BER Performance of OFDM System with Adaptive Modulation

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***Abstract*-** *Orthogonal Frequency Division Multiplexing (OFDM) is a multicarrier transmission scheme. OFDM transmits data by using a large number of narrow bandwidth carriers. In an OFDM transmission system, each subcarrier is attenuated individually under the frequency-selective and fast fading channel if the same fixed transmission scheme is used for all OFDM subcarriers thus it results in highest attenuation and hence poor performance. The purpose of this paper is to introduce the adaptive modulation to get an understanding of the differences between fixed and adaptive modulations schemes. In this work adaptive modulation is implemented by dividing whole subcarriers into blocks of adjacent subcarriers. Based on calculated average instantaneous signal to noise (SNR) same modulation scheme is applied to all subcarriers of same block. Here average bit error rate (BER) performance of OFDM system under fixed modulation and adaptive modulation is observed. Average BER performance of these modulation techniques is observed with various inverse fast Fourier transform (IFFT) size and using simpler adaptive quadrature amplitude modulation (QAM) schemes. The simulation results show that BER performance of OFDM system using adaptive modulation is better than fixed modulation*.

Keywords- Adaptive modulation, orthogonal frequency division multiplexing (OFDM), bit error rate (BER).

I. INTRODUCTION

OFDM based wireless systems are spectrally efficient, but they are vulnerable to inter carrier interference (ICI). In a wide area scenario, users will experience varying signal strength due to different individual path loss and also varying amount of Doppler spread because of their independent velocities. Therefore, the ICI among users will vary over a wide range. Adaptive sub carrier bandwidth (ASB) along with adaptive bit loading mitigates ICI in such conditions, which will keep receivers simple while maintaining maximum throughput in each situation. [1] Adaptive modulation is introduced by presenting some of the simpler adaptive quadrature amplitude modulation schemes and their performance for both perfectly known and predicted channels.[2]

A sub-band spreading technique for adaptive modulation (AM) in OFDM systems reduces signalling overheads and averages frequency selective fading channels causing different signal-to-noise ratio (SNR) values for subcarriers in each subband. [3]The adaptive code-rate and modulation OFDM system using punctured convolution code and various constellation size maximizes total capacity and adapt proper service for each user according to channel conditions and transmit power while maintaining transmission's quality of service (QoS) at the receiver.[4] The system throughput of an OFDM system is enhanced by adding turbo coding and adaptive modulation (AD). Each OFDM block is individually modulated according to channel state information acquired during the previous burst.[5]

This paper is organized as follows: The OFDM system implementation is described in Section 2. Block diagram of adaptive modulation is presented in Section 3.The adaptation procedure and switching thresholds used in the simulations are presented in Section 4.Simulation results of the adaptive modulation systems is discussed in Section 5.Finally conclusions are made in section 6.

II. OFDM SYSTEM

The concept of OFDM is the Orthogonality of subcarriers. When sine wave is multiplied by another of different frequency then area under sine wave multiplied by its own harmonic is always zero.

If n and m are frequencies of sine waves then multiplied sine waves is,

$$f(t) = \sin nwt \times \sin mwt \quad (1)$$

By simple trigonometric rule

$$f(t) - \frac{1}{2}\cos(n - m)wt - \frac{1}{2}\cos(n + m)wt \quad (2)$$

These two components are each a simusoid, so the integral is equal to zero over one period.

$$f(t) = \frac{1}{2}\int \cos(n - m)wt - \frac{1}{2}\int \cos(n + m)wt \quad (3)$$

when above integrals are integrated over range 0-2π ,then

$$f(t) = 0 - 0 \quad (4)$$

We conclude that when we multiply a sinusoid of frequency n by sine wave of frequency m then area under the product is zero.

OFDM can be implemented by FFT and IFFT. Let $X = [X_0, X_1, X_2 \ldots\ldots X_{N-1}]^T$ denote input data after serial to parallel converter. The complex baseband OFDM signal in time domain is given by

$$x(t) = \frac{1}{N}\sum_{n=0}^{N-1} X_n e^{j2\pi n\Delta f t}, 0 \le t \le NT \quad (5)$$

Where T is data period and NT is OFDM symbol duration and $\Delta f = \frac{1}{NT}$ is the subcarrier spacing.

In adaptive OFDM transmission, all subcarriers in an AOFDM symbol are split into blocks of adjacent subcarriers. The same modulation is employed for all subcarriers of the same block [1][2]. The choice of the modulations to be used by the transmitter for its next OFDM symbol is determined by the channel quality estimate of the receiver based on the current OFDM symbol. In this simulation the instantaneous SNR of the subcarriers is measured at the receiver. The channels quality varies across the different subcarriers for frequency selective channels. The received signal at any subcarrier can be expressed as:

$$R_n = H_n X_n + W_n \quad (6)$$

Where H_n is the channel coefficient at any subcarrier, X_n is the transmitted symbol and W_n is the Gaussian noise sample. So the instantaneous SNR can be calculated using :

$$SNR = \frac{H_n^2}{N_0} \quad (7)$$

where N_0 is the noise variance

For a real signal, x(n), sampled at fs Hz, the noise bandwidth will be half the sampling rate. Therefore, we find the average power of the noise by multiplying the power spectral density of the noise by the noise bandwidth:

$$N_0 = \frac{n_0 f_s}{2} \quad (8)$$

n_0 - One sided power spectral density of noise in W/Hz.

III. BLOCK DIAGRAM

The block diagram of this system is shown in Fig1. The channel estimation and modulation selection are done at the receiver side and the information is sent to the transmitter using a feedback channel [6]. In this modulation the adaptation is done frame by frame. The channel estimator is used to estimate the instantaneous SNR of the received signal. Based on the instantaneous SNR calculated, the best modulation will be chosen for the next transmission frame. This task is done by the modulation selector block. At the transmitter the adaptive modulator block consists of different modulators which are used to provide different modulation modulations. The switching between these modulators will depend on the instantaneous SNR.

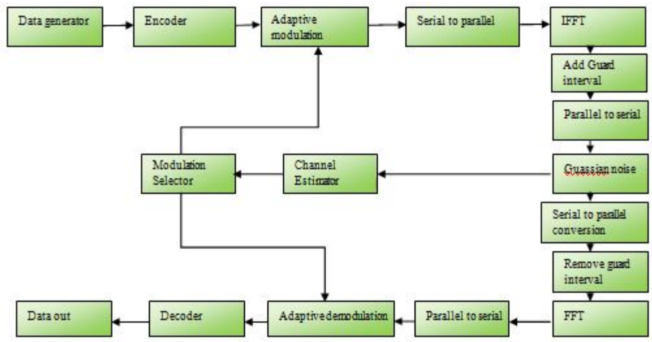

Figure. 1. Block diagram of Adaptive OFDM System

IV. ADAPTIVE MODULATION ALGORITHM

The following figure shows instantaneous SNR of received symbol for fixed MQAM techniques . It shows that when fixed 64QAM is applied to system the instantaneous SNR is less than 0.2 dB. Similarly when fixed 32QAM is applied to system the instantaneous SNR is in the range 0.2dB to 0.5dB. Also for 16QAM instantaneous SNR is in the range 0.5dB to 0.75dB and for 4QAM instantaneous SNR is in the range 1.1dB to 1.75dB. For fixed 2QAM ,system response shows that , instantaneous SNR is more than 1.75dB.

Hence, it is clear that for higher modulation instantaneous SNR is less as compare to lower modulation and therefore 64QAM is utilized when instantaneous SNR is greater than 1.75dB.Hence, from these instantaneous SNR values switching threshold are made for adaptive modulation as shown in Table 1. When instantaneous SNR is good then higher modulation scheme is applied and vice versa

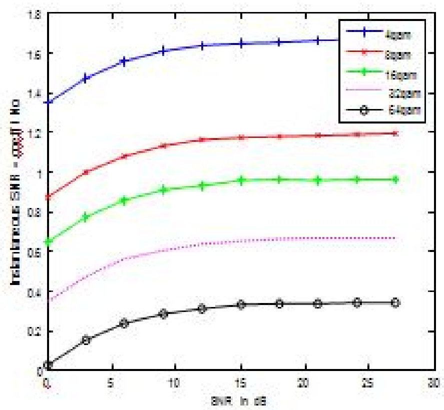

Figure. 2. Instantaneous SNR of fixed modulation

The switching threshold for activating different modulations can be determined by extensive simulation of the fixed modulation system. the switching algorithm used for the adaptive modulation is presented in Table 1.

TABLE 1. SWITCHING THRESHOLD FOR ADAPTIVE MODULATION

Threshold	Modulation
1.1dB≤SNR< 1.75dB	32QAM
0.75dB≤SNR≤1.1dB	16QAM
0.5dB≤SNR≤0.75dB	8 QAM
0.2dB≤SNR≤0.5dB	4 QAM
SNR≤0.2 dB	2 QAM
SNR≥ 1.75dB	64QAM

Following figure shows flowchart of Adpative Modulation. It takes OFDM symbol as an input to AWGN Channel receiver. This adds White Guassian noise into OFDM symbol. Then, instantaneous SNR of received symbol is calculated. This instantaneous SNR is compared with the switching threshold values , as shown in Table 1, where it checks the each threshold value against respective modulation scheme.
Once it found appropriate switching threshold range, It select respect modulation scheme for next OFDM symbol.

This selected modulation scheme information goes simultaneously to transmitter and receiver. In this way, flow-chart defines selection of modulation scheme based upon instantaneous SNR of received symbol.

In the next section – ‘V Simulation Results and Discussion’, we will analyse the BER performance of adaptive modulation based upon switching threshold values.

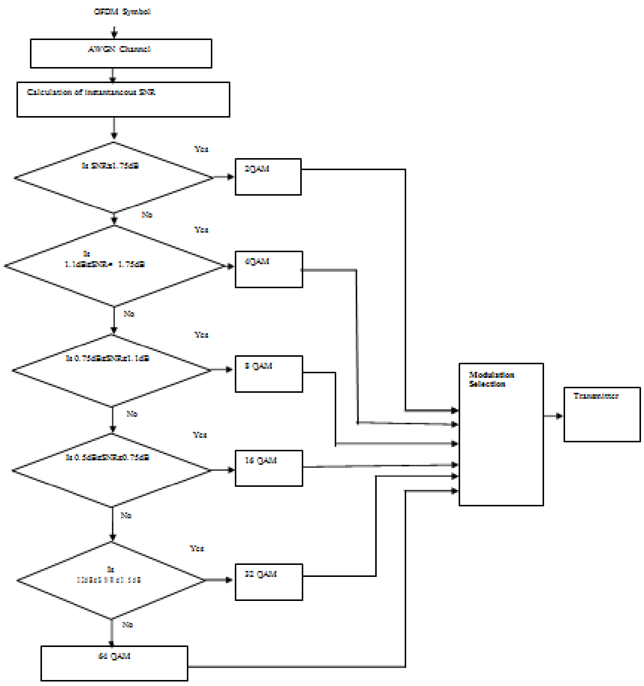

Figure. 3 . Adaptive Modulation flow-chart

V. SIMULATION RESULTS AND DISCUSSION

In this simulation, the performance of adaptive modulation is investigated in terms of BER performance. To highlight the advantages of adaptive modulation comparison is made with fixed modulation system under various IFFT size. BER is calculated using following formula

$$BER = \frac{Number\ of\ error\ bits\ per\ transmission}{Number\ of\ bits\ per\ transmission}$$

Here IFFT size is denoted by N. For IFFT size N=64, 128, 256,512 ,1024,2048 BER performance has shown below.

The average BER for 2QAM is 0.244035 for IFFT size N=64 and it is 0.043715996 for N=2048.

For 64 QAM the average BER is 0.974035 for IFFT size N=64 and it is 0.961319 for N=2048. For adaptive modulation the average BER is 0.979106 for IFFT size N=64 and it is 0.29479604 for N=2048. For higher IFFT size adaptive modulation has low average BER as compared to higher MQAM techniques such as 64QAM, 32QAM, 16QAM

TABLE 2.
AVERAGE BER OF 2QAM

SNR	N-64	N-128	N-256	N-512	N-1024	N-2048
0	0.31393	0.20536	0.19384	0.18344	0.1769	0.17722
3	0.31179	0.13571	0.12116	0.11478	0.11667	0.11359
6	0.26143	0.07875	0.073839	0.07183	0.066696	0.070859
9	0.23464	0.044821	0.036071	0.035312	0.039063	0.034933
12	0.22571	0.023393	0.020893	0.018304	0.019754	0.018817
15	0.22571	0.0125	0.009375	0.010089	0.0098661	0.01077
18	0.225	0.0067857	0.0055357	0.0050446	0.0053348	0.0059487
21	0.21893	0.0030357	0.0028571	0.0033482	0.003192	0.002433
24	0.20821	0.0019643	0.0011607	0.0012054	0.0011161	0.0016406
27	0.215	0.00089286	0.00071429	0.00075893	0.00064732	0.00094866
AVGBER	**0.244035**	**0.051321256**	**0.046544579**	**0.044411213**	**0.043923932**	**0.043715996**

TABLE 3.
AVERAGE BER OF 4QAM

SNR	N-64	N-128	N-256	N-512	N-1024	N-2048
0	0.60714	0.47	0.44063	0.4258	0.41717	0.41816
3	0.54107	0.34786	0.32545	0.32129	0.31049	0.30884
6	0.49464	0.22929	0.21536	0.20563	0.20333	0.19922
9	0.47036	0.1325	0.13259	0.11692	0.11692	0.12258
12	0.43179	0.079464	0.071339	0.070223	0.064911	0.061864
15	0.4225	0.038036	0.04125	0.04067	0.037835	0.037835
18	0.425	0.017857	0.020357	0.020045	0.017299	0.017377
21	0.44607	0.011429	0.010446	0.0098661	0.0079688	0.0087612
24	0.40071	0.0046429	0.0052679	0.0046429	0.0044643	0.0038839
27	0.41071	0.0014286	0.0028571	0.0026339	0.0020982	0.0023772
AVGBER	**0.464999**	**0.13325075**	**0.1265547**	**0.12177209**	**0.11824863**	**0.11808983**

TABLE 4.
AVERAGE BER OF 16QAM

SNR	N-64	N-128	N-256	N-512	N-1024	N-2048
0	0.92036	0.90625	0.90348	0.90415	0.89993	0.89892
3	0.90964	0.88768	0.88277	0.8858	0.88286	0.88429
6	0.9025	0.86161	0.86241	0.8646	0.86185	0.85919
9	0.88679	0.84929	0.84089	0.83513	0.83621	0.83468
12	0.8725	0.82268	0.80804	0.81415	0.8098	0.80746
15	0.86214	0.82393	0.79759	0.78871	0.78886	0.78806
18	0.86643	0.79179	0.77563	0.77089	0.77067	0.77169
21	0.87679	0.79143	0.77634	0.76924	0.76319	0.76133
24	0.86429	0.78536	0.76125	0.76138	0.75955	0.75475
27	0.86036	0.785	0.77375	0.75607	0.75473	0.7552
AVG BER	**0.88218**	**0.830502**	**0.818215**	**0.815012**	**0.812765**	**0.811557**

TABLE 5 .
AVERAGE BER OF 32QAM

SNR	N-64	N-128	N-256	N-512	N-1024	N-2048
0	0.95643	0.95929	0.96	0.95763	0.95696	0.95548
3	0.95857	0.95	0.94741	0.94817	0.95132	0.94881
6	0.94893	0.94571	0.9442	0.94353	0.94116	0.94155
9	0.94821	0.93643	0.93518	0.93125	0.92973	0.93081
12	0.94143	0.9225	0.91777	0.91487	0.91629	0.91624
15	0.9375	0.91143	0.91045	0.90598	0.90652	0.90311
18	0.93929	0.91089	0.89732	0.89482	0.89357	0.89344
21	0.92	0.89982	0.89071	0.88621	0.88585	0.88484
24	0.92821	0.89357	0.88741	0.88371	0.88292	0.88296
27	0.93929	0.89339	0.88446	0.8808	0.87971	0.87821
AVG	**0.941**	**0.922**	**0.917**	**0.914**	**0.914**	**0.913**

For IFFT size N- 64, 128, 256, 512, 1024 ,2048 theSNR vs BER graph has shown below for all MQAM techniques and adaptive modulation. At SNR=0 dB and N-2048, 2QAM has BER 0.17722 and 4QAM has BER 0.41816, for 8QAM BER is 0.77773. At SNR=0 dB and N-2048 16QAM has BER 0.89892 and 32QAM hasBER 0.95548, for 64QAM BER is 0.97994. Thus it has been observed that as SNR varies from 0 to 27 dB , for lower modulation techniques such as 2QAM

BER	786	303	491	697	403	545

TABLE 6.
AVERAGE BER OF 64QAM

SNR	N-64	N-128	N-256	N-512	N-1024	N-2048
0	0.98643	0.98232	0.98214	0.98076	0.97969	0.97994
3	0.98107	0.97679	0.98089	0.97817	0.97857	0.97873
6	0.97607	0.97607	0.97545	0.97451	0.97603	0.97483
9	0.97929	0.97518	0.9733	0.97165	0.97181	0.97046
12	0.97357	0.9675	0.96884	0.96629	0.96438	0.96565
15	0.97071	0.9625	0.95991	0.96031	0.96058	0.95848
18	0.97071	0.95768	0.95036	0.95585	0.95377	0.95206
21	0.96679	0.9575	0.94911	0.94911	0.94833	0.94708
24	0.96857	0.95464	0.94527	0.9429	0.94371	0.94433
27	0.96714	0.94625	0.94179	0.93665	0.94254	0.94163
AVG BER	**0.974035**	**0.965643**	**0.962706**	**0.96162**	**0.961941**	**0.961319**

TABLE 7.
AVERAGE BER OF ADAPTIVE MODULATION

SNR	N-64	N-128	N-256	N-512	N-1024	N-2048
0	0.98143	0.98054	0.98214	0.98299	0.98257	0.98273
3	0.37964	0.31214	0.32196	0.31987	0.31569	0.31433
6	0.355	0.25232	0.25098	0.25844	0.25574	0.25615
9	0.29571	0.18625	0.19009	0.19335	0.18998	0.1908
12	0.26107	0.1275	0.12562	0.12768	0.12661	0.13009
15	0.24893	0.069643	0.075982	0.076696	0.076071	0.082065
18	0.22679	0.037679	0.040089	0.040938	0.046607	0.04115
21	0.24321	0.020714	0.021339	0.022187	0.023571	0.024096
24	0.23107	0.011071	0.010714	0.012277	0.012679	0.01394
27	0.21786	0.0046429	0.0063393	0.0068304	0.0061607	0.0062054
AVG BER	**0.344071**	**0.20024999**	**0.20252533**	**0.20412584**	**0.20356787**	**0.20415564**

4QAM,8QAM has less BER as compared to higher modulation such as 32QAM,64QAM. Graphical results matches with theoretical results for high value of IFFT

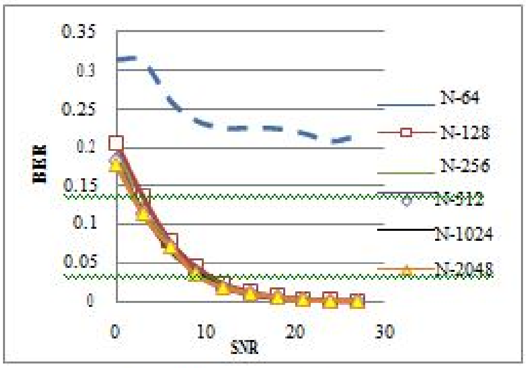

Figure 4.BER vs SNR graph of 2QAM

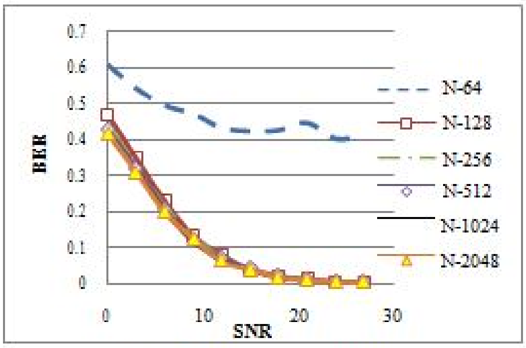

Figure 5. BER vs SNR graph of 4QAM

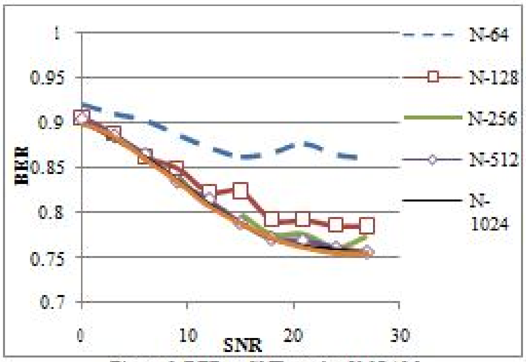

Figure 6. BER vs SNR graph of 16QAM

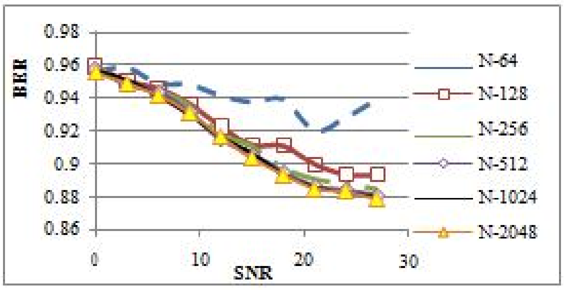

Figure 7. BER vs SNR graph of 32QAM

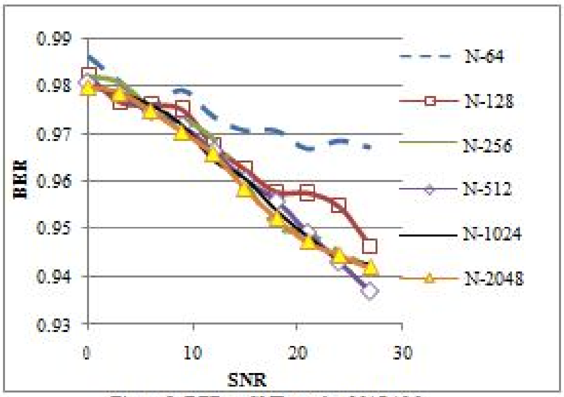

Figure 8. BER vs SNR graph of 64QAM

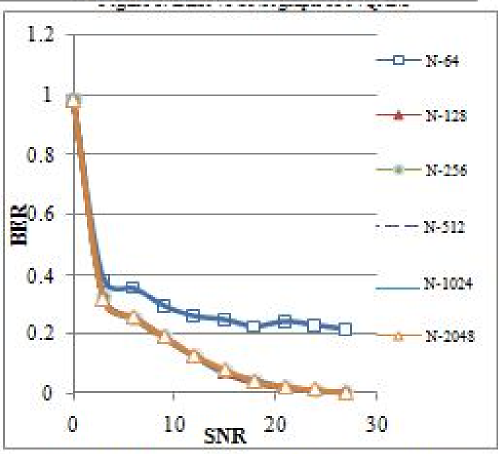

Figure 9. BER vs SNR graph of Adaptive modulation

Following results shows that at IFFT size N-1024 adaptive modulation has average BER 0.36013139 and 64QAM has 0.961941 ,for 32QAM average BER is 0.914403 and 2QAM has 0.043923932 average BER.

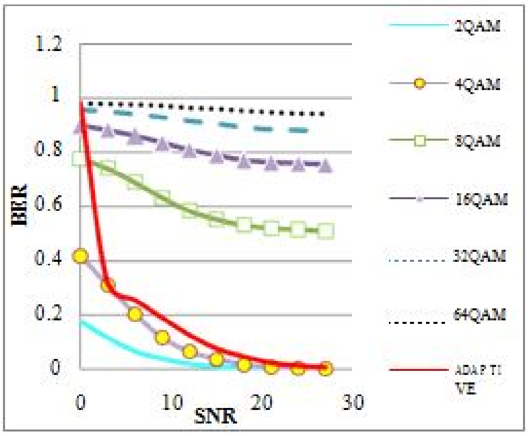

Figure10. BER vs SNR graph of adaptive and fixed modulation at N-1024

To further enhance adavantage of adaptive modulation over fixed modulation average BER comparison is made with IFFT size N= 2048. Following analysis shows that average BER of adaptive modulation is still less at higher IFFT size but with fixed modulation average BER remains still high remain..

TABLE 9.
AVERAGE BER OF ADAPTIVE & FIXED MODULATION AT N-1024&2048

Modulation	N-1024	N-2048
2QAM	0.043924	0.043716
4QAM	0.118249	0.11809
8QAM	0.605454	0.602622
16QAM	0.812765	0.811557
32QAM	0.914403	0.913545
64QAM	0.961941	0.961319
ADAPTIVE	0.203568	0.204156

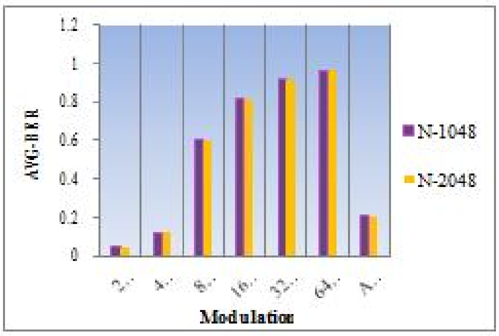

Figure 11. Average BER comparison between adaptive and fixed modulation

In QAM modulation technique, by moving to a higher- order constellation, it is possible to transmit more bits per symbol. However, if the mean energy of the constellation is to remain the same , the points must be closer together and are thus more susceptible to noise and other corruption; this results in a higher bit error rate and so higher-order QAM can deliver more data less reliably than lower-order QAM, for constant mean constellation energy. In order for the OFDM carriers to remain orthogonal to each other, the channel response must be approximately flat over the bandwidth of each subcarrier For OFDM to operate effectively, the frequency response must be approximately flat over the bandwidth of a subcarrier. If insufficient subcarriers are used then the frequency response changes too rapidly, leading to degraded performance.

VI. CONCLUSION

In adaptive modulation, modulation rate changes based upon value of an instantaneous SNR. The BER performance comparison between fixed and adaptive modulation shows that BER performance for all modulation techniques is better, when IFFT size is greater than 512. For all values of IFFT sizes, average BER of Adaptive modulation is approximately 0.203568 and for higher order fixed modulation it is approximately 0.913545 .Hence, it concludes that BER performance of adaptive modulation is better than fixed modulation with the cost of more execution time.

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