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SER Analysis using GFDM System with Maximal Ratio Transmission Technique under $\alpha-\mu$ Fading Channel

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Abstract

Generalized frequency division multiplexing (GFDM) system with maximal ratio transmission (MRT) scheme is considered to analyse the symbol error rate (SER) performance over $\alpha-\mu$ fading channel. In present days, low latency and low consumption of energy devices are used and these can be achieved using multicarrier techniques. The GFDM is one such multicarrier technique which has a capable to provide these requirements. Low out-of-band (OOB) radiation is one of the GFDM technique's main benefits. Initially, in this study, GFDM-MRT system is used to investigate the SER expression analysis in $\alpha-\mu$ fading. Initially, we have addressed the closed form of novel mathematical analysis of SER expression under $\alpha-\mu$ fading channel. The Rayleigh, Nakagami-m, and Nakagami-q fading channels are all special instances in the suggested derivation. Later, a Monte-Carlo simulation-based test-bed is developed in MATLAB software and simulations are evaluated for various values of fading parameters, different roll-off factors, and the number of transmitting antennas Nt. The GFDM-MRT technology provides lower SER values and it is more dependable for high-speed communications, it can be inferred. The main object of this paper is to compare the SER of GFDM-MRT system with GFDM system without using MRT technique in $\alpha-\mu$ fading channel for different comparing parameters like at number of transmitting antennas Nt , different values of roll-off factors (β) and fading parameters α and μ

Keywords: GFDM, MRT, SER, $\alpha-\mu$ fading, OOB

1. Introduction

In present days, 5G systems need to have very low latency, reliability, robust high throughput, and low value of out of band (OOB) emission. Several noteworthy waveforms have been designed in the literature for this situation. Because of its desirable qualities, including minimal OOB radiation to enable dynamic spectrum access and low latency, generalized frequency division multiplexing (GFDM) is one of the top options for future wireless applications. In GFDM, majority of the sub-carriers are non-orthogonal to one another, it is the key difference between GFDM and OFDM (orthogonal frequency division multiplexing) [1]. Cyclic prefixes (CP), which consume a lot of bandwidth, are not added to each subcarrier, which is another significant benefit of GFDM. We obtain the identical at the receiver in bits as those which are broadcast by the transmitter in GFDM because just to the combination of subcarriers, one CP is added. [2]. According to [3–4], the GFDM system is less complex, achieves minimal OOB, and offers a viable 5G option. The authors of [5] addressed how the adaptable technology known as GFDM circumvents the problems with 4G technology. In a nutshell, GFDM sends data in the form of data blocks made up of K sub-carriers and M sub-symbols. Each sub-carrier in GFDM has a low OOB radiation pulse with a circular shape.

As discussed earlier, GFDM is a non-orthogonal and we can make it orthogonal by employing different pulse shaping filters. Additionally, as GFDM is a less complicated method, it can be accomplished by combining it with orthogonal quadrature amplitude modulation (OQAM) [6-7]. To fulfil the demands of the most recent technologies, the GFDM system uses a variety of circular pulse shaping filters addressed in [8–10].

Numerous studies have been conducted on the performance of GFDM's bit error rate (BER) in various fading channels, considering a variety of pulse shaping filters at receiver that include zero forcing (ZF) and matched filter (MF) in [11–16]. In order to eliminate self-interference, the ZF receiver is used in performance evaluation of GFDM for time-varying Rayleigh fading channels in terms of SER. However, noise enhance factor (NEF) is used to boost up SER performance because of loss occur due to pulse shaping filter [17]. In [10-11], SER analytical expressions are provided under several fading environments.

The GFDM analysis based on multiple inputs and multiple outputs (MIMO), whose receiver complexity is higher, is presented in [12]. Prior to demodulation, this technique employs the MRC scheme (maximum ratio combining). In [18], large-scale MIMO transmission GFDM method is discussed. The information on the examination of MIMO-GFDM signals complexity identification is evaluated in [19]. Using the Monte Carlo approach, the detection complexity of the MIMO-GFDM system is further lowered in [20-21]. The complexity is also reduced by MIMO structure and maximal ratio transmission (MRT), and the effectiveness of the MRT scheme is also assessed in [22–23]. The MRT scheme reduces the receiver complexity in MIMO systems.

The performance of the MRT-based GFDM system is assessed in [24] using the Nakagami-*m* fading channel. The article [25] provides a thorough examination of the weibull fading channel. In the literature, there is not much discussion

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on GFDM with MRT. The α-μ fading is generalised fading distribution that can be considered in non-line of sight (NLOS) channel conditions and it forms various fading environment for a fixed values of $\alpha - \mu$. [26-27].

Despite efforts to examine GFDM under different fading situations, there is limited study connected to the effectiveness of the generalised $\alpha - \mu$ fading model in GFDM communication system documented in the literature. The literature on GFDM with MRT under $\alpha - \mu$ fading channel does not cover a lot of ground. The references mentioned above can be used to evaluate how well the GFDM with MRT scheme performs under $\alpha - \mu$ fading channel. The remaining four sections make up the rest of the paper. In section II, it is discussed about GFDM-based MRT scheme and the addition of $\alpha - \mu$ fading work. The innovative closed form of mathematical SER analysis in $\alpha - \mu$ fading is the subject of Section-3. Sections-4 and-5 presents the simulation analysis and conclusion of the paper.

2. GFDM-MRT Scheme

2.1. Background of paper

Fig.1. depicts the suggested GFDM-based MRT system model. The vectorial data (**b**) provided to the encoder that convert low bit rate input to a high bit rate data stream vectors ($\boldsymbol{b_c}$). The mapper block generates a **N X 1** data vector as output (**d**). This vectorial data is fed into an *N*-element GFDM modulator as input. The total vectorial data (**d**) is divided into **K** groups and **M** data symbols

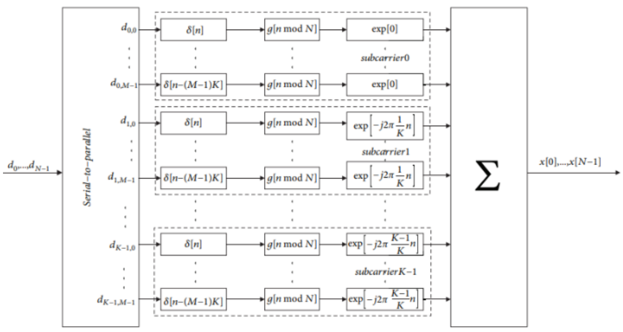

Fig. 1. Modulator of the GFDM.

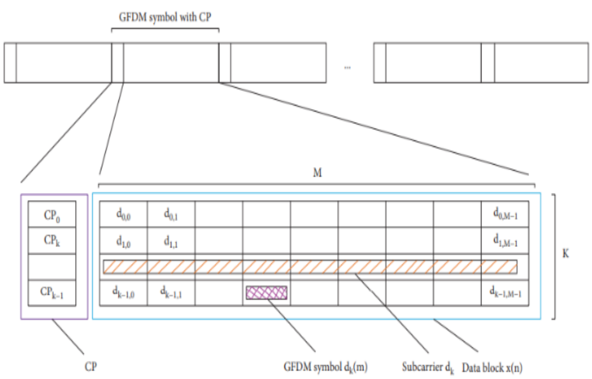

Fig. 2. Structure of GFDM data block.

$$d = [(d_0)^T, (d_1)^T, \ldots \ldots (d_{K-1})^T]^T \quad (1)$$

With

$$d_k = \left[d_{k,0}, d_{k,1}, \ldots \ldots d_{k,M-1}\right]^T \quad (2)$$

The term $d_{k,m}$ in eq. (2) represents the data symbol which will be passed through k-th sub carrier at m-th time slot. Later, it is multiplied with pulse shaping filter $\boldsymbol{g_{k,m}(n)}$. A GFDM block that uses **K** subcarriers, each of which has **M** data symbols, and generates **N = KM** samples. These sample values are filtered using a suitable transmit filter while using GFDM modulator is given as [11];

$$g_{k,m}[n] = g[(n - mk) mod N] e^{\frac{-j2\pi kn}{K}} \quad (3)$$

Where $\boldsymbol{g_{k,m}(n)}$ is both time and frequency shifted of $\boldsymbol{g(n)}$. The GFDM signal $x(n)$ can be is expressed as follows given in [11];

$$x[n] = \sum_{k=0}^{K-1} \sum_{m=0}^{M-1} d_{k,m} g_{k,m}[n], n = 0,1 \ldots \ldots KM - 1 \quad (4)$$

The samples of pulse shaping filter is;

$$g_{k,m} = \left[g_{k,m}[0], g_{k,m}[1] \ldots \ldots g_{k,m}[MK - 1]\right]^T \quad (5)$$

The eq. (4) can be shown in matrix form as [12];

$$\mathbf{x} = \boldsymbol{Ad} \quad (6)$$

Where A is GFDM matrix of size is $\boldsymbol{KM\ X\ KM}$ and it can be shown as [5];

$$A = \left[g_{0,0} \cdots g_{K-1,0}\ g_{0,1} \cdots g_{K-1,M-1}\right] \quad (7)$$

After the GFDM block, the cyclic prefix (CP) and cyclic suffix (CS) are added, and the signal components are then weighted using MRT coefficients as;

$$x_i = w_i x \quad (8)$$

Where w_i is MRT weighting coefficient for i-th antenna and $(i = 1,2 \ldots . N_t)$ [24];

$$w_i = \frac{h_i^*}{h_F} \quad (9)$$

$$h_F = \|h\| = \sqrt{\sum_{i=1}^{N_t} |h_i|^2} \quad (10)$$

In eq. (9), channel coefficient is h_i and Frobenius norm is h_F.

2.2. Channel model:

After removing CP, the received signal can propagate across the wireless channel using the following model

$$r = \boldsymbol{H}\mathrm{x} + \boldsymbol{w} \quad (11)$$

Where $\boldsymbol{H} = circ\ \{\tilde{h}\}$.

The GFDM signal is multiplied by the MRT coefficients and is represented mathematically as

$$r = \sqrt{P_t} \sum_{i=0}^{N_t} h_i w_i x + w = \sqrt{P_t} h_F x + w \quad (12)$$

Where **w is** a vector of noise$w \sim (0, \sigma_w^2)$.

2.3. Reception of channel model:

We have used ZF receiver as GFDM demodulator. The demodulated signal can be expressed as [5];

$$\hat{d} = \boldsymbol{B}y \tag{13}$$

Demodulation matrix is **B.**

$B_{ZF} = A^{-1}$ is the receiver demodulation matrix for ZF receiver. The self-interference is eliminated by a ZF receiver, but noise effect is increased. When using a ZF receiver, NEF (ζ) mathematical expression is [5], indicates how much the SNR value is reduced;

$$\xi = \sum_{i=0}^{MK-1} \left| [B_{ZF}]_{k,i} \right|^2 \tag{14}$$

where 'ξ' is equal for all $k = 0,1,\ldots.MK-1$. We took $\alpha-\mu$ fading channel into consideration in this article. The analyses compress to some frequently used fading channels for some values of $\alpha-\mu$.

Table 1. Representation of various fading channels for different $\alpha-\mu$ values.

$\alpha-\mu$ values	Fading Environment
α=2 and μ=1	Rayleigh fading
α=2 and $\mu > 1$	Nakagami-μ fading
μ=1	Weibull fading

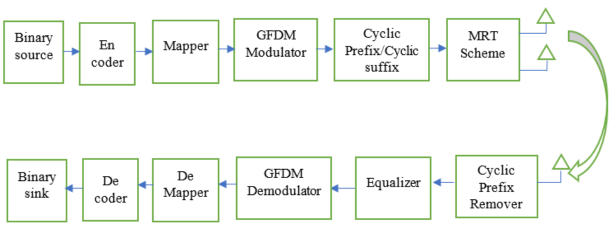

Fig. 3. Block diagram of GFDM-MRT scheme.

2.4. $\alpha-\mu$ Distribution

The $\alpha-\mu$ distribution can be used to model fading channels in the environment characterized by non-homogeneous obstacles that may be nonlinear in nature. The $\alpha-\mu$ fading is general distribution that can be used to represent various fading models. This distribution deals with non-linearity of propagation medium. Weibull and Nakagami can be easily derived from $\alpha-\mu$ distribution.

The $\alpha-\mu$ fading also considers the received signal to be collection of clusters of multipath components.

The physical relation between resultants of received multipath clusters and fading amplitude for $\alpha-\mu$ distribution can be given as;

$$X^{\alpha,\mu} = \sum_{i=1}^{n} \left(I_i^2 + Q_i^2 \right) \tag{15}$$

Where n is the number of clusters, I_i and Q_i are the resultant in-phase and quadrature phase components of $i-th$ cluster in the received signal.

3. Analysis of Symbol Error Rate

This section deals with the mathematical analysis of SER expression under $\alpha-\mu$ fading channel for GFDM-MRT system. Using a ZF receiver and the QAM modulation technique, the SER performance is assessed.

3.1. SER Calculation in AWGN Environment

The expression for SER utilising the GFDM scheme under the AWGN is [5];

$$P_{SER,AWGN}(\gamma) = 2\left(\frac{p-1}{p}\right) erfc(\sqrt{\gamma}) - \left(\frac{p-1}{p}\right)^2 erfc^2(\sqrt{\gamma}) \tag{16}$$

Where

$$\gamma = \frac{3R_T}{2(2^m-1)} \frac{E_s}{\xi N_0} \text{ and } R_T = \frac{NM}{NM+N_{CP}+N_{CS}} \tag{17}$$

In eq. (16) and (17), $p = \sqrt{2m}$, m-represents number of bits, N_{CP} , N_{CS} are length of CP and CS(Cyclic suffix) respectively. N and M are number of subcarriers and sub-symbols. For various fading environments SER expression can be calculated using [5];

$$P_{SER} = \int_0^{\infty} P_{AWGN}(\gamma)\, P_{\gamma}(\gamma) d\gamma \tag{18}$$

In eq. (18), $P_{\gamma}(\gamma)$ represents the PDF of different fading channels.

3.2. SER Calculation in $\alpha-\mu$ Fading Environment

To determine the SER expression for $\alpha-\mu$ fading, we need PDF expression of $\alpha-\mu$ fading. It is given in [27-28] as;

$$P_{\gamma}(\gamma) = \frac{\alpha\mu^{\mu}\gamma^{\frac{\alpha\mu}{2}-1}}{2\Gamma(\mu)\bar{\gamma}^{\frac{\alpha\mu}{2}}} e^{-\mu\left(\frac{\gamma}{\bar{\gamma}}\right)^{\frac{\alpha}{2}}} \tag{19}$$

Where $\bar{\gamma}$ is average channel SNR.

By keeping eq. (16) and eq. (19) in eq. (18), SER expression is obtained after some mathematical computations as;

$$P_{\alpha-\mu}(e) = 2\left(\frac{p-1}{p}\right) A\left(\overline{\gamma}_{\alpha-\mu}\right) - \left(\frac{p-1}{p}\right)^2 B\left(\overline{\gamma}_{\alpha-\mu}\right) \tag{20}$$

Where $\overline{\gamma}_{\alpha-\mu}$ is equivalent SNR under $\alpha-\mu$ fading channel given by

$$\overline{\gamma}_{\alpha-\mu} = \frac{2R_T\sigma_{\alpha-\mu}^2}{(2^b-1)} \frac{E_s}{\xi N_0} \tag{21}$$

where b is number of bits per QAM symbol and $\phi = \sqrt{2b}$.

$$R_T = \frac{NM}{NM+N_{cp}+N_{cs}} \tag{22}$$

Eq. (20) consists of two unknown values such as $A\left(\overline{\gamma}_{\alpha-\mu}\right)$ and $B\left(\overline{\gamma}_{\alpha-\mu}\right)$ which can be computed as;

$$A\left(\overline{\gamma}_{\alpha,\mu}\right) = 1 - \frac{1}{2\sqrt{\pi}} \frac{\alpha\mu^{\mu}\sqrt{k}(l)^{\frac{\alpha\mu}{2}}}{\Gamma(\mu)\overline{\gamma}^{\frac{\alpha\mu}{2}}(2\pi)^{\frac{l+k-2}{2}}}\, G_{2l,k+l}^{k+l,l}\left[\frac{\mu^k l^l}{k^k\overline{\gamma}^{\frac{\alpha\mu}{2}}} \middle| \begin{matrix} \Delta\left(l,\frac{1-\alpha\mu}{2}\right), \Delta\left(l,1-\frac{\alpha\mu}{2}\right) \\ \Delta(k,0)\ ,\ \Delta\left(l,\frac{-\alpha\mu}{2}\right) \end{matrix}\right] \tag{23}$$

$$B\left(\overline{\gamma}_{\alpha,\mu}\right) = 1 - \frac{2}{\pi}\frac{\mu^{\mu}}{(\overline{\gamma})^{\frac{\alpha\mu}{2}}}\sum_{j=0}^{\mu-1}\sum_{i=0}^{\infty}\frac{(-1)^{i}(\overline{\gamma})^{\frac{\alpha}{2}(\mu-j)}}{j!\ i!\ \mu^{\mu-j}}\frac{\sqrt{k}\,l^{i+\frac{\alpha j}{2}-\frac{1}{2}}}{(2\pi)^{\frac{l+k-2}{2}}}\quad G_{2l,k}^{k,2l}\left[\frac{l^{l}\mu^{k}}{\overline{\gamma}^{\frac{\alpha k}{2}}k^{k}}\middle|\begin{matrix}\Delta\left(l,\frac{1}{2}-i-cj\right),\ \Delta(l,-i-cj)\\ \Delta(k,0),\ \Delta\left(l,-i-cj-\frac{1}{2}\right)\end{matrix}\right] \tag{24}$$

The exact SER expression will be obtained by keeping eq. (23) and eq. (24) in eq. (20).

Similarly, for multiple antennas (N_t) case, SER expression can be achieved by replacing α with αN_t and μ with μN_t.

4. Results and Discussions

The findings of the simulation and their analysis are covered in this section. All simulations are run for 10^5 monte-carlo iterations with the following simulation parameters: length of CP and CS are N_{cp}=8, N_{cs}=0, K=64, M=5.

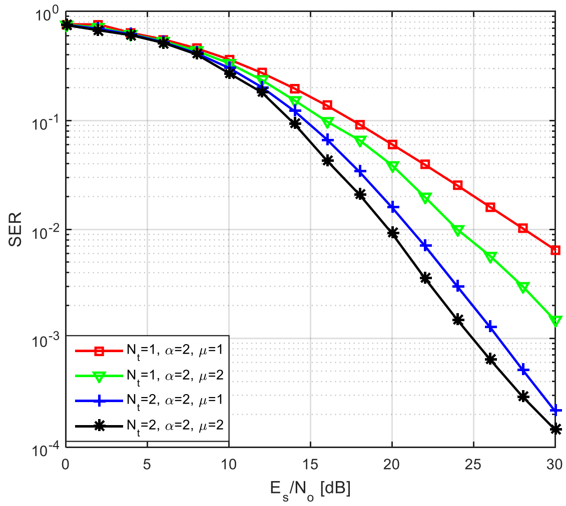

Fig. 4. SER vs Es / N0 performance with different N_t values.

The SER analysis is evaluated in Fig.4 for various values of E_s/N_o, $N_t = 1$, $N_t = 2$, and β=0.1. The simulation is evaluated for various values of μ and fixed value of α=2 under $\alpha - \mu$ fading. The analytical values obtained from the derived expression is in good agreement with the simulation results. From the simulation it is observed that SER performance falls with the rise in μ value. For a particular case, SER values are 0.137 and 0.097 with $N_t = 1$ and μ=1 and μ=2 respectively. SER values are 0.0669 and 0.0428 with $N_t = 2, \mu$=1 and μ=2 respectively at SNR= 16dB for α=2. From the above lines it is clear that rise in number of antennas decreases the SER value and this is due to the increase in diversity order. It may be said from the simulation that with the GFDM-MRT system, 4dB SNR gain can be achieved with $N_t = 2$ at SER=10^{-2}. It can also be observed that for $\mu = 1$ the curve obtained in Fig. 4 matches to that of [5]. As discussed in the Section III, $\alpha - \mu$ distribution covers Nakagami-m as special case for α=2 and $\mu = m$. The results also confirm the same that Fig.4 is the plot for the SER performance of Nakagami-m distribution [24].

Fig. 5 also gives SER analysis for various values of E_s/N_o, $N_t = 1$, $N_t = 2$, α values 2 and 5, μ=1, and β=0.1. The simulation curves are exactly matching with Weibull fading conditions and gives the same SER performance with μ=1 and this results perfectly in accordance to simulations which are shown in [29]. It is observed from the simulation that rise in α makes reduction of SER values.

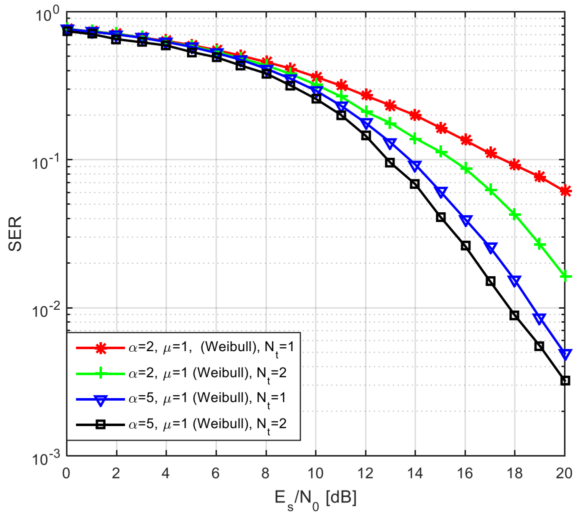

Fig. 5. SER vs Es / N0 performance for various values of α and μ=1.

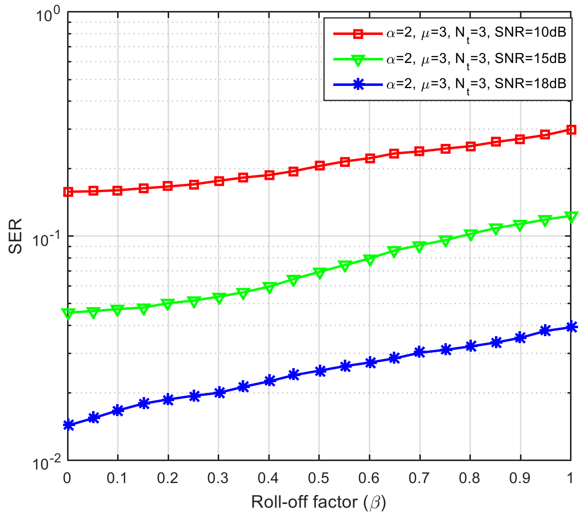

Fig. 6. SER performance for various β values.

For a particular case, SER values are 0.1993, 0.0926 with $N_t = 1$, SER values are 0.1393, 0.06823 with $N_t = 2$ for α= 2 and 5 are respectively at SNR=14dB. The SER value decrease 26.3% at SNR=14dB with the rise in α = 2 to α =5 indicating the less severity of fading as the α is increased. As discussed in the Section III, $\alpha - \mu$ distribution covers Weibull as special case for α varies and $\mu = 1$.

SER versus roll-off factor performance is depicted in Fig. 6 for various SNR values (10dB, 15dB, and 18dB), $N_t = 3, \alpha = 2, \mu = 3$, and employing 16-QAM modulation technique. With the rise in SNR from 10 dB to 18 dB, SER falls from 0.1872 to 0.0185 at β=0.4, indicating the reduction of SER value by 90.11% with the rise in SNR. Finally, it can be said that higher SNR=18dB values are always advised if you want to attain less SER.

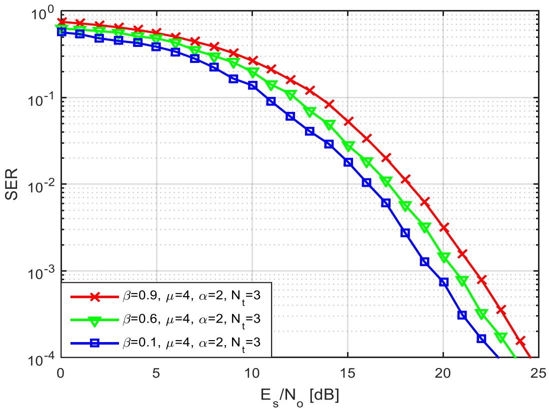

Fig. 7. SER vs E_s/N_0 analysis for various β values.

Simulation parameters $N_t = 3$, α=2, and 16-QAM modulation method are used in Fig.7 to shows the relationship between SER and E_s/N_0 for various β=0.1, 0.6, and 0.9 values. The NEF parameter ζ, which is important in GFDM, and its effect also explained in Fig. 7. As β value rises from 0.1 to 0.9, SER curve also rise. For various values of β=0.1, 0.6, and 0.9, SER values are 0.01814, 0.02814, and 0.05314 at SNR=15dB. The value of the SER lowers by 65.8% as the value of β falls from β=0.9 to 0.1.

SER analysis for various SNRs is plotted in Fig. 8 for several schemes of modulation QPSK (k=2) and 16-QAM (k=4)), N_t=3, and α=2 and μ=5. We may conclude from this simulation that the SER value for the QPSK technique is lower than 16-QAM modulation method. For a specific scenario, the SER values for the 16-QAM and QPSK methods are 0.3016 and 0.0128, respectively at SNR=10dB.

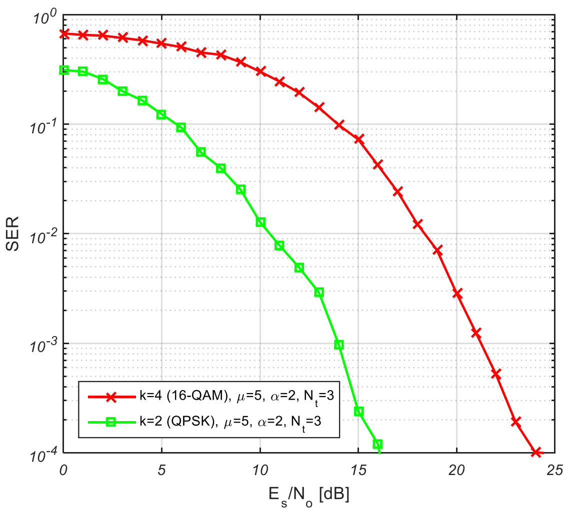

Fig.8. SER vs SNR performance for various modulation schemes.

The SER analysis different values of E_s/N_o with different numbers of antennas (N_t=1 and 2) and β=0.1 is shown in Fig.9. The simulation is assessed for a various range of fading parameters ($\alpha = 2$ and 5) and a fixed value of μ=3. The simulation shows that as α value rises, SER performance declines.

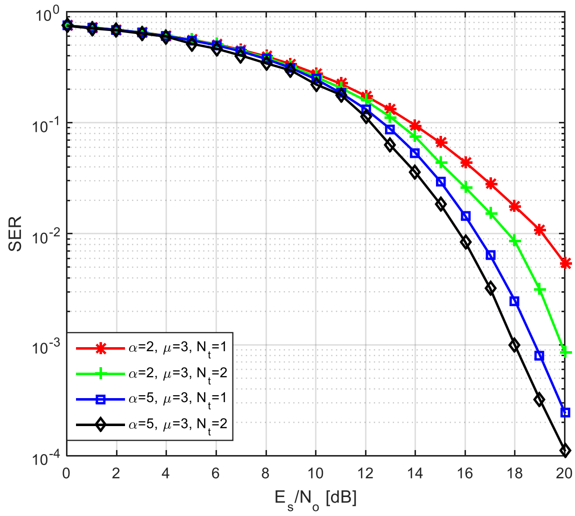

Fig. 9. SER vs E_s/N_0 performance for various values of α and μ=3.

At SNR=15dB, the SER values are 0.09447 and 0.07451 with N_t=1 and SER values are 0.05354 and 0.0357 with N_t=2 with the rise in α value from 2 to 5. From the aforementioned lines, it can be seen that an increase in antenna counts from N_t=1 to N_t=2, we have achieved 4dB gain at SER= 10^{-2}.

5. Conclusion

In this study, GFDM based MRT scheme is proposed and its performance is evaluated in terms of symbol error rate (SER) under $\alpha - \mu$ fading. Initially, we have evaluated SER expression under $\alpha - \mu$ fading environment for a single and multiple antennas case. Additionally, the effectiveness of the SER performance is assessed using the MATLAB simulations for a various simulation parameter, such as number of transmitting antennas N_t, various roll-off factors(β), and different fading parameters α and μ. We have observed that the error rates dropped as one fading parameter was fixed and another fading parameter was increased. With the usage of multiple transmitting antennas (N_t=2), SNR performance is enhanced by 4dB to at SER=0.01. The studied system model under $\alpha - \mu$ fading is useful in designing the wireless communication systems in a more generalized manner. If number of transmitting antennas N_t are maximized then circuit complexity will increase in MRT scheme

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