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The Performance Enhancement of Dual Relay Cooperative Wireless Network in Rician Fading Channel

Imran Ullah Khan, Tan Chong Eng

Abstract— ***The aim of this study was to investigate the performance enhancement of dual relay cooperative wireless network by using Amplify and Forward (AF) relaying protocol in Rician fading channel with different K-factors. The bit error rate (BER) and BER gain by using AF scenario in Rician fading channel are derived. The results obtained from the proposed models are compared to AF scenario in Rayleigh and Nakagami-m fading channels. It is found that the proposed BER model of AF cooperative scenario outperform as compared to non cooperative scenario in terms of less BER. It is indicated that at lower values of K (i.e., at severe fading as well as weak LOS reception), the proposed model of AF scenario in Rician fading channel showed less BER as compared to AF scenario in Rayleigh fading channel (i.e., K=0, which denotes severe fading as well as the scenario where LOS component completely vanishes and reception becomes non-LOS). It is shown that at severe fading (i.e., at lower K values) while keeping lower signal to noise ratio (SNR) the proposed model showed less BER. However, the proposed model shows constant BER as K approaches to infinity (i.e., the BER performance approaches AWGN channel error performance) while keeping low SNR values .It is also revealed that with the increase in K values 1 to 60 (i.e., decrease in severe fading to lowest fading as well as an increase from weak to strong LOS reception) the proposed model showed less BER and high BER gain as compared to Nakagami-m channel while keeping low values of SNR (i.e., 1-18dB).***

Key words: Bit error rate, bit error rate gain, Rician fading channel, cooperative network.

I. INTRODUCTION

The transmitted signal weakens when it travels from transmitter to receiver owing to the fading nature of the wireless channels. Cooperative communication is used to diminish the fading effects of the wireless channels by transmitting copies of the original signal through multiple relays. Due to this interesting phenomenon researchers took deep interest in cooperative diversity wireless networks. The cooperative diversity communication is parallel combination of direct communication (LOS) and communication through relays as shown in Fig. 1. The source broadcasts signal simultaneously to destination and relay. The relay amplifies and forwards the signal toward destination. The destination then combines the two received signals as well as extracts the information sent by the source.

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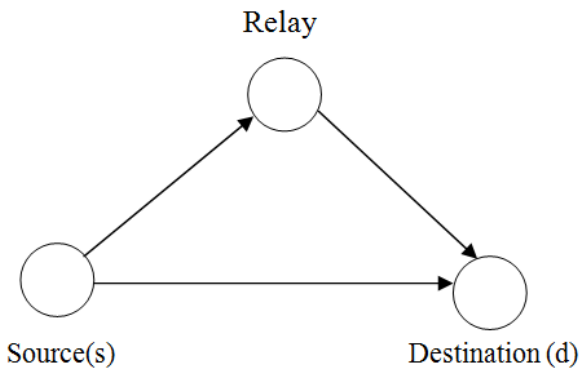

Fig.1. Single Relay Cooperative Network

The relays can be fixed or mobile stations, mostly use amplify and forward (AF) or decode and forward (DF) protocols. Cooperative communication uses different diversity techniques at the receiver to receive multiple copies of the original transmitted signal. These diversity techniques are frequency diversity, time diversity and spatial diversity. The most used technique is spatial diversity which takes the broadcast nature of wireless communication as well as the source and relay signal which is jointly processed at the receiver and hence achieves spatial diversity [1]. Furthermore, cooperative communication uses different protocols to achieve spatial diversity through node cooperation [1], [2]. The most widely used protocols of cooperative communication are AF and DF.

II. RELATED WORK

The performance of cooperative wireless networks over different fading channels has been investigated by many researchers by using a variety of modulation schemes. Different approaches like Probability Density Function (PDF), Moment Generating Function (MGF), Cumulative Distributive Function (CDF), Gamma function, Gauss hyperbolic functions have been used to derive the bit error rate (BER) and probability of outage at the receiver intended for different protocols (specifically AF and DF). For example, Laneman et al. [2] has described low complexity cooperative protocols (AF and DF) which are used to enable wireless nodes using a single antenna in order to fully exploit the spatial diversity in the channel. Analysis showed that these protocols perform well more specifically in the low spectral efficiency regimes. However, the analysis is restricted only to Rayleigh fading channel only. Moreover, there is cost issue associated with these protocols. Due to this phenomenon, an additional hardware is required for relaying the messages specifically intended for the case of multi-hop wireless network using frequency division multiplexing. Sendonaris et al. [3], [4] proposed a new cooperative diversity technique which is used to get an advantage of spatial diversity. By using this technique single antenna mobiles in multiuser environment share their antennas to generate virtual multiple antennas arrays in order to achieve spatial diversity. The performance analysis was carried out by using the low-rate CDMA implementation. However, the analysis of the new approach is only limited to additive white Gaussian noise channel.Hunter and Nosratinia [5], [6] achieved cooperative diversity using the channel coding. An inspiring gain was achieved using coded cooperation in contrast to non-cooperative scenario while maintaining the same information rate, transmit power and bandwidth. Nevertheless, analysis was limited only to Rayleigh fading channel. Further investigation is needed to deeply study the performance of coded cooperation over Rician and Nakagami-m fading channels.

Hasna and Alouini [7] derived PDF, CDF and MGF of the harmonic mean of two independent exponential random variables by using non-regenerative systems regarding single relay cooperative network. The average BER expressions for binary differential phase shift keying as well as outage probability formulas for noise limited systems have been derived also. They presented results which show that the non-regenerative system outperforms the regenerative system intended for low average signal to noise ratio. Moreover, the two systems show similar performance at high SNR. However, the system analysis was limited only by using the Rayleigh fading channel.

Ikki and Ahmed [8] described the performance of multiple relays cooperative wireless network using AF scenario over independently non-identical Nakagami-*m* fading channels. The multiple relays were used to provide manifold copies of the original signal at destination. Analysis was performed to derive BER and outage probability as well as the closed form approximations for PDF and MGF. Their results revealed that the derived BER and outage probability were tight lower bound at medium and high SNR. In addition, analysis was limited only to Nakagami-*m* fading channels with respect to the BPSK modulation.

Furthermore, by using the MGF approach over fading channels by Simon and Alouini [9] can be used to obtain the SEP rate in Hasna and Alouini [7] and BER in Ikki and Ahmed [8] for wide variety of M-array modulation schemes.

Ribeiro et al. [10] derived average symbol error probability (SEP) for general AF multi-relay cooperative links with the aid of maximum ratio combining (MRC) at receiver in order to receive multiple copies at the destination. However, due to the simplicity of derived expressions this method can be used to analyze complex cooperative links with any number of hops and branches. It is valid for large class of fading channels including Rayleigh and Rician fading channels. However, a complex mathematical tool was used developed by Zhengdao et al. [11]. In addition, simple MGF approach over fading channels by Simon and Alouini [9] could be used for the derivation as well as to use SEP for wide variety of modulation schemes. Yang and Chen [12] investigated the performance of the multiple dual-hop relay cooperative network concerning SEP to achieve cooperative diversity. In addition, MRC was used to obtain total SNR at destination. A closed form expressions were derived for the PDF of relay-channels as well as SER regarding the cooperative system mode. The SER obtained was tightly lower bound within the medium to high SNR regions. However, the derived expressions could be used to evaluate the SER for many coherent modulations schemes. In addition, the derived expressions were restricted only to Nakagami-*m* fading channel. Limpakom et al. [13] investigated the performance of dual hop single relay cooperative network over Rician fading channel by using different K-factor. The MRC technique was used at destination for received signals. Moreover, the MGF approach was used to derive the closed form expressions of PDF on behalf of the system model used. The derived expressions are limited to obtain SER by using Rician fading channel for a single modulation scheme. Further investigation is needed to derive SER in Rician channel for a variety of modulation schemes. It was revealed from the results that an increase in K values consequences in a decrease in outage probability. Similarly, for the same K values the wireless cooperative systems outperform as compared to the non-cooperative wireless systems in terms of outage probability. Adeane et al. [12] described the performance of single relay cooperative wireless network over Rician fading channel. The average BER and BER gain were derived at the destination for user-1. The derived expressions used simple MGF approach by using Rician fading channels as compared to [7], [8], [13]. Analysis showed that at low K-factor values BER gain obtained from cooperation is found to be greater than that available in Rayleigh channels. The derivation of BER is limited only to single relay network in Rayleigh. Further investigation is needed to derive BER and SER for multi-relay network by using Rayleigh and Rician fading channels.

Mainly the related work regarding the analysis of cooperative networks consider the Rayleigh channel model [2], [3], [4], [5], [6], [7], [10]. The Nakagami-*m* model was well thought-out for the performance analysis [8], [12]. In addition, the Rician channel model was considered for the performance analysis [10], [13], [14]. However, complex mathematical functions like gamma and Gauss hyperbolic functions have been used for derivations of closed form expressions regarding BER and outage probability [7], [8], [12], [13]. In addition, the analysis of BER and BER gain is limited to single relay cooperative network [9].

In this paper the performance analysis of dual relay wireless cooperative network over Rician fading channel has been investigated to understand the performance in application where LOS path exists. Simple MGF technique over fading channels by Simon and Alouini [9] has been used for the derivation of BER and BER gain. Binary phase shift keying technique is used as a modulation scheme.

III. SYSTEM MODEL AND ANALYSIS

The system model consists of source and destination along with two relays as shown in Fig. 2. The source communicates to destination directly as well as through two relays. Relays assist the source to provide copies of the original signal to the destination. The Rician fading channel using *K* fading factor is considered as the fading channel. The *AF* scenario is considered for the analysis.

The received signal to noise ratio *(SNR)* at the destination owing to relay 2 is shown by eq. (1).

$$\gamma_{eq1} = \frac{\gamma_{sr2}\gamma_{r2d}}{\gamma_{sr2} + \gamma_{r2d}} \tag{1}$$

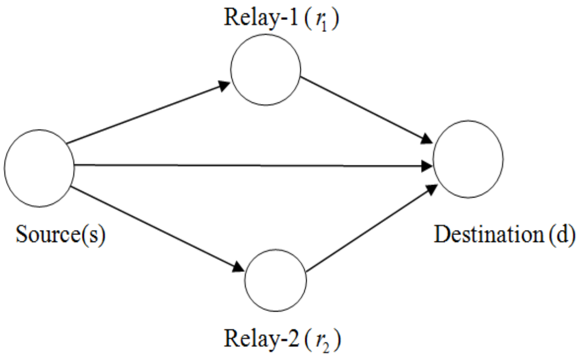

Fig.2. Two relay cooperative wireless network

The received *SNR* at the destination as a consequence of relay 1 is

$$\gamma_{eq2} = \frac{\gamma_{sr1}\gamma_{r1d}}{\gamma_{sr1} + \gamma_{r1d}} \tag{2}$$

However, assuming *MRC* at the destination the total *SNR* meant for received signal as of direct and two hops paths can be written by eq. (3), [8], [14], [15]

$$\gamma_{MRC} = \gamma_0 + \gamma_{eq1} + \gamma_{eq2} \tag{3}$$

Substituting (1) and (2) into (3), the total *SNR* can be expressed by eq. (4) as

$$\gamma_{MRC} = \gamma_o + \frac{\gamma_{sr2}\gamma_{r2d}}{\gamma_{sr2} + \gamma_{r2d}} + \frac{\gamma_{sr1}\gamma_{r1d}}{\gamma_{sr1} + \gamma_{r1d}} \tag{4}$$

Where $\gamma_{sr1} = h_{sr1}E_s / N_0$ is the signal to noise ratio regarding the path between source and relay 1, $\gamma_{r1d} = h_{r1d}E_s / N_0$ is the SNR of the path between relay 1 and destination, $\gamma_{sr2} = h_{sr2}E_s / N_0$ is the SNR2 with respect to the path between source and relay 2, $\gamma_{r2d} = h_{r2d}E_r / N_0$ is the signal to noise ratio concerning the path between relay 2 and destination, $\gamma_0 = h_0E_s / N_0$ is the signal to noise ratio of direct path *(LOS)* between source and destination. E_s and E_r are the source and relay energies respectively. Hence, the probability of bit error using *MRC* approach can be expressed by eq. (5). Furthermore, the Q-function while using the error function can be expressed by eq. (6).

A. *Alternative Expression for Probability of Erro*

$$Pe_{sd}^{(AF-Non\_cooperative)} = \frac{1}{\pi}\int_0^{\pi/2} \frac{\sin^2\theta + K_{sd}\sin^2\theta}{(1+K_{sd})\sin^2\theta + \overline{\gamma_{sd}}} \exp\left(-\frac{K_{sd}\overline{\gamma_{sd}}}{(1+K_{sd})\sin^2\theta + \overline{\gamma_{sd}}}\right) \times \frac{\sin^2\theta + K_{r1d}\sin^2\theta}{(1+K_{r1d})\sin^2\theta + \overline{\gamma_{r1d}}} \exp$$

$$\times \frac{(1+K_{r2d})\sin^2\theta}{\sin^2\theta + K_{r2d}\sin^2\theta + \overline{\gamma_{r2d}})} \exp\left(-\frac{K_{r2d}\overline{\gamma_{r2d}}}{\sin^2\theta + K_{r2d}\sin^2\theta + \overline{\gamma_{r2d}}}\right) d\theta \tag{13}$$

$$Pe_{sd}^{(AF-Non\_cooperative)} =$$

$$\frac{1}{\pi}\int_0^{\pi/2} \frac{\sin^2\theta + K_{sd}\sin^2\theta}{(1+K_{sd})\sin^2\theta + \overline{\gamma_{sd}}} \exp\left(-\frac{K_{sd}\overline{\gamma_{sd}}}{(1+K_{sd})\sin^2\theta + \overline{\gamma_{sd}}}\right)$$

$$\prod_{l=1}^{2}\left(\frac{\sin^2\theta + K_l\sin^2\theta}{(1+K_l)\sin^2\theta + \bar{\gamma}_l}\right) \exp\left(-\frac{K_l\bar{\gamma}_l}{(1+K_l)\sin^2\theta + \bar{\gamma}_l}\right)$$

(14)

The alternative expression for the Gaussian Q-function can be expressed by eq. (7), [14], [16]

$$P_e^{(AF)} = Q\sqrt{2\left(\gamma_0 + \frac{\gamma_{sr2}\gamma_{r2d}}{\gamma_{sr2} + \gamma_{r2d}} + \frac{\gamma_{sr1}\gamma_{r1d}}{\gamma_{sr1} + \gamma_{r1d}}\right)}$$

(5)

$$Q(z) = \frac{1}{2} erfc\left(\frac{z}{\sqrt{2}}\right) \tag{6}$$

$$Q(x) = \frac{1}{\pi}\int_0^{\pi/2} \exp\left(-\frac{x^2}{2\sin^2\theta}\right) d\theta, \quad x \geq 0 \tag{7}$$

Similarly, the total average probability of error for source at the destination can be shown by eq. (8). [9], [14], [17]

$$Pe_{SD}^{(AF)} = \frac{1}{\pi}\int_0^{\pi/2} M_{\gamma(sd)}(s) M_{\gamma(sr_1d)}(s) M_{\gamma(sr_2d)}(s) d\theta$$

(8)

Where $M_X(.)$ is MGF of the random variable s. However, the probability density function of Rician distributed random variable X has been expressed by eq. (9). [14], [17]

$$p_X(x) = \frac{x}{\sigma^2} e^{-\frac{x^2+A^2}{2\sigma^2}} I_0\left(\frac{Ax}{\sigma^2}\right), \; x \geq 0$$

(9)

Where, A is the peak amplitude of the LOS component and $I_0(.)$ is the 0^{th} order modified Bessel function of the first kind. Moreover, the probability distribution function of the SNR per symbol can be expressed eq. (10), [8]. Where, $\bar{\gamma}$ is the average *SNR* per symbol, $K=A^2/2\theta^2$ is the ratio of the power of the LOS component to that of the scattered signals, and σ is the standered deviation of real and imaginary Gaussian

$$p_\gamma(\gamma) = \frac{(1+K)e^{-K}}{\bar{\gamma}} \exp\left(-\frac{(1+K)\gamma}{\bar{\gamma}}\right) \times I_o\left[2\sqrt{\frac{K(K+1)\gamma}{\bar{\gamma}}}\right]$$

(10)

The MGF of the received SNR over Rician fading can be expressed by eq. (11), [8], [9], [17]

$$M_\gamma(s) = \frac{(1+K)}{(1+K) - s\bar{\gamma}} \exp\left[\frac{sK\bar{\gamma}}{(1+K) - s\bar{\gamma}}\right]$$

(11)

Furthermore, the average BER of a LOS transmission between source and destination non-cooperative scenario can be expressed by eq. (15)

$$Pe_{sd}^{(NC)} = \frac{1}{\pi}\int_0^{\pi/2} \frac{\sin^2\theta + K_{sd}\sin^2\theta}{(1+K_{sd})\sin^2\theta + \gamma_{sd}} \exp\left(-\frac{2K_{sd}\overline{\gamma_{sd}}}{(1+K_{sd}\sin^2\theta + 2\overline{\gamma_{sd}})}\right) d\theta$$

……………(15)

From equations (11) and (8) the probability of bit error rate intended for source at the destination can be expressed by eq. ……………(12).

$$Pe_{SD}^{(AF)} = \frac{1}{\pi}\int_0^{\pi/2} \frac{(1+K_{sd})}{(1+K_{sd}) - s\bar{\gamma}} \exp\left[\frac{sK_{sd}\bar{\gamma}}{(1+K_{sd}) - s\bar{\gamma}}\right] \times \frac{(1+K)}{(1+K) - s\bar{\gamma}} \exp\left[\frac{sK_{sr_1d}\bar{\gamma}}{(1+K_{sr_1d}) - s\bar{\gamma}}\right]$$

$$\times \frac{(1+K_{sr_2d})}{(1+K_{sr_2d}) - s\bar{\gamma}} \exp\left[\frac{sK_{sr_2d}\bar{\gamma}}{(1+K_{sr_2d}) - s\bar{\gamma}}\right] d\theta$$

(12)

Substituting s = -(g/sin^{2}θ) and g=1 as well as using equations (8), (11) and (12), the BER at the destination for AF scenario using non-

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symmetrical links (i.e., $\bar{\gamma}_{r1d} \neq \bar{\gamma}_{r2d}$) regarding dual relay cooperative wireless network can be derived as shown by eq. (13). Likewise, for AF scenario using symmetrical links (i.e., $\bar{\gamma}_{r1d} = \bar{\gamma}_{r2d}$), the BER in eq. (13) reduces to eq. (14). Furthermore, the average BER of a LOS transmission between source and destination non-cooperative scenario can be expressed as

$$Pe_{sd}^{(NC)} = \frac{1}{\pi}\int_0^{\pi/2} \frac{\sin^2\theta + K_{sd}\sin^2\theta}{(1+K_{sd})\sin^2\theta + \bar{\gamma}_{sd}} \exp\left(-\frac{2K_{sd}\bar{\gamma}_{sd}}{(1+K_{sd}\sin^2\theta + 2\bar{\gamma}_{sd})}\right)d\theta$$

(15)

Finally, the BER gain of AF scenario at a particular SNR can be shown as

$$\text{BER gain} = \frac{Pe_{sd}^{(AF-cooperative)}}{Pe_{sd}^{(Non-cooperative)}}$$

(16)

Where, $Pe_{sd}^{(AF-cooperative)}$ is the probability of bit error for AF cooperative scenario and $Pe_{sd}^{(Non-cooperative)}$ is the probability of bit error intended for non-cooperative scenario.

IV. NUMERIC SIMULATION AND RESULTS

Numeric simulation was performed to examine the performance enhancement of dual relay cooperative wireless network in Rician channel using the derived BER and BER gain of AF protocol. The BER for cooperative and non-cooperative AF scenarios using Rician fading channel is shown in Fig. 3 and Fig. 4 respectively. Symmetrical links (i.e., γ_{r1d} = γ_{r2d}) are used for AF cooperative scenario. It is found that the proposed BER model of AF cooperative scenario outperform as compared to non-cooperative scenario in terms of less BER with respect to the increase in K values from 1 to 60 (i.e., from severe to low fading) while keeping low to high SNR (i.e., 1-18db). It is also shown that for the K values beyond 60 (i.e., lowest fading as well as strong line of sight component as compared to multipath) there is a sharp decrease in BER for both cooperative and non-cooperative scenarios while maintaining low to high SNR (i.e., 1-18dB). It is due to the fact that with the increase in K values there is a decrease in multipath delays and the LOS component dominates the multipath. It is also found that at severe fading (i.e., for K values 1, 2, 3 and 4 as well as weak LOS reception) the proposed BER model of AF cooperative scenario in Rician channel perform well in terms of less bit error rate as compared AF cooperative scenario in Rayleigh fading channel (i.e., K=0, the most severe fading scenario which arises when the LOS component completely vanishes and reception becomes only non-LOS) as shown in Fig. 3.

It is found that for lower signal to noise ratio values (i.e., 1dB, 5dB and 10dB) as well as low to medium values of K the cooperation is advantageous in terms of less bit error rate as shown in Fig. 5. However, the BER remains constant as $K \to \infty$ (i.e., the scenario where the BER performance approaches AWGN channel error performance). It is due to the fact that as $K \to \infty$ the LOS path between transmitter and receiver dominates as compared to scattered paths and noise effect on channel decreases with respect to the increase in K values. Moreover, for signal to noise ratio values 15dB and 20 dB the BER decreases linearly as K approaches to infinity owing the increase in transmit power. The BER gain for AF cooperative scenario using symmetrical links (i.e., γ_{r1d} = γ_{r2d}) is shown in Fig. 6.

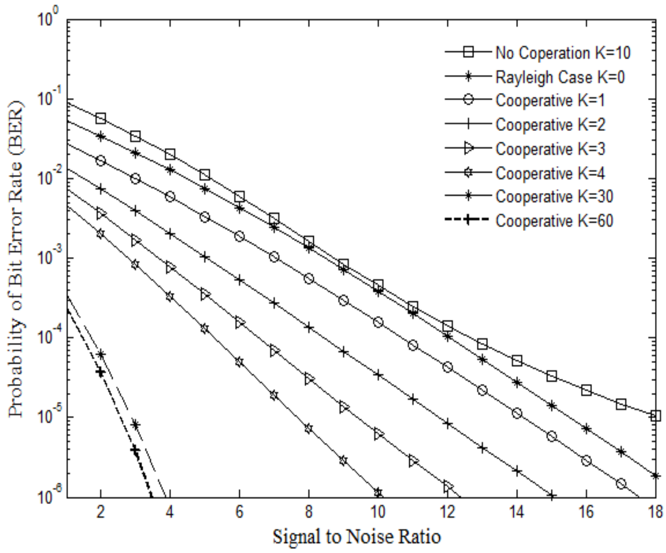

Fig. 3 BER of AF cooperative scenario using Rician and Rayleigh channel

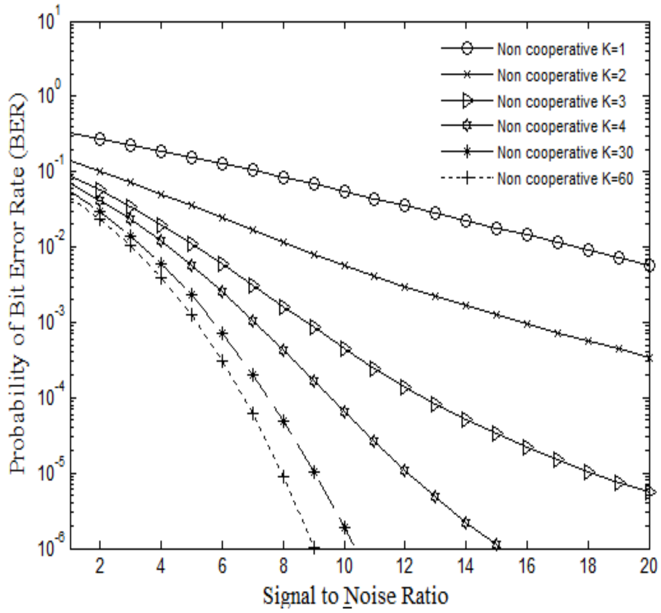

Fig. 4 BER of AF non-cooperative scenario using Rician channel

It is revealed that the BER gain first increases and then remains constant with the increase in K values from 1 to infinity for the SNR values 1dB, 3dB, 5dB, 8dB and 10dB. Owing to the fact that with the increase in K value mean decrease in fading as well as dominant LOS component as compared to multipath, which results in increase in BER gain. At $K \to \infty$ the channel is AWGN with no fading due to which the BER gain remain constant.

The results obtained from the proposed BER model of AF scenario are compared with the results from previous work Seddik et al. [15, eq. (47)] in Nakagami-*m* channel for further evaluation. It is found that for K values 1 to 60 (i.e., increase from low to strong LOS reception as well as decrease from severe to low fading), the proposed BER model of AF scenario showed less bit error rate as compared to AF scenario in Nakagami-m channel while keeping low to high values of SNR (i.e., 1-18dB) as shown in Fig. 7.

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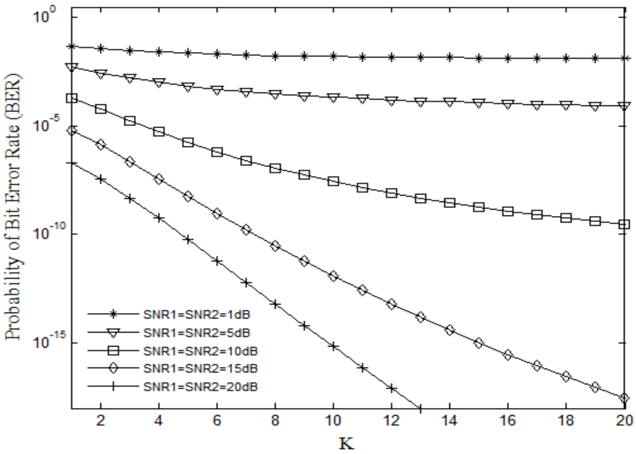

Fig. 5 BER of AF scenario using Rician channel with $\gamma_{r2d} = \gamma_{r1d}$

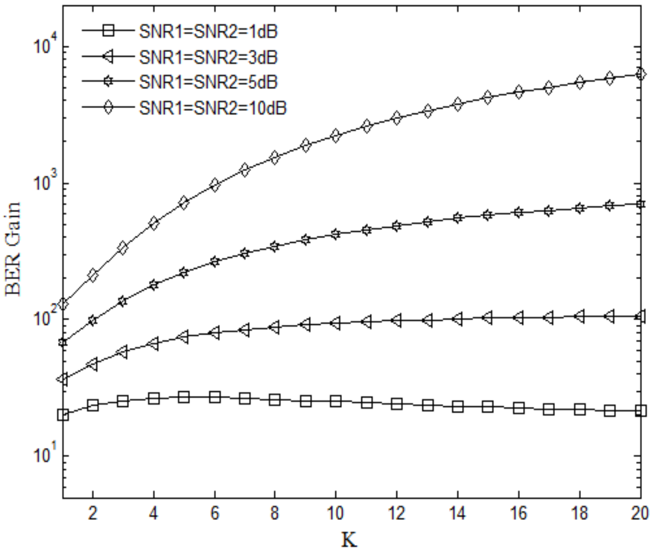

Fig. 6 BER gain of AF scenario using Rician channel with $\gamma_{r1d} = \gamma_{r2d} = 1dB - 15dB$

However, for the K value 3, the proposed BER model showed high BER as compared to AF scenario using Nakagami-m fading channel while keeping higher values of SNR (i.e., 7-18dB). It is due to the fact that with the increase in transmit power the previous

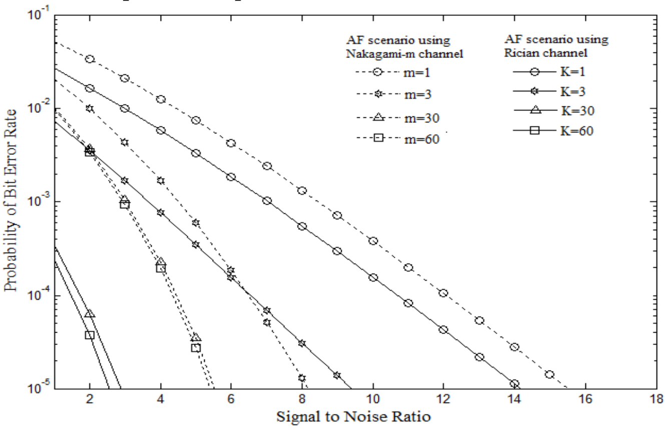

Fig. 7. Comparison of the BER of AF scenario using Rician channel and Nakagami-m channel assuming symmetrical links $\gamma_{r1d} = \gamma_{r2d}$.

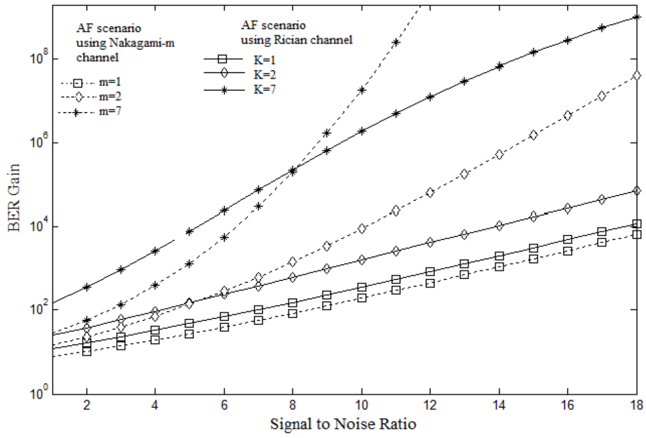

Fig. 8. Comparison of the BER gain of AF scenario using Rician channel and Nakagami-m channel assuming $\gamma_{r1d} = \gamma_{r2d}$.

proposed BER model showed better results in terms of low BER. It is also indicated that with the increase in K values the proposed model perform better in terms of high BER gain as compared to AF scenario using Nakagami-m channel while keeping low SNR values (i.e., 1-10dB) as shown in Fig. 8. However, AF scenario using Nakagami-m channel perform well by using high SNR values (i.e., 10-18dB) for the K values 2 to 10. Moreover, the two AF scenarios expressed similar behavior for medium SNR values (i.e., 5dB, 8dB, 9dB and 10dB) as well as for K values 1, 2, and 7.

V. CONCLUSION

In this paper, the performance improvement of dual relay cooperative wireless network by using the proposed BER and BER gain models in Rician fading channel has been evaluated. It is concluded that the proposed BER model of AF cooperative scenario perform well in terms of less bit error rate as compared to AF non-cooperative scenario for K values 1 to 60 (i.e., from severe to low fading). For the K values beyond 60 (i.e., lowest fading) there is strong LOS reception and sharp decrease in BER for both AF cooperative and non-cooperative scenarios. It is also revealed that using symmetrical links (i.e., $\gamma_{r1d} = \gamma_{r2d}$) and even at lower values of K (i.e., severe fading and weak LOS reception), the proposed model indicated less BER as compared AF scenario in Rayleigh fading channel (i.e., K=0, the scenario where LOS completely vanishes and reception becomes only non-LOS). It is also expressed that with the increase in K values (i.e., decrease in fading) the BER first decreases and remain constant as K approaches to infinity (i.e., the BER performance approaches AWGN channel error performance with no fading) while keeping lower SNR values (1dB, 5dB and 10dB). However, for higher SNR values (i.e., more than 10dB) the proposed model showed linear decrease in BER owing to the increase in transmits power. Moreover, the proposed BER gain model shows an increase in BER gain with the increase in K values and remains constant as K approaches to infinity. It is due to the fact that as the value of K increases the channel fading decreases and LOS reception increases due to the decrease in delay spread.

It is also concluded that the proposed model showed less BER and high BER gain at severe fading (i.e., at lower K values as well as weak LOS reception) as compared to AF scenario in Nakagami-m channel while keeping low SNR values. However, at higher SNR values the previous proposed model showed less BER and high BER gain as compared to the proposed model. Finally, the results obtained in this work can be used to provide information to communication engineers in order to evaluate and design a communication link over Rician fading channel. The proposed models can also be extended to evaluate the performance of Rician faded wireless link by using hybrid combining of AF and DF protocols.

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