals the theoretical figure and begins to improve it.

More so, at 10^{-1} BER, theoretical value is betters than GMSK by about 6dB. At 10^{-2} BER, it is about 14dB and at increased values of BER; GMSK has no comparism because at higher Eb/No, its BER deteriorates. This implies the inadequacies of the GMSK to handle errors or signal bursts at higher Eb/No, owing to the presence of pronounced Rayleigh fades. By this, Telecom Operators, that uses GMSK Scheme, may likely have difficulties meeting users demand. Also, radio signal outages might be experienced and adequate power control system must be built into the network to make the system function at optimal value.

In the case of PSK, at 10^{-1} BER, theoretical QAM value is better than PSK by about 4dB. At 10^{-2} BER, it is better than PSK by about 2 dB and at increased Eb/No values, PSK deteriorates. A similar trend with the GMSK is observed. This implies that Telecom operators in Nigeria using PSK for their Uplink/Downlink transmission would have similar consequences as the GMSK with little or no significant advantage over the other.

In comparing the simulation results of Star 16 QAM, GMSK and PSK, we find that, at low Eb/No, that is 5 dB; Star 16 QAM has the same BER with theoretical star 16 QAM and better BER than GMSK and PSK. As this value increases, specifically at 7 dB and 10 dB, the

BERs equal PSK and GMSK respectively. Further than these, Star 16 QAM deteriorates at higher values of Eb/No until at 35dB and upward, it outperforms the PSK and GMSK. These results or finding reveal to us the capability of the QAM to function best at low, when signal quality degrades and at high Eb/No, when signal quality exceed or operates at critical limits. This implies the effectiveness of the QAM schemes to adapt their rate relative to the channel integrity.

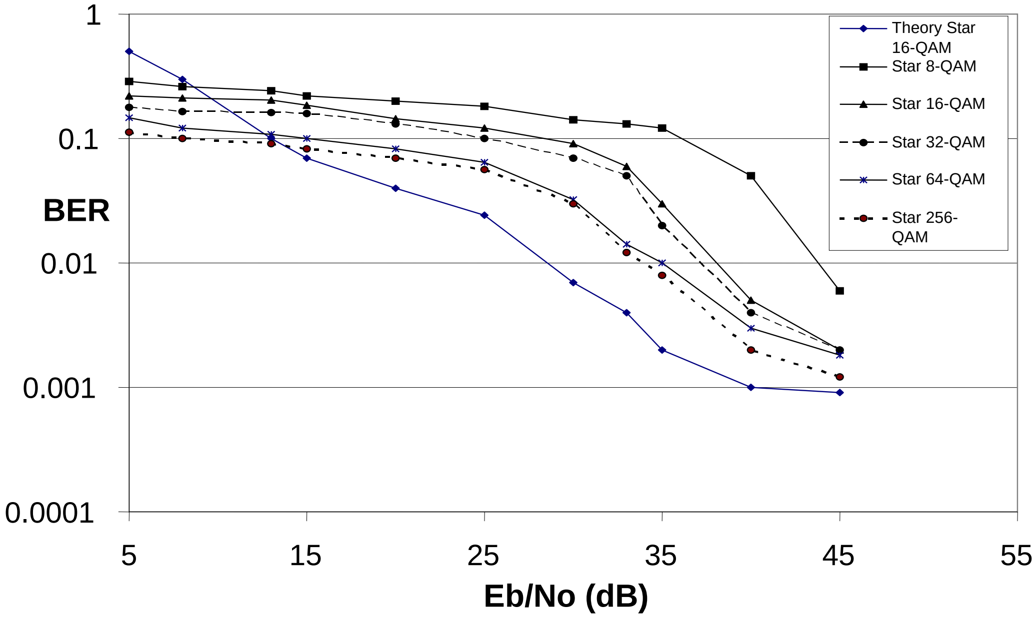

Figure 5: Performance of BER for various Star M-QAM.

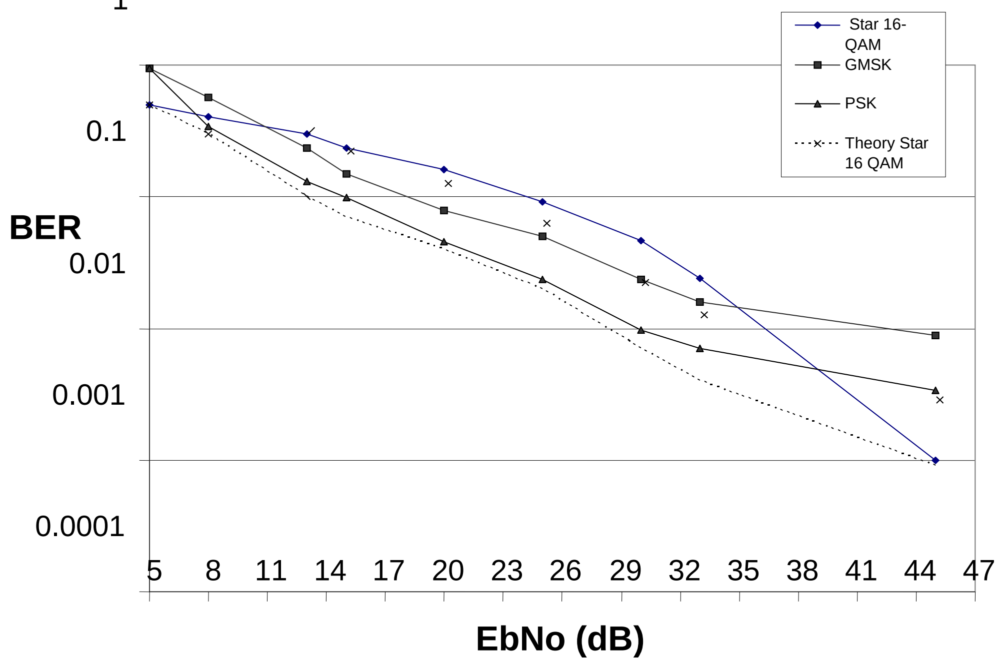

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Figure 6: BER Comparison of Star QAM, GMSK and PSK over Eb/No (dB)

V. CONCLUSION

In this work, adaptive modulation based TDMA system has been studied in Rayleigh fast fading environment. As transmission between Base Station (BS) and Mobile Station (MS) or vice versa, continue, the presence of fades cause considerable increases and decreases in the received signal strength to the point of disrupting communication services. Our result of the adaptive system clearly indicates that without sacrificing the BER performance, the system capacity, quality and performance could be enhanced by the dynamic rate of the modulation format according to the varying channel conditions.

More so, it reveals the capability of the Star M-QAM to function best at low Eb/No when signal quality degrades and at high Eb/No when signal quality exceed or operates at critical limits. This implies the effectiveness of QAM schemes to adapt their rates relative to the channel integrity and thereby improving the spectral efficiency of the cellular radio communication.

On this note, Telecom Operators in Nigeria are advised to embrace and employ QAM Scheme for their network operations. Since more users are demanding greater capacity and diverse services with more kinds of traffic requirements and more flexible transmission methods, Operators are to invest in equipment that does more by providing wide range of functions with high efficient and durable quality of service. This certainly will cater for the reliability and availability requirements of wireless signals in Nigeria.

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