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Performance Analysis of SSK Modulation using multipath with multihop DF relay over Nakagami-m fading channel

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Abstract **-** The data transfer between devices should be prominent in the future generations for Internet of Things (IoT) applications. IoT systems need a sophisticated communication setup with less hardware and complexity. Space Shift Keying (SSK) modulation is the perfect scheme to fulfill IoT system requirements by activating a single antenna. Moreover, Cooperative communication has more reliability in point-to-point communication by the relaying system. Thus, end-to-end Bit Error Rate (BER) in the multi-hop multi-branch relaying model under cooperative communication scenario using SSK modulation scheme for IoT systems is analyzed. The closed-form expression for BER is derived over Nakagami-m fading channels and the results are verified with Monte Carlo simulation.

Keywords **-** Space Shift Keying, Bit error rate, Nakagami-m fading channel, Cooperative communication

1 Introduction

Now a day's people are expecting more sophisticated technologies for their daily life activities. The emerging of Internet of Things (IoT) indulged in revolution and that made people to curious about revised technologies in future communication systems. In comparison to 4G communication technologies, 5G will provide additional advancements with the integration of IoT systems.

The data exchange and coverage area are two important issues in wireless communication system. The secure data exchange can be achieved by using Space shift keying (SSK) in the MIMO scenario and also observed that it is suitable for the IoT applications in future generation 5G without any leakage of data. The coverage area of the communication system can be extended by including the IoT-based relaying system. Relaying in IoT may serve a variety of goals in a cellular network, such as improving topology, boosting network robustness, and decreasing power usage. Different types of relaying systems are compared based on LTE-A standards and also explained new relay deployment models which are being considered for future generation 5G [1]. Relay technology can also be used for improving the topology and reducing the power consumption in the cellular network [2]. The secret transmission performance of an electric vehicle (EV) in a heterogeneous network is investigated when it communicates with the vehicle to grid (V2G) using a relay selection approach [3]. The secrecy capacity of IoT systems is improved by the cooperative communication systems with amplify-and-forward (AF) relaying [4].

The concept of SSK modulation in MIMO systems is introduced in [5]. Because only one transmitting antenna is active at a time in SSK, the receiver complexity is modest. Inter channel interference and inter antenna synchronization are not possible with single antenna activation. When a single RF chain is adequate for data transfer, the hardware complexity is reduced. Instead of sending data directly to the receiver, data symbols are mapped as transmitting antenna indices, and the receiver section decodes the transmitting antenna indices to recover the original data.

The use of SSK modulation to improve secrecy can help suitable IoT communication applications in the smart city environment avoid data transmission leakage. Closed-form expression for the probability of bit error of SSK modulation over Nakagami-m fading channel in a MIMO system is determined [6]. A dual-hop AF relay system is studied under symmetric (Nakagami-m/Nakagami-m) and non-symmetric (Nakagami-m/Rician) fading channels and also a mathematical expression for ABEP in both cases is derived[7]. In [8] author introduced the Quadrature SSK (QSSK) concept over a mixed channel with dual-hop AF relaying system. Performance of SSK in the cooperative scenario with multi-hop multipath DF relaying system is analyzed and also derived a mathematical expression for an end to end probability of error over complex Gaussian fading channels [9]. End-to-end symbol error probability in decode and forward (DF) cooperative relaying is derived for SSK modulation in [9]. In [10], performance analysis of wireless transmissions in IoT systems is studied where one direct link and one multihop relay are present and also derived the outage probability and BER of the entire IoT system over a Nakagami-m fading channel based on probability distribution function (PDF) at receiver. However, to the best of the author's knowledge, the performance of SSK modulation for multihop multipath relay over a Nakagami-m fading channel is not yet analyzed.

In this paper, the performance analysis of cooperative communication with multihop multipath relay is analyzed. SSK modulation scheme is employed for data transmission and DF relaying is introduced at each relay because it is more suited to communications in IoT systems. The closed-form expression for end-to-end BER over a Nakagami-m fading channel is derived. The derived expression is in closed form with special functions like hypergeometric and gamma functions.

2 System Model

Consider a multi-hop multipath cooperative communication model with source (S), destination (D), and relays (R_{ij}) where ij indicates the position of the relay i.e. i^{th} relay in j^{th} branch in multi-hop multipath channels. There is a direct link from S to D and indirect links are existing from S to relay, relay to relay, finally relay to D. The system consists of L diversity branches (excluding direct link S-D), indicated with B_1, B_2, B_3, …. , B_L and each branch having the M_1, M_2, M_3, …. , M_L number of relays respectively. S and R_{ij} are equipped with n_t number of transmitting antennas but only one antenna will be active at a time due to SSK modulation. Each R_{ij} and D are having $n_{ij,l}$, n_r number of receiving antennas respectively.

The S node will map the data symbols as an index of the antennas with the usage of SSK mapper before transmission. If x is the transmitted symbol, which is considered as a deterministic signal with unit energy then the received signals at the first hop in each branch and node D can be formulated as

$$\boldsymbol{y}_{sr_{1,j}} = \boldsymbol{H}_{sr_{1,j}} x + \eta_{sr_{1,j}},\ j = 1,2,\dots,L \tag{1}$$

$$\boldsymbol{y}_{sd} = \boldsymbol{H}_{sd} x + \eta_{sd} \tag{2}$$

where $\boldsymbol{H}_{sr_{1,j}} \in \mathbb{C}^{n_{i1,j} \times n_t}$ is the channel vector matrix, contains channel coefficients between S to the first hop of each branch i.e. $R_{11,}R_{12,}R_{13\dots\dots}R_{1L}$,$\eta_{sr_{1,j}} \in \mathbb{C}^{n_{i1,j} \times 1}$ is the Additive Gaussian noise vector at first relay,$\boldsymbol{H}_{sd} \in \mathbb{C}^{n_d \times n_t}$ is a channel vector matrix observed from S to D node and $\eta_{sd} \in \mathbb{C}^{n_d \times 1}$ is Additive Gaussian Noise vector at node D.

All the relays are equipped with DF relaying system. According to DF, if the data is correctly decoded, the relay node will only continue forwarding the data; otherwise, the terminal will be discarded. In this process, only some of the branches (out of L+1) may reach D. Let n be the number of branches that reach D where n lies between [0,L] and C be the set of diversity branch indices which contains the set of elements $\{\mathrm{c}_1, \mathrm{c}_2, \mathrm{c}_3, \dots .\mathrm{c}_\mathrm{n}\}$. If the n value is an integer (greater than zero), it means D node receives the signal from the branch. The combined received signal vector at D can be formed as

$$\begin{bmatrix} y_{sd} \\ y_{M_{u_1,d}} \\ \vdots \\ y_{M_{u_n,d}} \end{bmatrix} = \begin{bmatrix} H_{sd} \\ H_{M_{u_1,d}} \\ \vdots \\ H_{M_{u_n,d}} \end{bmatrix} x + \begin{bmatrix} \eta_{sd} \\ \eta_{M_{u_1,d}} \\ \vdots \\ \eta_{M_{u_n,d}} \end{bmatrix} \tag{3}$$

where $y_{M_{u_1,d,}} y_{M_{u_2,d\dots\dots}} y_{M_{u_n,d}}$ are the received signal vectors from the branches those which are giving the symbols $c_1, c_2, c_3, \dots . c_n$ at D node respectively and $H_{M_{u_1,d}} H_{M_{u_2,d}} \dots . H_{M_{u_n,d}}$ are the channel co-efficient matrices between the relays $R_{M_{u_1,u_1}} R_{M_{u_2,u_2}} \dots . R_{M_{u_n,u_n}}$ and D node.

Due to more practical experienced results in different realistic environments Nakagami-*m* channel is considered in the designed system model. Nakagami- *m* channel is a generalized channel and can give the different types of channels by varying the values of m. If m is 0.5 then it gives the one-sided Gaussian channel and acts like a Rayleigh channel when m is 1. If m values are increasing to infinity then the channel becomes a perfect channel. The probability density function (PDF) can be modeled as [11]

$$f_\gamma(\gamma) = \frac{2m^m \gamma^{2m-1}}{\Gamma(m)\Omega^m} \exp(\frac{-m\gamma^2}{\Omega}) \tag{4}$$

where m is the shape parameter ($m \geq 1/2$) and Ω is the spread controlling parameter of Nakagami-m distribution. The channel matrices can also exist between relay to relay i.e., R_{i-1j} to R_{ij} for a single branch j is denoted as $H_{i-1,i,j}$. All channel matrices H_{sd}, $H_{sr_{1,j}}$, $H_{i-1,i,j}$, $H_{M_j,d}$ are modeled as a Nakagami-m fading channels with different average signal to noise ratios (SNR) represented as $\sigma^2_{sd,}$ $\sigma^2_{sr_{1,j},}$ $\sigma^2_{i-1,i,j,}$ $\sigma^2_{M_j,d}$ respectively.

3 Optimal detection for DF relaying system

Let's assume a single relay present in each multipath along with S and D nodes. If the S node transmits the energy E_s by activating the l^{th} antenna at a particular time instant, the received signals at p^{th} relay and D nodes are modeled as

$$y_{sr_p} = \sqrt{E_s} h_{p,l}\, x + \eta_{sr_p}, \quad l = 1,2,\dots,n_t \tag{5}$$

$$y_{sd} = \sqrt{E_s} h_l\, x + \eta_{sd} \tag{6}$$

where $h_{p,l}$ is Nakagami-m fading channel coefficient existing between l^{th} antenna in source and p^{th} relay. η_{sr_p} isa AWGN noise at p^{th} relay. Each relay will perform DF operation and transfer the signal to D, only if it is detected correctly. In this process, some relays may be lost the connection to D. The received signal at D from correctly decoded p^{th}relay is modeled as

$$y_{r_pd} = \sqrt{E_r}\, h_{p,l}\;\; g_p\, x + \eta_{r_pd}\,, \quad l = 1,2,\dots,n_t \tag{7}$$

$$y_{r_pd} = S_{p,l} + \eta_{r_pd} \tag{8}$$

where E_r is transmitted energy at p^{th} relay by activating the l^{th} antenna and g_p is Nakagami-m fading channel co-efficient existing between l^{th} antenna of p^{th} relay and D. Decision metric(D_l) is the parameter in optimal detector to find the exact transmitted signal or antenna index from which the signal is received. Let k be the activated antenna index for the symbol transmission and it can be obtained by the following expression [12]

$$k = \arg \max_{l=1,2,\dots,n_t} \{D_l\} \tag{9}$$

Decision metric (D_l) can be defined as

$$D_l = Re\left\{\int_{T_s} y_{sd} \times h_l^* \, dt\right\} - \frac{1}{2}\int_{T_s} h_l \times h_l^* \, dt + \sum_{p=1}^{n} Re\left\{\int_{T_s} y_{r_p d} \times S_{p,l}^* \, dt\right\} - \frac{1}{2}\int_{T_s} S_{p,l} \times S_{p,l}^* dt \quad (10)$$

Let data symbol is transmitted from u antenna, then the decision metric can be simplified as

$$D_{l|l=u} = \sum_{p\in C} \frac{E_r}{2} \left| h_{p,u} \right|^2 \left|g_p\right|^2 + \frac{E_s}{2}|h_u|^2 + \sum_{p\in C} \sqrt{E_r} \left| h_{p,u} \right| \left|g_p\right| \tilde{n}_{p,1} + \sqrt{E_s}|h_u|\tilde{n}_1 \quad (11)$$

$$D_{l|l\neq u} = \sum_{p\in C} E_r Re\left\{\left|g_p\right|^2 \left| h_{p,l} \right| \left| h_{p,u} \right|\right\} + \frac{E_r}{2}\left| h_{p,l} \right|^2 \left|g_p\right|^2 + \sqrt{E_r}\left| h_{p,u} \right| \left|g_p\right| \tilde{n}_{p,2} + E_s Re\{|h_l||h_u|\} - \frac{E_s}{2}|h_l|^2 + \sqrt{E_s}|h_l|\tilde{n}_2 \quad (12)$$

Where $\tilde{n}_{p,1} = Re\left\{\int_{T_s} \hat{n}_p(t) e^{-(j\emptyset_{p,l})} x^*(t) \; dt\right\}$, $\tilde{n}_{p,2} = Re\left\{\int_{T_s} \hat{n}_p(t) e^{-(j\emptyset_{p,u})} x^*(t) \; dt\right\}$, $\tilde{n}_1 = Re\left\{\int_{T_s} n_{s-d}(t) \times e^{-(j\varphi_l)} x^*(t) \; dt\right\}$, $\tilde{n}_1 = Re\left\{\int_{T_s} \hat{n}_{s-d}(t) \times e^{-(j\varphi_l)} x^*(t) \; dt\right\}$. The instantaneous probability of error can be computed as the sum of two individual probabilities. The first probability occurs when the detection metric value of antenna 1 is greater than antenna 2's metric value but antenna 2 is activated. Similarly, a second probability occurs when the detection metric value of antenna 2 is greater than antenna 1's metric value but antenna 1 is activated.

$$P_e = \frac{1}{2} P_r\left(D_{1|l=1} < D_{2|l=1}\right) + \frac{1}{2} P_r\left(D_{2|l=2} < D_{1|l=2}\right) \quad (13)$$

After implementing some algebraic manipulations, closed form expression for conditional error probability is given as

$$P_e = Q\left(\sqrt{\frac{E_r \sum_{p\in ?} \left|g_p\right|^2 P_s \left| h_{p,2} - h_{p,1} \right|^2 + E_s | h_2 - h_1 |^2}{2N_0}}\right) \quad (14)$$

4 End to End BER Analysis

Let E be the error event which occurred at the destination node after receiving the signals set C and the number of transmitting antennas at source and relays are considered as n_t=2. The conditional error probability of the event E can formulated by remodifying (14) as

$$p(E/\varphi = ?) = Q(\sqrt{\frac{\|h^1 - h^2\|^2}{2\sigma^2}}) \quad (15)$$

$$= Q(\sqrt{\delta}) \quad (16)$$

Here h^p is the p^{th} column in the channel matrix H and $\|h^1 - h^2\|^2 = \left\|h_{sd}^1 - h_{sd}^2\right\|^2 + \sum_{k=1}^{n} \left\|h_{M_{u_k,d}}^1 - h_{M_{u_k,d}}^2\right\|^2$, h_{sd}^p, $h_{M_{u_k,d}}^p$ are the p^{th} column coefficients of H_{sd}, $H_{M_{j},d}$,respectively and σ^2 is the inverse of signal to noise ratio at receiver end.δ be the sum of the n+1 independent Nakagami-m random variable .It can be represented as

$$\delta = \delta_{sd} + \sum_{k=1}^{n} \delta_{M_{u_k,d}} \quad (17)$$

Here $\delta_{sd} = \frac{\left\|h_{sd}^{1} - h_{sd}^{2}\right\|^2}{2\sigma^2}$ and $\delta_{M_{u_k,d}} = \frac{\sum_{k=1}^{n}\left\|h_{M_{u_k,d}}^{1} - h_{M_{u_k,d}}^{2}\right\|^2}{2\sigma^2}$, these expressions can be simplified by [11].The probability density function for the δ_{sd} and $\delta_{M_{u_k,d}}$ are derived as

$$f_{\delta_{sd}(\gamma)} = \mathfrak{H}\langle\left(\frac{m}{2\Omega_{sd}}\right)^{z+1}\gamma^{z} e^{\frac{-m\gamma}{2\Omega_{sd}}}\rangle \tag{18}$$

$$f_{\delta_{M_{u_k,d}}(\gamma)} = \mathfrak{H}\langle(\frac{m}{2\Omega_{M_{u_k,d}}})^{z+1}\gamma^{z} e^{\frac{-m\gamma}{2\Omega_{M_{u_k,d}}}}\rangle \tag{19}$$

Where the operator $\mathfrak{H}\langle\chi\rangle$can be defined as

$$\mathfrak{H}\langle\chi\rangle = \sum_{x=0}^{m-1}\sum_{y=0}^{m-1}\frac{(x+y)!\,(1-m)_x(1-m)_y}{(x!)^2(y!)^2 2^{x+y}}\sum_{z=0}^{x+y}\frac{(-(x+y))_z}{(z!)^2}\chi\,. \tag{20}$$

Spreading parameter, $\Omega_{sd} = \frac{\sigma_{sd}^2}{\sigma^2}$, $\Omega_{M_{u_k,d}} = \frac{\sigma_{M_{u_k,d}}^2}{\sigma^2}$. The average conditional error probability is given by averaging (16) as

$$p(E/\varphi = \square) = \int_0^{\infty} Q(\sqrt{\gamma}) f_{\delta}(\gamma)\ d\gamma \tag{21}$$

$$= \int_0^{\infty}\frac{1}{\pi}\int_0^{\frac{\pi}{2}} e^{(-\frac{\gamma}{2\sin^2\theta})}\, d\theta f_{\delta}(\gamma)\ d\gamma \tag{22}$$

$$= \int_0^{\infty}\frac{1}{\pi}\int_0^{\frac{\pi}{2}} e^{(-\frac{\gamma}{2\sin^2\theta})}\, d\theta f_{\delta}(\gamma)\ d\gamma$$

$$= \frac{1}{\pi}\int_0^{\frac{\pi}{2}}\int_0^{\infty} e^{(-\frac{\gamma}{2\sin^2\theta})}\, f_{\delta}(\gamma)\, d\gamma\, d\theta$$

$$= \frac{1}{\pi}\int_0^{\frac{\pi}{2}} M_{\delta}(-\frac{\gamma}{2\sin^2\theta})\, d\theta. \tag{23}$$

Here $M_{\delta}(v)$, $v = -\frac{\gamma}{2\sin^2\theta}$, is the Moment generating function δ. But δ is sum of the $n+1$ random variables. From the property [13], $M_{\delta}(v)$ can be written as

$$M_{\delta}(v) = M_{\delta_{sd}+\sum_{k=1}^{n}\delta_{M_{u_k,d}}}(v) = M_{\delta_{sd}}(v).\prod_{k=1}^{n} M_{\delta_{M_{u_k,d}}}(v) \tag{24}$$

The Equation (23) can be modified as

$$p(E/\varphi = \square) = \frac{1}{\pi}\int_0^{\frac{\pi}{2}} M_{\delta_{sd}}\left(-\frac{\gamma}{2\sin^2\theta}\right).\prod_{k=1}^{n} M_{\delta_{M_{u_k,d}}}\left(-\frac{\gamma}{2\sin^2\theta}\right) d\theta \tag{25}$$

The functions $M_{\delta_{sd}}(v)$ and $M_{\delta_{M_{u_k,d}}}(v)$ are the moment generating functions of δ_{sd} and $\delta_{M_{u_k,d}}$ random variables and can be simplified as follows.

$$M_{\delta_{sd}}\left(-\frac{\gamma}{2\sin^2\theta}\right) = \int_0^{\infty} e^{(-\frac{\gamma}{2\sin^2\theta})}\, f_{\delta}(\gamma) d\gamma \tag{26}$$

$$= \int_0^{\infty} e^{(-\frac{\gamma}{2\sin^2\theta})}\,\mathfrak{H}\langle(\frac{m}{2\Omega_{sd}})^{z+1}\gamma^{z} e^{\frac{-m\gamma}{2\Omega_{sd}}}\rangle\, d\gamma \tag{27}$$

Using (20) ,the above expression can be simplified as

$$= \mathfrak{H}\langle(\frac{m}{2\Omega_{sd}})^{z+1}\int_0^{\infty} e^{(-\frac{\gamma}{2\sin^2\theta})}\,\gamma^{z} e^{\frac{-m\gamma}{2\Omega_{sd}}}\, d\gamma\rangle \tag{28}$$

$$= \mathfrak{H}\langle\left(\frac{m}{2\Omega_{sd}}\right)^{z+1}\frac{\Gamma(z+1)}{\left(\frac{1}{2\sin^2\theta}+\frac{m}{2\Omega_{sd}}\right)^{z+1}}\rangle \quad (29)$$

$$= \mathfrak{H}\langle\Gamma(z+1)\left(\frac{\Omega_{sd}}{m\sin^2\theta}+1\right)^{-(z+1)}\rangle \quad (30)$$

Integration in (28) is solved from [14, (3.351)] under the constraint $\frac{1}{2\sin^2\theta}+\frac{m}{2\Omega_{sd}}>0$ and the expression is further simplified as (30). Similarly the MGF, $M_{\delta_{M_{u_k,d}}}(v)$ can also be obtained as

$$M_{\delta_{M_{u_k,d}}}\left(-\frac{\gamma}{2\sin^2\theta}\right) = \mathfrak{H}\langle\Gamma(z+1)\left(\frac{\Omega_{M_{u_k,d}}}{m\sin^2\theta}+1\right)^{-(z+1)}\rangle \quad (31)$$

Moment generating functions, (30) and (31) are substituted in (25) then the final expression is given as

$$p(E/\varphi = ⍰) = \frac{1}{\pi}\int_0^{\frac{\pi}{2}}\mathfrak{H}\langle\Gamma(z+1)\left(\frac{\Omega_{sd}}{m.\sin^2\theta}+1\right)^{-(z+1)}\rangle.\prod_{k=1}^{n}\mathfrak{H}\langle\Gamma(z+1)\left(\frac{\Omega_{M_{u_k,d}}}{m.\sin^2\theta}+1\right)^{-(z+1)}\rangle\, d\theta \quad (32)$$

If all channels having the same spreading parameter is considered, then (32) can be modified as

$$p(E/\varphi = ⍰) = \frac{1}{\pi}\int_0^{\frac{\pi}{2}}\left(\mathfrak{H}\langle\Gamma(z+1)\left(\frac{\Omega_{sd}}{m.\sin^2\theta}+1\right)^{-(z+1)}\rangle\right)^{(n+1)} d\theta \quad (33)$$

The total probability of received signal at destination node can be formulated as

$$p(\varphi = ⍰) = \prod_{l\in U}P(C_l)\prod_{q\in U'}(1-P(C_q) \quad (34)$$

Where C_l is the event of diversity branch B_l for that index, being present in the set ⍰ and q is the index of that branch which is not present in the set C, and the probability of the event C_l can be defined as

$$P(C_l) = (1-P(E_{sr_1}^l))\prod_{a=2}^{M_l}(1-P(E_{a-1,a}^l)) \quad (35)$$

Here $E_{sr_1}^l$ is the error event that occurred between the source and first relay in l^{th} branch and similarly $E_{a-1,a}^l$ is the error event occurred between two relays. The average total probability of error for a single branch l is given as [9]

$$P(E_{sr_1}^l) = \int_0^\infty Q(\sqrt{\lambda})f_{\delta_{sr_1}}(\lambda)d\lambda \quad (36)$$

In the above expression, $f_{\delta_{sr_1}}(\lambda)$ is the probability density function (PDF) for a random variable δ_{sr_1}, which exist between source to first relay. The random variable is obtained from the designed system model is $\delta_{sr_1} = \frac{\left\|h_{sr_1,l}^1-h_{sr_1,l}^2\right\|^2}{2\sigma^2}$, where $h_{sr_1,l}^p$ is the pth column coefficients of $H_{sr_1,l}$.

$$P(E_{sr_1}^l) = \int_0^\infty\int_{\sqrt{\lambda}}^\infty\frac{e^{-\frac{v^2}{2}}}{\sqrt{2\pi}}dv\left(\mathfrak{H}\langle\left(\frac{m}{2\Omega_{sr_1}}\right)^{z+1}\lambda^z e^{\frac{-m\lambda}{2\Omega_{sr_1}}}\rangle\right)d\lambda \quad (37)$$

$$= \int_0^\infty\int_0^{v^2}\left(\mathfrak{H}\langle\left(\frac{m}{2\Omega_{sr_1}}\right)^{z+1}\lambda^z e^{\frac{-m\lambda}{2\Omega_{sr_1}}}\rangle\right)d\lambda.\frac{e^{-\frac{v^2}{2}}}{\sqrt{2\pi}}dv \quad (38)$$

$$= \int_0^\infty\left(\mathfrak{H}\langle\left(\frac{m}{2\Omega_{sr_1}}\right)^{z+1}\int_0^{v^2}\lambda^z e^{\frac{-m\lambda}{2\Omega_{sr_1}}}\,d\lambda\rangle\right)\frac{e^{-\frac{v^2}{2}}}{\sqrt{2\pi}}dv \quad (39)$$

$$= \int_0^\infty \left(\mathfrak{H} \langle \Upsilon(z+1, \frac{m}{2\Omega_{sr_1}} v^2) \rangle \right) \frac{e^{-\frac{v^2}{2}}}{\sqrt{2\pi}} dv \tag{40}$$

$$= \frac{1}{2\sqrt{2\pi}} \left(\mathfrak{H} \langle \int_0^\infty t^{-\frac{1}{2}} e^{-\frac{t}{2}} \Upsilon(z+1, \frac{m}{2\Omega_{sr_1}} t)\, dt \rangle \right) \tag{41}$$

$$= \frac{1}{2\sqrt{2\pi}} \left(\mathfrak{H} \langle \frac{\left(\frac{m}{2\Omega_{sr_1}}\right)^{z+1} \Gamma(z+\frac{3}{2})}{(z+1)(\frac{m}{2\Omega_{sr_1}}+\frac{1}{2})^{z+\frac{3}{2}}} 2F_1(1, z+\frac{3}{2}; z+2; \frac{\frac{m}{2\Omega_{sr_1}}}{\frac{m}{2\Omega_{sr_1}}+\frac{1}{2}}) \rangle \right) \tag{42}$$

The Equation (38) is obtained by changing the order of integration and internal integration in (39) is evaluated on the basis of [14, (3.351)] and named as (40), where $\Upsilon(.,.)$ is a incomplete gamma function. Changing the variable $v^2 = t$ then (40) is modified as (41). Integration is solved using [14, (6.455)] and finally the simplified expression is framed in (42), where $\Omega_{sr_1} = \frac{\sigma^2_{sr_1,l}}{\sigma^2}$, spreading constant between source to first relay of the l^{th} branch and $2F_1(.,.;.;.)$ is the hypergeometric fuction. Similarly the average error probability between relay to relay $\left(P\left(E^l_{a-1,a}\right)\right)$ and last relay to destination $\left(P\left(E^l_{M_l,d}\right)\right)$can also be derived as

$$P\left(E^l_{a-1,a}\right) = \frac{1}{2\sqrt{2\pi}} \left(\mathfrak{H} \langle \frac{\left(\frac{m}{2\Omega_{a-1,a,l}}\right)^{z+1} \Gamma(z+\frac{3}{2})}{(z+1)(\frac{m}{2\Omega_{a-1,a,l}}+\frac{1}{2})^{z+\frac{3}{2}}} 2F_1(1, z+\frac{3}{2}; z+2; \frac{\frac{m}{2\Omega_{a-1,a,l}}}{\frac{m}{2\Omega_{a-1,a,l}}+\frac{1}{2}}) \rangle \right) \tag{43}$$

$$P\left(E^l_{M_l,d}\right) = \frac{1}{2\sqrt{2\pi}} \left(\mathfrak{H} \langle \frac{\left(\frac{m}{2\Omega_{M_l,d}}\right)^{z+1} \Gamma(z+\frac{3}{2})}{(z+1)(\frac{m}{2\Omega_{M_l,d}}+\frac{1}{2})^{z+\frac{3}{2}}} 2F_1(1, z+\frac{3}{2}; z+2; \frac{\frac{m}{2\Omega_{M_l,d}}}{\frac{m}{2\Omega_{M_l,d}}+\frac{1}{2}}) \rangle \right) \tag{44}$$

where $\Omega_{a-1,a,l} = \frac{\sigma^2_{a-1,a,l}}{\sigma^2}, \Omega_{M_l,d} = \frac{\sigma^2_{M_l,d}}{\sigma^2}$ are the spreading constants in relay to relay and last relay to destination channel links.

The total end to end probability of the event can be modelled as

$$P(E) = \sum_{\varphi \in U} P(\varphi) P({}^{E}/_{\varphi}) \tag{45}$$

The above probability only includes the branches which are reached to destination node.

5 Results And Discussion

The analytical expression for end-to-end probability of error is derived over independent and identically distributed Nakagami-*m* fading channels as a function of signal-to-noise ratio (SNR). Here $\frac{1}{\sigma^2}$ is considered as SNR. The analytical expressions (33), (42), (43), (44) are derived for 2×1 MISO at each node, and results are plotted as BER vs SNR for different conditions. In all cases σ^2_{sd}, $\sigma^2_{a-1,a,l}$, $\sigma^2_{M_{u_k},d}$are assumed to be 0dB. Fig.2 depicts the probability of error (BER) vs SNR for two paths cooperative communication scenario by changing the number of relays in each path. All paths are assumed to be having the same number of relays and acquire the results for $M_1 = M_2 = 2,3,4$. For an instance at SNR -2dB, BER value obtained as

4.06829×10^{-2}, 2.72167×10^{-2}, and 1.82078×10^{-2} for $M_1 = M_2 = 2, 3, 4$ respectively. It can be observed from Fig.2 that the error performance improved by increasing the number of relays in each path.

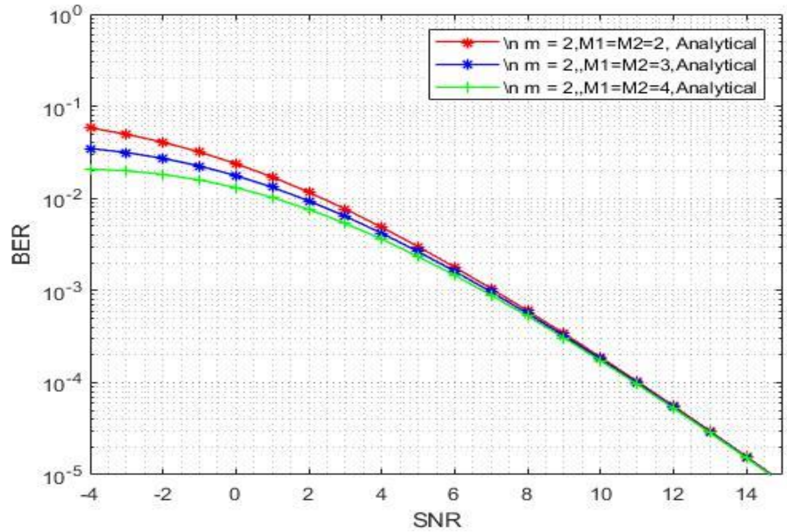

Fig. 2. BER comparison for different number of relays in each path over a Nakagami-*m* fading channels.

Nakagami-*m* fading channel is mainly depends on the channel shape parameter (m). Fig.3 shows a plot of BER vs. SNR produced by changing m=1, 2, 3 for a specific value of $M_1 = M_2 = 2$.It is observed that when the m values increase, the BER steadily decreases at low SNR values, while at high SNR values, the BER contradicts. However, if the m value continues to rise, the channel will become an ideal channel with a better BER.

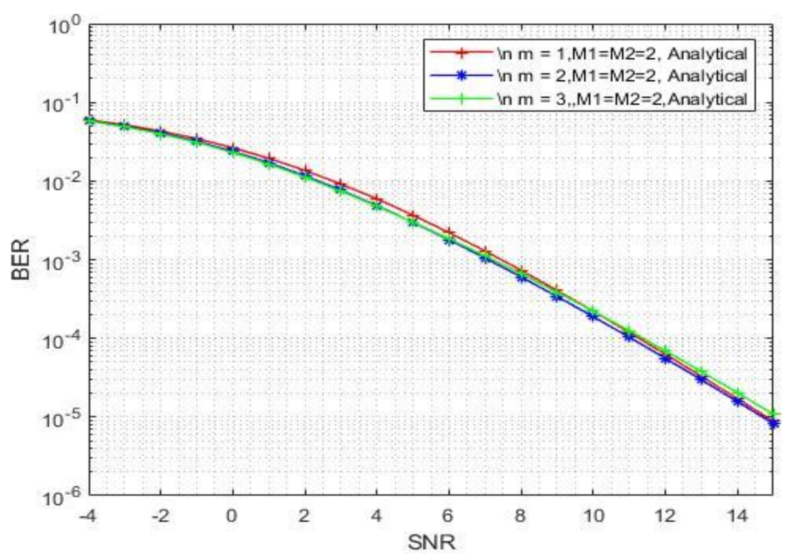

Fig. 3.BER comparison for different values of m in Nakagami-*m* fading channels

Due to the presence of DF amplifier, all multiple paths data may not reach to destination node. Fig. 4 illustrates a BER plot for different numbers of multiple paths (L=2,3,4). In this case, all channels are not considered to reach the final destination without any errors. When L=2, no path is considered to be terminated at middle of communication whereas in the cases of L=3 and L=4, one path (k=1) and two paths (k=2) are assumed to be lost the link in the middle respectively. For an instance at SNR -2dB, BER value obtained as 4.06829×10^{-2}, 1.34662×10^{-2}, and 4.45736×10^{-3} for $\mathrm{L} = 2, 3, 4$ respectively. It can be observed that BER performance is improved when the number of paths in the communication is increased.

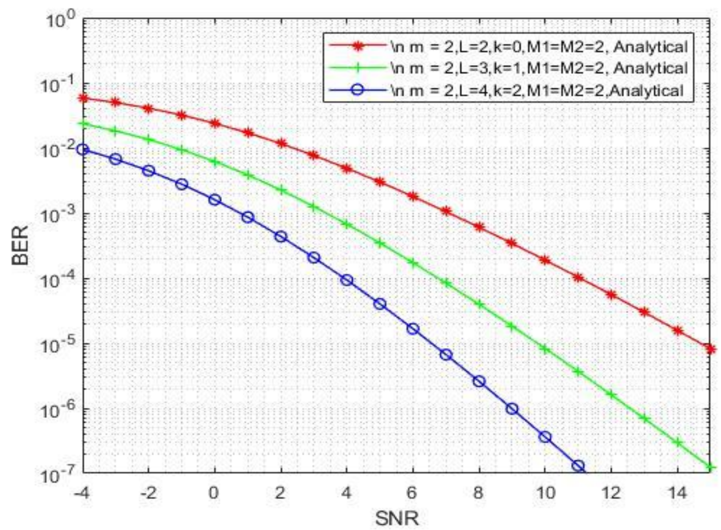

Fig. 4.BER comparison for different number of multipaths with same number of relays over a Nakagami-*m* fading channels

Perfect data reception depends on the channel co-efficient in wireless communication systems. The BER vs. SNR plot is produced by changing the various values of $\sigma_{sd}^2 = \sigma_{a-1,a,l}^2 = \sigma_{M_{u_k},d}^2$displayed in Fig.5. The plot includes three distinct values, such as -1dB, 0dB and 1dB. σ_{sd}^2, $\sigma_{a-1,a,l}^2$, $\sigma_{M_{u_k},d}^2$arise as a result of different loses in the communication system.For an instance at SNR -2dB, BER value obtained as 4.97128×10^{-2} , 4.06829×10^{-2} , and 3.1861×10^{-2} for $\mathrm{w} = -1\mathrm{dB}, 0\mathrm{dB}, 1\mathrm{dB}$ respectively. It resembles that the cooperative wireless communication system will provide better performance when moving from -1dB to 1dB.

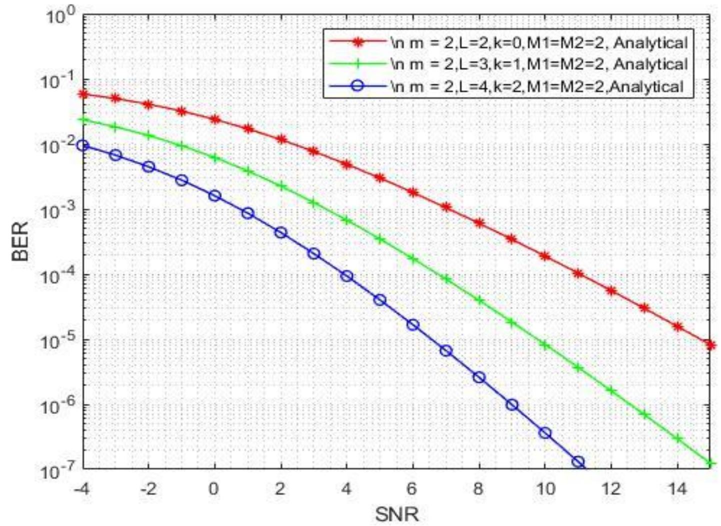

Fig. 5.BER comparison for different values of $\sigma_{sd}^2 = \sigma_{a-1,a,l}^2 = \sigma_{M_{u_k},d}^2$over a Nakagami-$m$ fading channels

6 Conclusion

The closed-form expression for end-to-end BER is derived for SSK modulation of multi-hop multipath DF relaying system over Nakagami-m channels. The analysis of the considered system implies that there is an improvement in the system performance when increasing the number of relays in each path. Moreover, it is noticed that by increasing the channel shape parameter value at low SNR, we can improve the overall system performance. Similarly, the performance increases by increasing the number of paths and channel co-efficient values in the considered Nakagami-m fading channel. The overall system complexity is reduced by the inclusion of the SSK modulation scheme. This type of wireless communication scenario will be helpful in the IoT systems for better data transfer schemes in the upcoming 6G networks.

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