Improvement of Quality of Service (QoS) in MISO-OFDM Systems Using Superposition Based Adaptive Modulation (SPAM) and Space Frequency Block Coding (SFBC) Technique

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***Abstract*— 4G based wireless communication systems require high data rate with high QoS with minimal system complexity. In wireless environment, as the effect of multipath fading increases, Bit Error Rate (BER) also increases. To offer high data rate, the bandwidth has to be increased which is a limited resource. The best possible solution for obtaining high data rate is to combine Multi Input Multi Output (MIMO) with OFDM. To ameliorate the performance of MIMO-OFDM systems over multipath fading channels, we use the concept of SFBC which retrieves the orthogonality property of OFDM signals in frequency selective fading channels. In frequency selective fading environment, adaptive modulation gives better performance than fixed modulated systems but with increased decoding complexity. Adaptive modulation implemented with SPAM offers less decoding complexity. Adaptive modulation combined with diversity schemes still improves the reliability of the system. In this paper, SPAM based SFBC is proposed with OFDM to give better performance with less decoding complexity. From the Simulation results we can conclude that proposed system will have better performance compared to fixed modulated systems.**

Keyword- Orthogonal Transmit Diversity (OTD), Space Time Block Codes (STBC), Space Time Trellis Codes (STTC)

I. INTRODUCTION

The consequence of multipath fading and interferences detoriates the channel conditions which affects reliable data transmission. The effect of frequency selective fading enhances Inter Symbol Interference (ISI). The major hindrance of single carrier systems is the necessity of using complex equalizers to combat the effect of ISI, as a result receiver complexity increases. OFDM overcomes this drawback by transforming frequency selective fading channels to many non-frequency selective fading sub-channels. Hence, one tap equalization is sufficient which makes receiver design simple. Compared to single carrier systems, OFDM systems have longer symbol duration as a result ISI effects only the initial part of the OFDM symbol. This can also be removed by introducing cyclic prefix with minor loss in throughput. OFDM offers high data rate transmission [4]. It is used for various applications such as Digital Video Broadcasting (DVB), Digital Audio Broadcasting (DAB) and Asymmetric Digital Subscriber Line (ADSL) services. It can also be used for LTE, Wi-MAX based 4G systems ([5], [10]).

MIMO Systems were originally developed for flat fading channels. In order to implement MIMO concept for frequency selective channels, some corrective measures have to be used. Hence MIMO with OFDM can be used to transform frequency selective fading channel into several flat fading sub channels. MIMO offers spatial multiplexing and diversity gain. Spatial multiplexing is mainly for data rate improvement and diversity gain is to increase reliability of the system ([7], [9]). Transmit diversity and receive diversity are the two different diversities implemented in MIMO-OFDM systems. Transmit diversity is attractive for downlink purposes as more number of transmitting antennas can be used in the base station (BS). To combat fading and also to achieve high data rate with transmit diversity STTC can be used for encoding. Vector form of Viterbi decoder is required for the decoding process. When the number of states increases, complexity of STTC exponentially increases. Since complexity is a significant factor, we don't prefer STTC [8]. The alternate solution is to use STBC which provides less complexity. But both STTC and STBC are ideal for flat fading channels. The major drawback of applying STBC for frequency selective fading channel is that fading destroys the orthogonality of STBC matrix. So it is preferred only for indoor environment and low data rate applications [3]. In order to combat this drawback, MIMO equalizers are used with STBC systems for frequency selective fading channels. This again increases the complexity of the system. Hence, the preferred solution is SFBC.

Performance of adaptive modulated systems is superior when compared to non-adaptive modulated systems. The combination of frequency and space diversity enhances the performance of adaptive modulation remarkably. In frequency selective fading some of the sub channels will have higher attenuation compared to the other sub channels. Because of this, the average BER of all sub channels will exceed the target BER. In this paper, we are considering two transmitting antennas and one receiving antenna. In conventional adaptive modulation individual channels for both the antennas are evaluated and their average is given to each of the antennas. Based on the channel conditions, modulation schemes are adapted. For good channels, higher order modulation schemes are used and for bad channels, lower order modulation schemes are used which increases the decoder complexity. Again, complexity is an important factor and so we need to find alternate solution for conventional adaptive modulation. In Reference [1], Adaptive modulation implemented with SPAM gives less decoding complexity. But it was implemented for STBC. In this paper SPAM is implemented for SFBC for frequency selective fading environments.

The remaining paper is organized in the following way. We discuss about advantages of using SPAM over other fixed modulation schemes in Section II. In Section III we give a detailed explanation about SFBC. The system model of SPAM-SFBC-OFDM is discussed in Section IV. Section V contains the simulation and results of the proposed scheme and Section VI concludes the paper.

II. SPAM

SPAM is an alternate method for conventional adaptive modulation. In Reference ([1], [6]), it is proved that SPAM gives less decoding complexity. With different power factors we can obtain different constellation. This is done in order to overcome the receiver complexity problem faced in general adaptive modulation scheme. The concept of SPAM is implemented using the following equation:

$$c = \sum_{m=0}^{r-1} p_m * (-1)^{q_m} \qquad (1)$$

Where c represents the generated modulated symbol, p_m represents power factors, q_m represents each bit in the message , r is the number of bits per symbol.

For example, let the power factors be 1 and 1j and if we consider r=2, the possible values of q_m will be 00, 01, 10, 11. Since m runs from 0 to r-1, in this case it takes the values 0 and 1. Let us consider q_0 =0 and q_1=0. By substituting the values of q_0, q_1, p_0 and p_1 in equation (1) we get, 1+1j. Similarly, for 01 we get 1-1j, for 10 we get -1+1j and for 11 we get -1-1j.

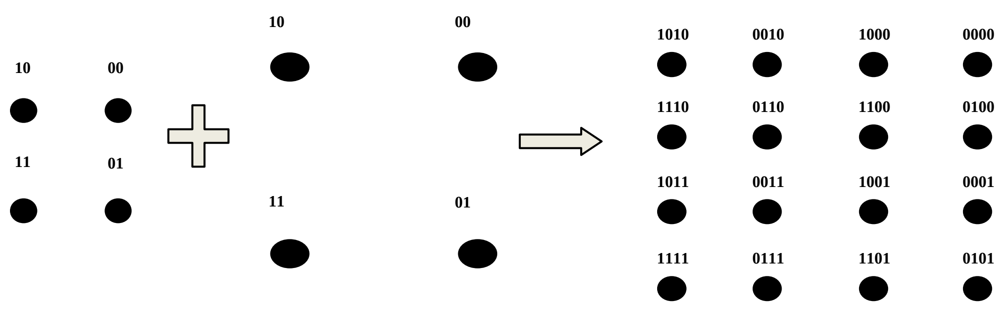

Fig. 1.Example of Superposition Coding

To generate higher order QAM, p_m, q_m and r values are increased accordingly. For example to generate 16-QAM modulated symbol, four power factors {1,1j,2,2j}, r=4 and any four bit combination of binary inputs are needed. In this paper we assume only two set of modulations, 4-QAM and 16-AQM. When the sub channel is too poor, it is left with no data being loaded.

Fig 1, shows how we can convert two 4-QAM symbols into a 16-QAM modulated system. For the first 4-QAM consider power factors {1,1j} and for the second {2,2j}. Consider the bits 0001. Using first power factor 00 can be modulated to 1+j and 01 is modulated to 2-2j. If the channel is good one 16-QAM modulated symbol can be transmitted instead of two 4-QAM in neighboring subcarriers. The modulated symbol for this input bit combination is 3-j which can also be obtained by adding two 4-QAM symbols.

III. SFBC

Transmit antenna diversity in the form of SFBC utilize frequency and space diversity and achieves a maximum diversity gain for two transmit antennas [9].

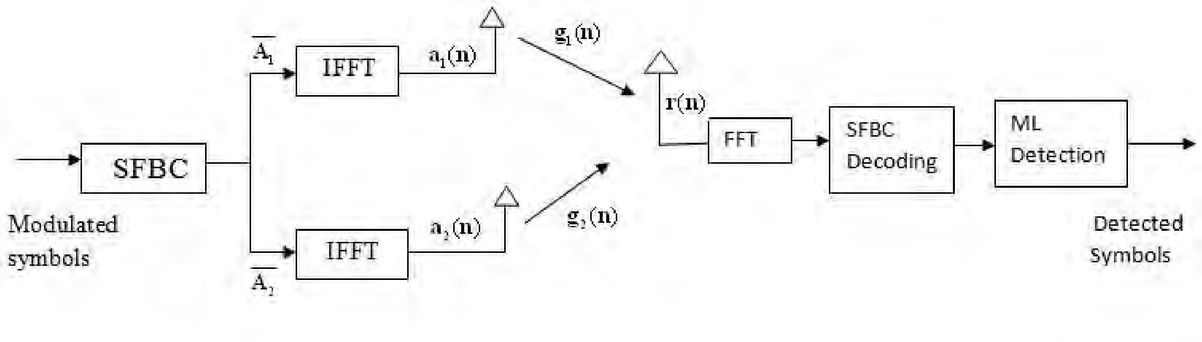

Fig.2. SFBC-OFDM Block Diagram

As shown in Fig. 2, the modulated symbols are transmitted through a SFBC encoder. The symbols are encoded in such a way that frequency and spatial diversity is achieved and IFFT is performed on each data. The SFBC coded OFDM symbols $a_1(n)$ and $a_2(n)$ are transmitted through transmitting antenna1 and 2 respectively. These symbols are sent through two different channels with channel gains $g_1(n)$ and $g_2(n)$. At the receiver end both the symbols are combined and FFT is performed. Then these symbols are sent through a SFBC decoder and Maximum Likelihood detection is performed to estimate the symbols.

OFDM symbols are modulated separately and are transmitted from two antennas in such a way that the two channels are independent. Usually a minimum distance of λ/2 is maintained between the two transmitting antennas so that the channels between them become independent. It is also assumed that both OFDM symbols transmitted from antenna 1 and antenna 2 have same number of subcarriers.

The SFBC code matrix for two transmit antennas is given as

$$H_2 = \begin{pmatrix} X_{2i} & X_{2i+1} \\ -X^*_{2i+1} & X^*_{2i} \end{pmatrix} \qquad i=0,1\ldots N/2-1 \tag{2}$$

where i is the OTD Matrix index and N is the number of subcarriers.

When i=0,

$$H_2 = \begin{pmatrix} X_0 & X_1 \\ -X^*_1 & X^*_0 \end{pmatrix} \tag{3}$$

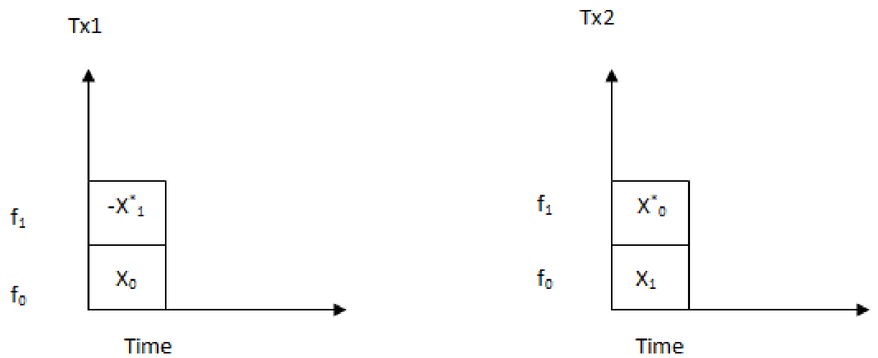

Fig.3. SFBC Encoding

The first column in equation (3) represents the symbols to be sent by 1st antenna and the second column represents the symbols sent by 2nd antenna. In the same fashion all the modulated symbols are SFBC coded and transmitted from two antennas. Fig.3. shows how space and frequency diversity is achieved through SFBC. The two modulated symbols X_0 and X_1 are sent as X_0 and $-X_1^*$ at frequencies f_0 and f_1 respectively by transmitter 1 and similarly X_1 and X_0^* at frequencies f_0 and f_1 respectively by transmitter 2. The same symbol is transmitted in two different frequencies and also in two different antennas. Thus frequency and space diversity improves the reliability of the system.

IV. SPAM-SFBC-OFDM: A PROPOSED SOLUTION

The performance of SPAM with SFBC is better when compared to SFBC with fixed modulation and conventional adaptive schemes [1]. SPAM-SFBC scheme decreases the complexity and increases the reliability of the system.

A. Encoding:

The following process has to be performed at the transmitter.The input block codes in vector form are

$$\bar{A}_1 = \left[X_0, -X_1^*, ..., X_{N-2}, -X_{N-1}^*\right]^T \quad (4)$$

$$\bar{A}_2 = \left[X_1, X_0^*, ..., X_{N-1}, X_{N-2}^*\right]^T \quad (5)$$

Where $\bar{A}_1$ and $\bar{A}_2$ are the SFBC coded modulated symbols transmitted through antenna 1 and antenna 2 respectively. In the above input vector code the first element represents the 1st subcarrier and the second element represents the 2nd subcarrier. These two subcarriers should have the same channel conditions. Similarly the neighboring subcarriers should have same channel. Here both the OFDM symbols contain the same data.

B. Decoding:

In the transmitter, two OFDM symbols are transmitted from two transmit antennas which are received by one receiving antenna. The discrete received symbol is (6)

$$r(n) = a_1(n) * g_1(n) + a_2(n) * g_2(n) + w(n)$$

where w(n) represents the Additive White Gaussian Noise (AWGN) and n is the discrete symbol index.

After performing discrete FFT on equation (6) we get,

$$R(k) = A_1(k).G_1(k) + A_2(k).G_2(k) + W(k) \qquad k=0, 1\text{…….}N-1 \quad (7)$$

Where k is the subcarrier index. To explain the SFBC decoding process in the receiver, we consider two sub carriers of the received data. This procedure is applicable for the rest of the sub-carriers.

$$R(1) = A_1(1)G_1(1) + A_2(1)G_2(1) + W(1) \quad (8)$$

$$R(2) = A_1(2)G_1(2) + A_2(2)G_2(2) + W(2) \quad (9)$$

Since the neighboring sub carriers will have the same channel gain, we assume that,

$$G_1(1) = G_1(2) = G_1 \quad (10)$$

$$G_2(1) = G_2(2) = G_2 \quad (11)$$

Substituting the values of the first two subcarriers in the OFDM symbols $a_1(n)$ and $a_2(n)$ we get,

$$\left.\begin{array}{ll} A_1(1) = X_0 & A_2(1) = X_1 \\ A_1(2) = -X_1^* & A_2(2) = X_0^* \end{array}\right\} \quad (12)$$

Substituting equation (12) in (8) and (9) we get,

$$R(1) = X_0G_1 + X_1G_2 + W(1) \quad (13)$$

$$R(2) = -X_1^*G_1 + X_0^*G_2 + W(2) \quad (14)$$

Conjugating equation (14) we get,

$$R^*(2) = -X_1G_1^* + X_0G_2^* + W^*(2) \quad (15)$$

Stacking equation (13) and (15) into the matrix we get,

$$\begin{bmatrix} R(1) \\ R^*(2) \end{bmatrix} = \begin{bmatrix} G_1 & G_2 \\ G_2^* & -G_1^* \end{bmatrix} \begin{bmatrix} X_0 \\ X_1 \end{bmatrix} + \begin{bmatrix} W(1) \\ W^*(2) \end{bmatrix} \quad (16)$$

Let,

$$G = \begin{bmatrix} G_1 & G_2 \\ G_2^* & -G_1^* \end{bmatrix} \quad (17)$$

Multiplying both the sides of equation (16) with G^H we get,

$$\begin{bmatrix} G_1^* & G_2 \\ G_2^* & -G_1 \end{bmatrix} \begin{bmatrix} R(1) \\ R^*(2) \end{bmatrix} = \begin{bmatrix} G_1^* & G_2 \\ G_2^* & -G_1 \end{bmatrix} \begin{bmatrix} G_1 & G_2 \\ G_2^* & -G_1^* \end{bmatrix} \begin{bmatrix} X_0 \\ X_1 \end{bmatrix} + \begin{bmatrix} W(1) \\ W^*(2) \end{bmatrix} \quad (18)$$

Therefore, equation (18) becomes,

$$\Rightarrow \begin{bmatrix} \tilde{R}(1) \\ \tilde{R}(2) \end{bmatrix} = \begin{bmatrix} |G_1|^2 + |G_2|^2 & 0 \\ 0 & |G_1|^2 + |G_2|^2 \end{bmatrix} \begin{bmatrix} X_0 \\ X_1 \end{bmatrix} + \begin{bmatrix} W(1) \\ W^*(2) \end{bmatrix} \quad (19)$$

Where,

$$\tilde{R}(1) = G_1^* R(1) + G_2 R^*(2) \quad (20)$$

$$\tilde{R}(2) = G_2^* R(1) - G_1 R^*(2) \quad (21)$$

Therefore,

$$\tilde{R}(1) = \| G \|^2 X_0 + W(1) \quad (22)$$

$$\tilde{R}(2) = \| G \|^2 X_1 + W^*(2) \quad (23)$$

Applying zero forcing (ZF) equalization to get,

$$\tilde{X}_0 \simeq \frac{\tilde{R}(1)}{\| G \|^2} \qquad \tilde{X}_1 \simeq \frac{\tilde{R}(2)}{\| G \|^2} \quad (24)$$

The above symbols are demodulated using Maximum Likelihood Detection (MLD) to get the original transmitted symbols [2].

The theoretical BER expression for M-QAM SFBC is given by

$$\overline{BER}_{MQAM} = \frac{0.2}{\left(1 + \frac{1.6\alpha_s}{R_c M_{nt} \left(2^{\delta} - 1\right)}\right)^{M_{nt}}} \quad (25)$$

where M_{nt} denotes the number of transmitting antennas, R_c denotes the code rate, α_s is the ratio of symbol energy to noise and δ denotes the number of bits loaded. This theoretical BER is derived in the appendix section of this paper.

V. SIMULATION RESULTS

In this paper we have considered a 2*1 MISO system and used 4-QAM and 16-QAM modulation schemes. For implementation of SPAM we have used power factors {1,1j,2,2j}. A three tap multipath channel with jakes spectrum is taken. We have evaluated the performance of 16 QAM modulated SFBC for 2*1 MISO system.

Substituting number of transmitting antennas (M_{nt}) as 2, code rate R_c as 1 and δ=4 in equation (25) and varying SNR (α_s) from 0 to 30 dB we get the theoretical BER. Theoretical BER and simulated BER is compared in Fig.4.

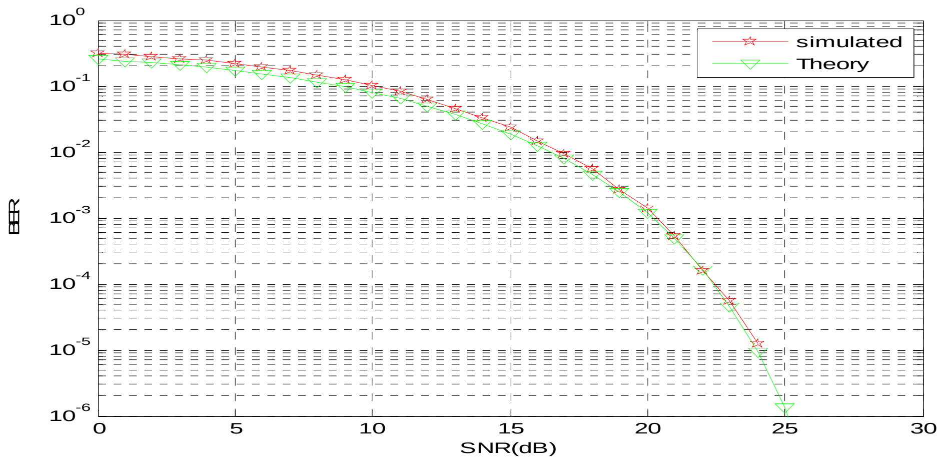

Fig.4. Comparison between Theoretical BER and Simulated BER

From Fig.4. we can infer that as the SNR value increases both the curves merge together that is they give the same BER values. However for low SNR values there is a disparity between the BER given by the two curves.

We compare the performance of fixed modulated SFBC and SPAM modulated SFBC under different channel conditions for a 2*1 MISO OFDM system. The average results for SNR (dB) vs BER is shown in Fig.5. The proposed system is compared with fixed 16-QAM and 4-QAM modulated SFBC OFDM systems. These modulation schemes are employed irrespective of the sub channel gain. When 16-QAM modulation is applied for low gain sub channels, total BER of the system increases. The minimum Euclidean distance for 16-QAM is less when compared to 4-QAM. Then obviously to maintain the target BER, SNR has to be increased. The 4-QAM modulated system offers less BER for low and high gain sub channels. But it reduces the spectral efficiency of the system. Because of this tradeoff 4-QAM modulated SFBC OFDM system is also not preferred.

In the proposed scheme channel for both the antennas are estimated and average channel gain is calculated. This average channel gain is given for both the transmitter antennas. The proposed scheme modulates each subcarrier using this average channel gain. When the sub channel is good, 16-QAM modulation is used. The sub channels with moderate gain are 4-QAM modulated. When the sub channel gain is too poor, no modulation scheme is used.

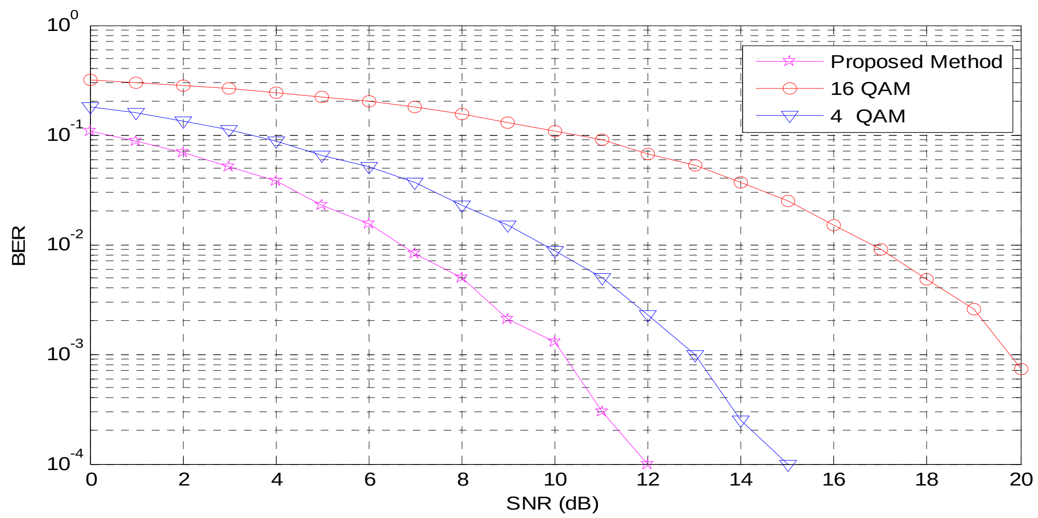

Fig.5. Comparison between SPAM-SFBC-OFDM and fixed modulated SFBC-OFDM.

From Fig.5, we can infer, SPAM-SFBC-OFDM achieves a BER of 10^{-3} at 10 dB SNR value, whereas 4-QAM-SFBC-OFDM achieves the same BER at 13 dB and 16-QAM-SFBC-OFDM achieves at 19.5 dB. The proposed system achieves a coding gain of 9.5 dB over 16-QAM-SFBC-OFDM and 3 dB coding gain over 4-QAM-SFBC-OFDM. Thus we can clearly state that the performance of SPAM-SFBC is the best when compared to fixed modulation schemes.

VI. CONCLUSION

In this paper, we have introduced the concept of SPAM-SFBC-OFDM for frequency selective fading channels. The results show that the proposed system gives better throughput performance than the fixed modulation system. SPAM-SFBC also offers a very good coding gain over fixed modulated system which improves the QoS of the system. By employing proper antenna selection scheme still the QoS of the system can be improved. The proposed system achieves a coding gain of 9.5 dB over 16-QAM-SFBC-OFDM and 3 dB coding gain over 4-QAM-SFBC-OFDM.

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APPENDIX

Here we will discuss about the closed form BER expression for M-QAM SFBC-OFDM systems.

The instantaneous BER can be expressed as,

$$\alpha = \frac{1}{M_{nt} R_c} \sum_{i=1}^{M_{nt}} |G_i[k]|^2 \alpha_s \tag{26}$$

Similar to conventional OFDM, we can express the BER of the MQAM-SFBC-OFDM over a frequency selective fading channel as

$$BER_{MQAM} = \frac{2}{N\delta}\left(1 - \frac{1}{\sqrt{2^\delta}}\right) \times \sum_{k=0}^{N-1} \operatorname{erfc}\left(\sqrt{\frac{1.5\alpha_s \sum_{i=1}^{M_{nt}} |G_i(k)|^2}{R_c M_{nt}\left(2^\delta - 1\right)}}\right) \tag{27}$$

Equation (27) can be approximated as

$$BER_{MQAM} \approx \frac{0.2}{N} \sum_{k=0}^{N-1} \exp\left(-\frac{1.6\alpha_s \sum_{i=1}^{M_{nt}} |G_i(k)|^2}{R_c M_{nt}\left(2^\delta - 1\right)}\right) \tag{28}$$

The average BER can be represented as

$$\overline{BER}_{MQAM} = \int_0^\infty \ldots\ldots \int_0^\infty BER_{MQAM}\, p(\alpha_1)\ldots\ldots p(\alpha_{M_{nt}})\, d\alpha_1 \ldots\ldots\ldots d\alpha_{M_{nt}} \tag{29}$$

Where $\alpha_i = \alpha_s(|G(k)|^2)$ and $p(\alpha_i)$ is the probability density function.

$$p(\alpha_i) = \frac{1}{\alpha_i} \exp\left(-\frac{\alpha_i}{\alpha_s}\right) \qquad \alpha_i \geq 0 \tag{30}$$

Substituting equation (28) and (30) in (29), we get

$$BER = \frac{0.2}{N}\sum_{0}^{N-1}\int_{0}^{\infty}\exp\left[\frac{-1.6\alpha}{R_c\left(2^{\delta}-1\right)}\right]\frac{1}{\alpha_s}\exp\left[\frac{-\alpha_i}{\alpha_s}\right]d\alpha \qquad (31)$$

$$BER = \frac{0.2}{N\alpha_s}\sum_{k=0}^{N-1}\int_{0}^{\infty}\exp\left[-\alpha\left[\frac{1.6\alpha_s + R_c\left(2^{\delta}-1\right)}{\alpha_s R_c\left(2^{\delta}-1\right)}\right]\right]d\alpha \qquad (32)$$

$$BER = \frac{0.2}{N\alpha_s}\sum_{0}^{N-1}\left[\frac{-\exp\left[-\alpha\left[f\right]\right]}{f}\right]_{0}^{\infty} \qquad (33)$$

Where

$$f = \frac{1.6\alpha_s + R_c\left(2^{\delta}-1\right)}{\alpha_s R_c\left(2^{\delta}-1\right)} \qquad (34)$$

Substituting the integral limits we get

$$BER = \frac{0.2}{N\alpha_s}\sum_{k=0}^{N-1}\frac{\left[1-0\right]}{f} \qquad (35)$$

By substituting the value of (f) from equation (34) we get,

$$BER = \frac{0.2}{1+\frac{1.6\alpha_s}{R_c\left(2^{\delta}-1\right)}} \qquad (36)$$

Therefore for M_{nt} transmitting antennas the BER becomes,

$$\overline{BER}_{MQAM} = \frac{0.2}{\left(1+\frac{1.6\alpha_s}{R_c M_{nt}\left(2^{\delta}-1\right)}\right)^{M_{nt}}} \qquad (37)$$