THE DIVERSITY ORDER IMPROVEMENT AND THE RELAY DISPLACEMENT ANALYSIS OF THE AMPLIFY-AND-FORWARD THREE TIME SLOTS TDMA-BASED PROTOCOL

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ABSTRACT *—Various researchers have investigated the two and three time slots Amplify-and-Forward (AF) Time Division Multiple Access (TDMA) based protocols. However, the low diversity order reduces the performance of these TDMA based protocols and has several limitations. Moreover, the two time slots protocols exhibit low performance when the relay is placed far from the source. Therefore, in this work an Improved Amplify-and-Forward (IAF) three time slots TDMA based protocol with inter-relay communication has been proposed. The relay displacement analysis with respect to different relays location is also carried out and the optimal relays location has been identified. The IAF protocol demonstrated improved performance, in terms of low BER and high BER-Gain values with the increase in SNR values, in contrast to previous two and three time slots protocol. The proposed protocol also showed better performance at optimal relays location, in terms of low BER and high BER-Gain values with the increase in SNR values. The accuracy of the IAF protocol is evaluated using Global-Percentage-Error-Decrease (GPED) and Local-Percentage-Error-Decrease (LPED) methods.*

Index Terms—TDMA, BER, AF protocols, BER-Gain, GPED, LPED

I. INTRODUCTION

The mobile radio signal experiences several signal variations and weakens due to multipath fading effects during transmission of data from source to destination. To mitigate the multipath fading, diversity communication has been used, to send the same data over independent fading paths (diversity branches). For this purpose, some common techniques like micro diversity, macro diversity, space diversity, frequency diversity and time diversity have been used, to achieve diversity communication [1]. However, these methods tend to increase the size, complexity and the total power of the wireless network devices [2-3]. In order to solve these issues, cooperative diversity communication has been introduced recently. In cooperative diversity communication, cooperation among users or relays ensures the diversity at destination. Each user or relay transmits their own information data as well as their partner data to destination, virtually seeking the advantages of MIMO spatial diversity [4-7].

Each user in cooperative diversity uses either Amplify-and-Forward (AF) or Decode-and-Forward (DF) protocol, in order to transmit the information data to destination [8]. In DF mode, the relay decodes the received signal from the source and forwards to destination [9-10]. However, in AF mode the relay amplifies the received signal from the source and forwards to destination [5],[11-18]. Cooperative communication solves the issues of size, cost, and hardware limitations of multiple antennas [19]. Moreover, cooperative communication also helps to reduce the effects of multi-path fading and increase capacity of wireless channel as well as achieves high data rates [20-21]. Different multiple access techniques such as time-division multiple access (TDMA), frequency division multiple access (FDMA), and code division multiple access (CDMA) have been proposed by various researchers to achieve high diversity order at destination [22-23].

Three different TDMA based two time slots protocols have been proposed by [24]. Using protocol I, the source broadcasts to relay and destination over the 1st time slot. In the 2nd time slot, the relay as well as source broadcasts to destination. This protocol has maximum degree broadcasting at source and maximum diversity order, at destination. Using protocol II, the source broadcasts to destination and relay, over the 1st time slot. In the 2nd time slot, the relay only transmits to destination. This protocol has maximum degree of broadcasting at source and low diversity order, as compared to protocol I. Using protocol III the source communicates to relay only, in the 1st time slot. In the 2nd time slot, the source as well as relay communicates to destination. This protocol exhibits no broadcasting but realizes maximum degree of diversity order. The performance analysis of the two time slots TDMA-based protocols over Nakagami-m fading channel has been analyzed [25]. The closed form Moment Generating Function (MGF) of the total Signal to Noise Ration (SNR) has been derived and used to obtain the diversity order and Symbol Error Rate (SER) at destination. The novel scheme of cooperative network using three time slots has been analyzed [26]. Data exchange between relays is used over the third time slot, in order to improve the link performance between relays and destination. Hybrid TDMA-FDMA based three time slots protocol with inter-relay communication over Nakagami-m fading channel has been proposed [27]. The BER, outage probability and Gain have been used as performance metrics. Three time slots TDMA based protocol is proposed [27-29]. In this protocol, the source broadcasts to relays and destination over the 1st time slot. In the second time slot, the relays broadcast to destination. Similarly, the relays also exchange their data in the 2nd time slot. In the 3rd time slot, the relay broadcasts the data to destination which was previously exchanged by the relays, in the 2nd time slot. The performance analysis of single relay and multiple relay cooperative network over Nakagami-m fading channels has been carried out [30]. The closed form expression of MGF for the total SNR is derived. Moreover, the expressions of symbol error rate, outage capacity, and outage probability have been obtained using the derived MGF.

The low diversity order at the destination and low broadcasting degree at the source reduces the performance of previous AF two time slots and three times slots TDMA based protocols and has several limitations. Moreover, the previous two protocols exhibit high BER and BER-Gain values when relay is placed away from the source. Furthermore, the source of the previous three time slots protocol remains silent during the 2nd and 3rd time slots, which also affect the performance of these protocols, in terms of low diversity order at destination with high BER and low BER-Gain values.

In this paper, the Improved Amplify-and-Forward (IAF) three time slots TDMA based protocol with inter-relay communication has been proposed, and investigated the performance of the IAF protocol using relay displacement. The main contribution of this work is that the source has been activated over the 2nd and 3rd time slots, and the diversity order has been improved at destination, to get low BER and high BER-Gain values. Moreover, the optimal relay locations have been identified, in terms of low BER and high BER-Gain values. Simulation results indicated that the IAF protocol demonstrated low BER and high BER-Gain values over Previous Proposed Amplify-and-Forward (PPAF) two time slots protocol [24] and PPAF three time slots protocol [28]. Furthermore, the IAF indicated low BER values at optimal relay location, in contrast to previous two time and three time slots protocols.

II. THE IMPROVED AMPLIFY-AND-FORWARD (IAF) THREE TIME SLOTS PROTOCOL USING INTER-RELAY COMMUNICARTION

In the IAF three time slots protocol, the source broadcasts to destination, relay1 and relay2 over 1st time slot. Both the relays transmit to destination as well as exchange their data, over the 2nd time slot. In the third time slot, the relays transmit the data which was previously exchanged in the 2nd time slot to destination. Moreover, in the proposed protocol, the source does not remain silent during 2nd and 3rd time slots and continuously broadcasts to destination along with the relays. Due to this, the proposed protocol has high degree of broadcasting at source, and high diversity order as well as less BER at destination, as compared to three time slots protocol proposed [28]. Furthermore, the proposed protocol with one extra time slot makes the proposed protocol superior, in terms of low BER and high BER-Gain at destination, as compared to two time slots protocol proposed [24]. The summary of the proposed protocol is shown in table I.

TABLE I: THE IAF THREE TIME SLOTS TDMA BASED TRANSMISSION PROTOCOL

Time Slot 1	Time Slot 2	Time Slot 3
$S \rightarrow R_1, S \rightarrow R_2$ $S \rightarrow D$	$R_1 \rightarrow D, R_2 \rightarrow D$ $R_1 \rightarrow R_2, R_2 \rightarrow R_1$ $S \rightarrow D$	$R_1 \rightarrow D, R_2 \rightarrow D$ $S \rightarrow D$

A. *System Model For The Iaf Three Time Slots TDMA Based Protocol*

The system model for the proposed IAF three time slots protocol is shown in Fig. 1.

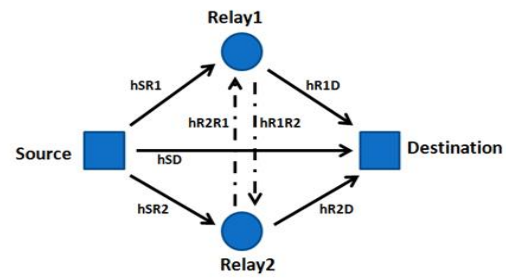

Fig. 1. Inter-relay wireless communication network using proposed TDMA based three times slots protocol.

The system model consists of wireless cooperative network with source, two relays and destination. The source (S), relay 1 (R1), relay 2 (R2) and destination (D) all are equipped with single antenna. The h_{SR1}, h_{SR2}, h_{R1D}, h_{R2D}, h_{R1R2} and h_{R2R1} are the Rician fading channels from source to relay1, source to relay2, relay1 to destination, relay2 to destination, relay1 to relay2 and relay2 to relay1 links respectively. The amplify-and-forward communication is used by the relays.

B. *Signal Models for the IAF Three Time Slots TDMA Based Protocol*

The received signals at relay1, relay2 and destination over the first time slot are y_{SR1}, y_{SR2} and $y_{SD,1}$ respectively and given by eq.[1-3] as:

$$y_{SR1} = E_S h_{SR1} s + n_{SR1} \quad (1)$$

$$y_{SR2} = E_S h_{SR2} s + n_{SR2} \quad (2)$$

$$y_{SD,1} = E_S h_{SD} + n_{SD} \quad (3)$$

where E_S is the average transmit energy by the source per symbol. The parameters h_{SR1}, h_{SR2} and h_{SD} are Rician multipath fading channels of source to relay1, source to relay2 and source to destination links respectively. Similarly, the parameters n_{SR1}, n_{SR2} and n_{SD} are the Additive White Gaussian noises (AWGN's) added to the source to relay1, source to relay2 and source to destination channels respectively. The Rician fading models are used as multipath fading models for the entire source to relays and destination channels.

The relay1 and relay2 normalize the received signals and broadcast to destination. The received signals at destination from relay1, relay2 and source, over the second time slot are y_{R1D}, y_{R2D} and $y_{SD,2}$ respectively and given by eq.[4-6] as:

$$y_{R1D} = E_1 h_{R1D} \frac{y_{SR1}}{\sqrt{E_s |h_{SR1}|^2 + 1}} + n_{R1D} \quad (4)$$

$$y_{R2D} = E_2 h_{R2D} \frac{y_{SR2}}{\sqrt{E_s |h_{SR2}|^2 + 1}} + n_{R2D} \quad (5)$$

$$y_{SD,2} = E_S h_{SD} + n_{SD} \quad (6)$$

where E_1 and E_2 are the average transmit energy per symbol by relay1 and relay2 respectively. The parameters h_{R1D} and h_{R2D} are Rican multipath fading channels of relay1 to destination and relay2 to destination links respectively. Similarly, the parameters n_{R1D} and n_{R2D} are the AWGN's added to the relay1 to destination and relay2 to destination channels respectively. In addition, both the relays normalize the received signals from source and exchange their data, over the second time slot. The received signals at relay2 from relay1 and at relay1 from relay2 are y_{R1R2} and y_{R2R1} respectively and given by eq. [7-8] as:

$$y_{R1R2} = E_1 h_{R1R2} \frac{y_{SR1}}{\sqrt{E_s |h_{SR1}|^2 + 1}} + n_{R1R2} \quad (7)$$

$$y_{R2R1} = E_2 h_{R2R1} \frac{y_{SR2}}{\sqrt{E_s |h_{SR2}|^2 + 1}} + n_{R2R1} \quad (8)$$

where h_{R1R2} and h_{R2R1} are the Rican multipath fading channels of relay1 to relay2 and relay2 to relay1 links respectively. The parameters n_{R1R2} and n_{R2R1} are the AWGN's in the relay1 to relay2 and relay2 to relay1 channels respectively.

In the 3rd time slot, both the relay1 and relay2 normalize the exchange data received during the 2nd time slot and broadcast to destination. The received signals at destination from relay1, relay2 and source over the 3rd time slot are y_{R1D}, y_{R2D} and $y_{SD,3}$ respectively and given by eq. [9-11] as:

$$y_{R1D} = E_1 h_{R1R2} \frac{y_{R1R2}}{\sqrt{E_1 |h_{R1R2}|^2 + 1}} + n_{R1D} \quad (9)$$

$$y_{R2D} = E_2 h_{R2R1} \frac{y_{R2R1}}{\sqrt{E_2 |h_{R2R1}|^2 + 1}} + n_{R2D} \quad (10)$$

$$y_{SD,3} = E_S h_{SD} + n_{SD} \quad (11)$$

Maximum Ratio Combining (MRC) is used at destination, in order to extract the required information at destination.

C. System Model for the Relay Displacement Analysis

The purpose of relay displacement analysis was to find out the best relay locations in terms of low BER and high BER-Gain values. The system model used for the relay displacement is shown in figure 2.

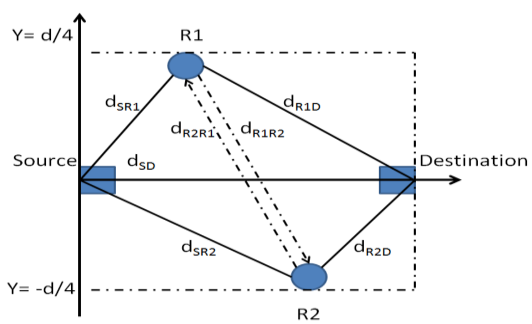

Fig. 2. Inter relay wireless cooperative network for relay displacement analysis

The parameters d_{SR1}, d_{R1D}, d_{SR2}, d_{R1D}, d_{R1R2} and d_{R2R1} are the distances between source to relay1, relay1 to destination, source to relay2, relay2 to destination, relay1 to relay2 and relay2 to relay1 links, respectively. The distance between source and destination is taken d_{SD}. The distances between source to relay1 and source to relay2 are taken initially $d_{SD}/4$ and $-d_{SD}/4$ respectively. However, these distances increase or decrease, due the relays movement with respect to the source. Similarly, the distances between relay1 to destination and relay2 to destination also increase or decrease, due to the relay movement with respect to the source and destination.

D. Signal Models for Relay Displacement Analysis

The received signals at realy1, relay2 and destination over the first time slot are y_{SR1}, y_{SR2} and $y_{SD,1}$ respectively and given by eq.[12-14] as:

$$y_{SR1} = (d_{SR1})^{-\alpha} E_S h_{SR1} s + n_{SR1} \quad (12)$$

$$y_{SR2} = (d_{SR2})^{-\alpha} E_S h_{SR2} s + n_{SR2} \quad (13)$$

$$y_{SD,1} = (d_{SD})^{-\alpha} E_S h_{SD} + n_{SD} \quad (14)$$

Where α is the path loss exponent. The relay1 and relay2 receive the signals from the source, in the second time slot, normalize the received signals and broadcast to destination. Similarly, the relay1 and relay2 also exchange their data, in the 2nd time slot. The received signals at destination from relay1, relay2 and source, in the second time slot are y_{R1D}, y_{R2D} and $y_{SD,2}$ respectively and given by eq. [15-17] as:

$$y_{R1D} = (d_{R1D})^{-\alpha} E_1 h_{R1D} \frac{y_{SR1}}{\sqrt{E_s |h_{SR1}|^2 + 1}} + n_{R1D} \quad (15)$$

$$y_{R2D} = (d_{R2D})^{-\alpha} E_2 h_{R2D} \frac{y_{SR2}}{\sqrt{E_s |h_{SR2}|^2 + 1}} + n_{R2D} \quad (16)$$

$$y_{SD,2} = (d_{SD})^{-\alpha} E_S h_{SD} + n_{SD} \quad (17)$$

The parameter E_1 and E_2 are relay1 and relay2 energies respectively. The received signals at relay2 from relay1 and at relay1 from relay2, in the second times lot are y_{R1R2} and y_{R2R1} respectively and given by eq. [18-19] as:

$$y_{R1R2} = (d_{R1R2})^{-\alpha} E_1 h_{R1R2} \frac{y_{SR1}}{\sqrt{E_s |h_{SR1}|^2 + 1}} + n_{R1R2} \quad (18)$$

$$y_{R2R1} = (d_{R2R1})^{-\alpha} E_2 h_{R2R1} \frac{y_{SR2}}{\sqrt{E_s |h_{SR2}|^2 + 1}} + n_{R2R1} \quad (19)$$

In the 3rd time slot, both relay1 and relay2 normalize the exchanged data received during 2nd time slot, and broadcast to destination. The received signals at destination from relay1, relay2 and source over the 3rd time slot are y_{R1D}, y_{R2D} and $y_{SD,3}$ respectively and given by eq.[20-22] as:

$$y_{R1D} = (d_{R1D})^{-\alpha} E_1 h_{R1R2} \frac{y_{R1R2}}{\sqrt{E_1 |h_{R1R2}|^2 + 1}} + n_{R1D} \quad (20)$$

$$y_{R2D} = (d_{R2D})^{-\alpha} E_2 h_{R2R1} \frac{y_{R2R1}}{\sqrt{E_2 |h_{R2R1}|^2 + 1}} + n_{R2D} \quad (21)$$

$$y_{SD,3} = (d_{SD})^{-\alpha} E_S h_{SD} + n_{SD} \quad (22)$$

Maximum Ratio Combining (MRC) is used at destination to take out the required information. MRC is the diversity combining technique, in which the signals from independent paths are added together, to determine the total error rate due to independent multiple paths. The derived received information signal at destination using MRC is y_D and given by eq. [23] as:

$$y_D = y_{R1D} h^*_{R1D} h^*_{SR1} + y_{R2D} h^*_{R2D} h^*_{SR2} + y_{SD} h^*_{SD} + y_{R2D} h^*_{R2D} h^*_{R1R2} h^*_{SR1} + y_{R1D} h^*_{R1D} h^*_{R2R1} h^*_{SR2} + y_{SD} h^*_{SD} + y_{SD} h^*_{SD} \quad (23)$$

where h^*_{SR1}, h^*_{SR2}, h^*_{R1D}, h^*_{R2D}, h^*_{SD}, h^*_{R1R2} and h^*_{R2R1} are the conjugates of the source to relay1, source to relay2, relay1 to destination, relay2 to destination, source to destination, relay1 to relay2 and relay2 to relay1 channels respectively. The channel conjugates used in the derived y_D signal improve the performance of IAF three time slots protocol, in term of low BER and high BER-Gain values.

III. SIMULATION RESULTS AND DISCUSSION

The simulation model is shown in Fig. 3. The 10^5 symbols are used at source. Bipolar Phase Shift Keying (BPSK) modulation is used to modulate the signals, at the source. The distance between source and destination is taken d_{SD} which is assumed 10m in this model. Moreover, the distances between source to relays and relays to destination as well as between relays (i.e. inter-relay distances) are calculated by using eq. [24-29] as:

$$d_{SR1} = \sqrt{(0.1 \times i \times d_{SD})^2 + (d_{SD}/4)^2} \quad (24)$$

$$d_{SR2} = \sqrt{(0.1 \times i \times d_{SD})^2 + (-d_{SD}/4)^2} \quad (25)$$

$$d_{R1D} = \sqrt{((d_{SD} - i)/(10 \times d_{SD}))^2 + (d_{SD}/4)^2} \quad (26)$$

$$d_{R2D} = \sqrt{((d - i)/(10 \times d_{SD}))^2 + (-d_{SD}/4)^2} \quad (27)$$

$$d_{R1R2} = \sqrt{(d_{SD}/2)^2 + (0.1 \times i \times d_{SD})^2} \quad (28)$$

$$d_{R2R1} = \sqrt{(-d_{SD}/2)^2 + (0.1 \times i \times d_{SD})^2} \quad (29)$$

where the variable i indicates the scaling parameter which is used to find the links distances with respect to different relay locations from the source and destination.

Initially, the relay1 is kept at $d_{SD}/4$ distance from the source and relay2 at $-d_{SD}/4$ from the source. Moreover, the relay2 is kept close to destination and relay1 is moved along x-axis from source to destination. Similarly, the relay1 is kept close to destination and relay2 is moved along x-axis from source to destination.

The Rician multipath channels h_{sr1}, h_{sr2} and h_{sd} are created, for the source to relay1, source to relay2 and source to destination links respectively. The distances d_{SR1} and d_{SR2} obtained from equations 24 and 25 are included to h_{sr1} and h_{sr2} respectively. However, the assumed 10m distance (d_{SD}) is included to h_{sd}. The BPSK modulated signal along with average energy per symbol is passed through each of the Rician multipath channel. In addition, AWGN's are included to each Rician multipath channels, in order to make the distance dependent Rician multipath noisy signals. These noisy signals along with multipath effects are received at relay1, relay2 and destination over the 1[st] time slot.

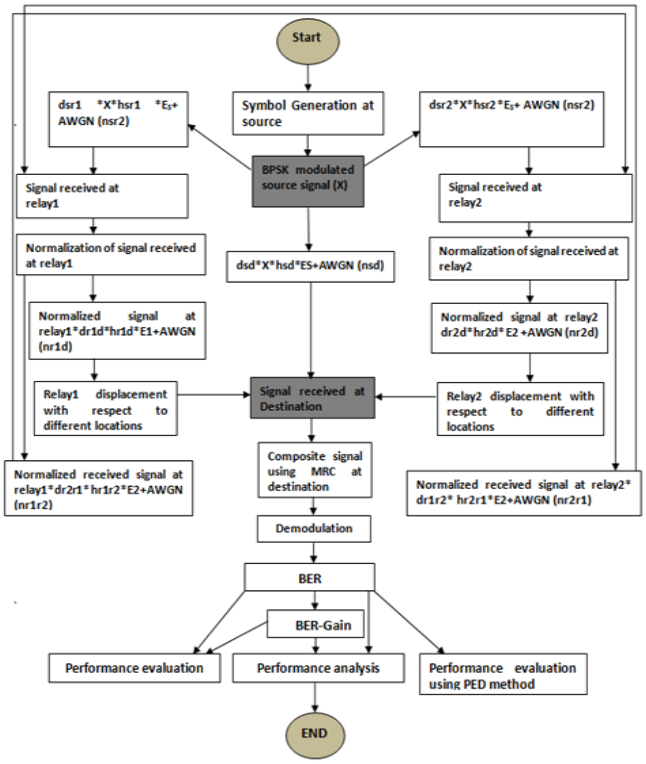

Fig. 3. Simulation model of the IAF three time slots protocol with respect to the relay displacement

The received signals at relay1, relay2 are then normalized to transmit for the 2[nd] time slots. The Rician multipath channels h_{r1d}, h_{r2d}, h_{r1r2} and h_{r2r1} are created for the relay1 to destination, relay2 to destination, relay1 to relay2 and relay2 to relay1 links respectively. The distances d_{R1D}, d_{R2D}, d_{R1R2} and d_{R2R1} obtained from equations 26, 27, 28 and 29 are included to h_{r1d}, h_{r2d}, h_{r1r2} and h_{r2r1} respectively. The normalized signals along with average energy per symbol are passed across each Rician multipath channel (i.e. h_{r1d}, h_{r2d}, h_{r1r2} and h_{r2r1}), in order to make distance dependent noisy signals. Moreover, the AWGN's are included to each Rician multipath channel, to make the distance dependent Rician multipath noisy signals. These noisy distance dependent signals are received by destination, over the 2[nd] time slot. Moreover, the relay1 receives the Rician multipath noisy signal from relay2 and relay2 receives the Rician multipath noisy signal from relay1, over the 2[nd] time slot. The relay 1 and relay2 again normalize the received signal, in order to transmit for the 3[rd] time slot. The Rician multipath channel h_{r1d} and h_{r2d} are created and the distances d_{R1D} and d_{R2D} from equations 26 and 27 are included to the Rician multipath channels respectively. The normalized signals along with average energy per symbol are passed across each Rician multipath channel (i.e. h_{r1d} and h_{r2d}), to make distance dependent noisy signals, for the 3[rd] time slot. Moreover, the AWGN's are included to each of the multipath channel, to make the signal distance dependent as well as noisy, for the 3[rd] time slot. The destination receives these noisy signals from relay1 and relay2, over the 3[rd] time slot. In addition, the destination also receives the noisy Rician multipath noisy signal from the source directly, over the 3rd time slot. The MRC is used to get the composite signal at destination, and demodulation is used to get BER and BER-Gain at destination. Finally, the performance analysis and evaluation as well as the performance evaluation using Percentage Error Decrease Method (PED) method have been carried out.

The performance of IAF three time slots protocol is evaluated with the comparison of previous Proposed Amplify-and-Forward (PPAF) two time slots protocol proposed [24]. The BER and BER-Gain are used as the performance metrics at destination. The MRC is used at destination to combine the signals received in different time slots from relays and to extract the information from the incoming received signals. The IAF three time slots protocol performed better over PPAF two time slots protocol, in terms of low BER and high BER-Gain values with the increase in SNR values, while, keeping constant K values (i.e. K=0 and 4), as shown in Fig. 4 and Fig. 5 respectively.

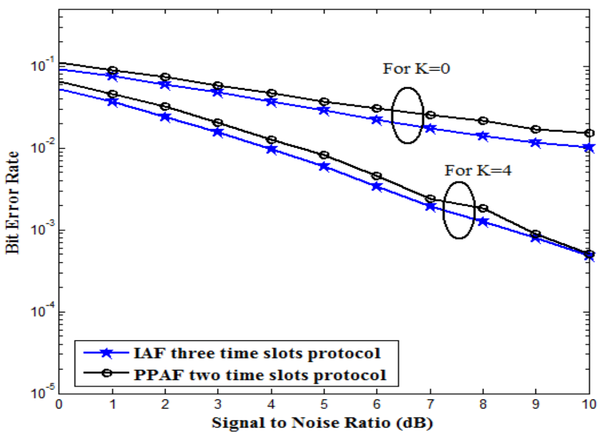

Fig. 4. BER comparison of IAF protocol with PPAF two time slots protocol with increase in SNR values and at different constant K values

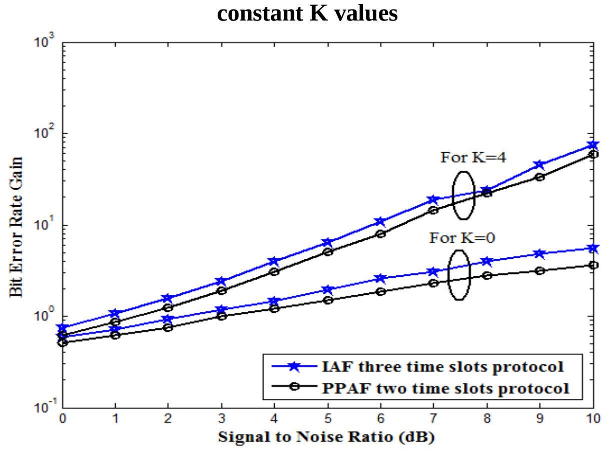

Fig. 5. BER-Gain comparison of IAF protocol with PPAF two time slots protocol with the increase in SNR values and at different constant K values

It is because of the fact that the IAF protocol has one extra time slot, over which it exchanges the data between the relays. Due to this, the destination receives two additional copies of the source signal, which increases the diversity order at destination. Moreover, the source transmits in the 2nd and 3rd time slots to destination, which also increases the diversity order at destination. Due to high diversity order, the low BER and high BER-Gain values have been indicated by the IAF three time slots protocol as compared to PPAF two time slots protocol.

The IAF three time slots protocol is also evaluated with the comparison of PPAF two time slots protocol, with the increase in K values, whereas, keeping constant SNR values (e.g. SNR=3dB and 5dB). The purpose of taking 3dB and 5dB SNR values was to analyze the performance of PAF three time slots protocol at low SNR values. The PAF three time slots protocol demonstrated low BER and high BER-Gain values over PPAF two times slots, with the increase in K values, while, keeping constant SNR values, as shown in Fig. 6 and Fig. 7 respectively.

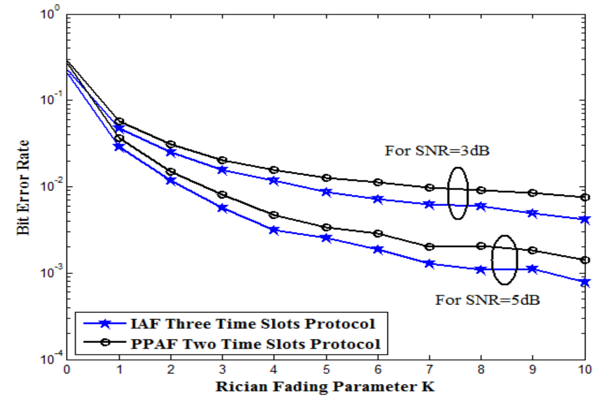

Fig. 6. BER comparison of IAF protocol with PPAF two time slots protocol with the increase in K values and at different constant SNR value

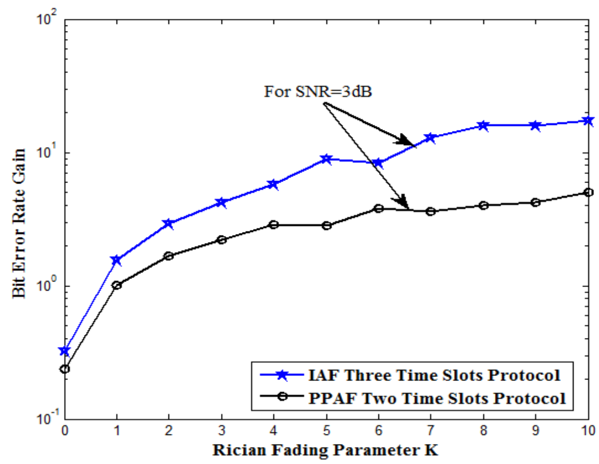

Fig. 7. BER-Gain comparison of IAF protocol with PPAF two time slots protocol with increase in K values and at different constant SNR values

Owing to the fact that the IAF protocol has high diversity order, as compared to PPAF two time slots protocol. Due to high diversity order, low BER values and high BER-Gain values have been demonstrated by the IAF three time slots protocol.

The performance of the IAF three time slots protocol is also evaluated with the comparison of PPAF three time slots protocol [28]. The IAF three time slots protocol showed better performance over PPAF three time slots protocol, in terms of low BER values, with the increase in SNR values, while, keeping constant K values, as shown in Fig. 8. Moreover, high BER-Gain values have been achieved by the proposed protocol, in contrast to PPAF three time slots protocol, with respect to the increase in SNR values, while, keeping constant K values, as shown in Fig. 9.

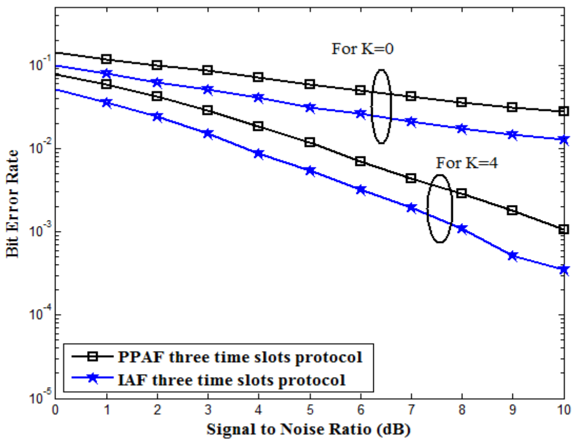

Fig. 8. BER comparison of IAF protocol with PPAF three time slots protocol with the increase in SNR values and at different constant K values

It is due to the fact that unlike the PPAF three time slots protocol, the IAF protocol source does not remain silent during the 2nd and 3rd time slots, and continues broadcasting to destination. Due to this phenomenon, the high diversity order has been observed, which results in low BER and high BER-Gain values at destination.

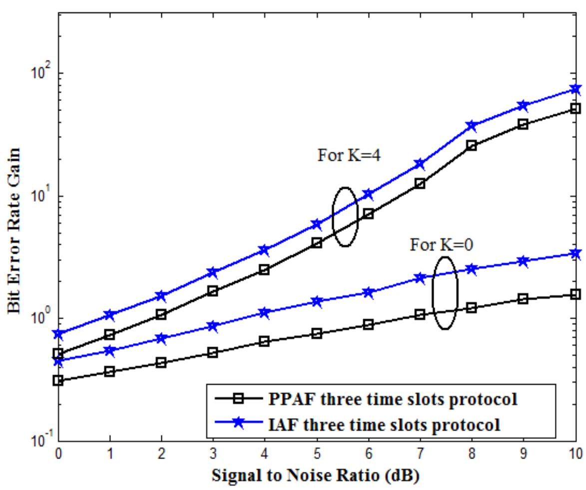

Fig. 9. BER-Gain comparison of IAF protocol with PPAF three time slots protocols with the increase in SNR values and at different K values

Moreover, the IAF protocol indicated low BER values over PPAF three times slots protocol, with respect to the increase in K values, while, keeping SNR values constant, as shown in Fig. 10. Furthermore, the high BER-Gain values are demonstrated by IAF three time slots protocol over PPAF three time slots protocol, with respect to the increase in K values, but, Keeping SNR values constant, as shown in Fig. 11.

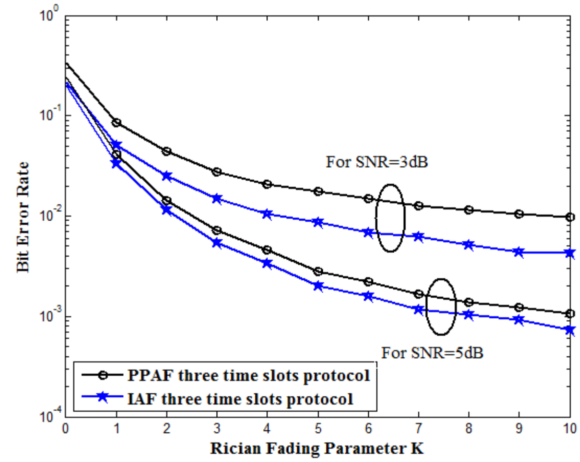

Fig. 10. BER comparison of IAF three time slots and PPAF three time slots protocols at different SNR values

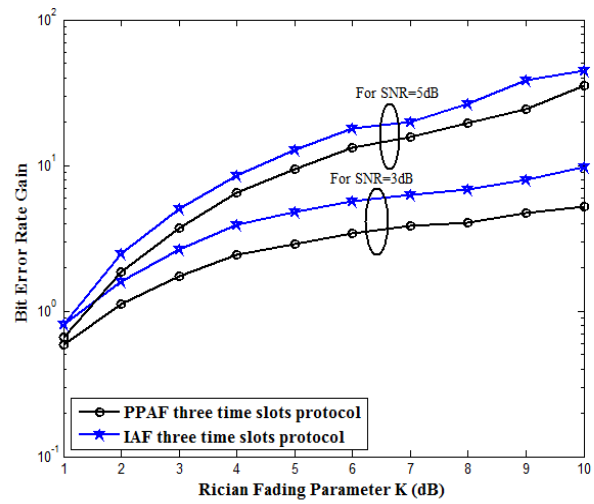

Fig. 11. BER-Gain comparison of IAF three time slots and PPAF three time slots protocols at different SNR values

The performance analysis of IAF protocol using relay displacement has been also carried out. In order to measure the performance, two performance metrics i.e. BER and BER-Gain are used at destination. Moreover, the BER and BER-Gain values have been obtained with respect to different relay locations. First, the relay2 is kept at fix position close to destination, while, relay1 is moved along x-axis from source towards the destination. Secondly, relay1 is kept at fix position close to destination, whereas, relay2 is moved along x-axis from source towards destination. The proposed protocol showed high BER and low BER-Gain values when both relays are closed to destination or closed to source, as shown in figures 12 and 13 respectively. It is because, when both relays are close to the source, the relays to destination distances are high as compared to source to relays distances, which results in high BER low BER-Gain values. Similarly, when both the relays are closed to the destination, the source to relays distances are high as compared to relays to destination distances. It is also indicated from results in Fig. 12 and Fig. 13 that the proposed protocol indicated high BER and low BER-Gain values when relay1 is closed to source and relay2 is closed to destination or when relay2 is closed to source and relay1 is closed to destination. Owing to the fact that when relay1 is close to the source and relay2 is close to the destination, the relay1 to destination and source to relay2 links have high distances, which leads to high BER and low BER-Gain values. Moreover, when relay1 is closed to destination and relay2 is closed to source, the source to relay1 and relay2 to destination distances are high, which results in high BER and low BER-Gain values. Furthermore, in both the cases (i.e. relay1 close to source and relay2 close to destination or relay1 close to destination and relay2 close to source), the inter-relay distances are maximum.

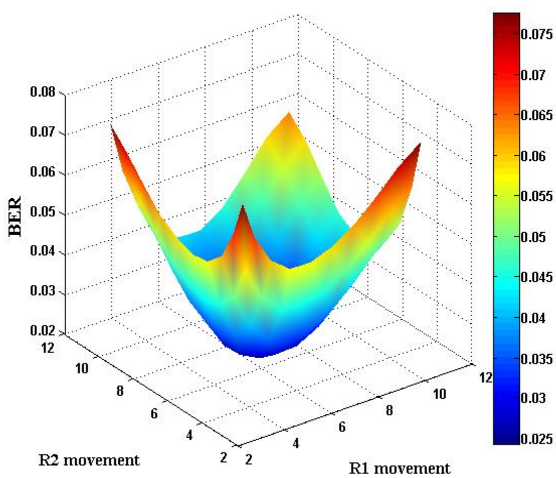

Fig. 12. BER values for IAF three time slots protocol using relay1 and relay2 movements

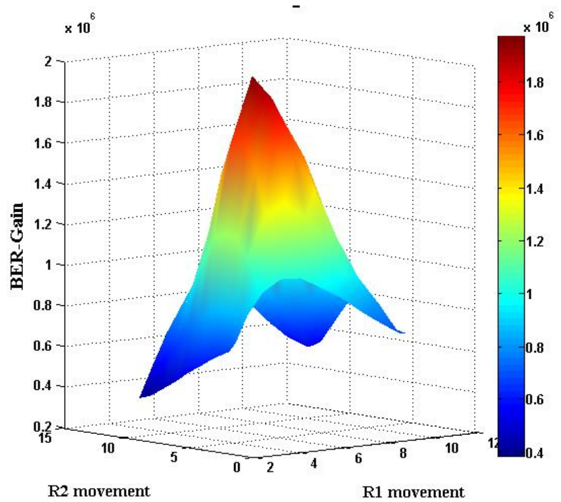

Fig. 13. BER-Gain values for IAF three time slots protocol using relay1 and relay2 movements

It is also shown from the results that the proposed protocol demonstrated optimal results, in terms of low BER and high BER-Gain values, when both the relays are placed with minimum inter-relay distances and the source to relays and relays to destination distances are same. The links distances (i.e. source to relays, relays to distance as well as inter-relay) which predicted the optimal relay 1 and relay2 locations, in terms of low BER and high BER-Gain values are d_{SR1} = 5.5902m, d_{R1D} = 5.5902m, d_{SR2} = 5.5902, d_{R2D} = 5.5902, d_{R1R2} = 7.0711m and d_{R2R1} =7.0711m.

It is demonstrated from results that using the optimal relays location with optimal links distances (i.e. d_{SR1} = 5.5902m, d_{R1D} = 5.5902m, d_{SR2} = 5.5902, d_{R2D} = 5.5902, d_{R1R2} = 7.0711m and d_{R2R1} = 7.0711m), the IAF protocol showed low BER and high BER-Gain values. Therefore, the IAF protocol is further evaluated using the optimal relays location, with the comparison of PPAF two time slots protocol [24] and PPAF three time slots protocol [28]. The SNR values from 0dB to 15 dB have been used for evaluation. The purpose of taking SNR values from 0dB to 15dB was to evaluate the performance of IAF protocol at low to medium SNR values. Moreover, the performance evaluation is carried out at severe fading conditions i.e. at k=1.

The IAF three time slots protocol indicated improved performance in contrast to previous two and three times slots protocols using the optimal relays location (i.e. links distances d_{SR1} = 5.5902m, d_{R1D} = 5.5902m, d_{SR2} = 5.5902, d_{R2D} = 5.5902, d_{R1R2} = 7.0711m and d_{R2R1} = 7.0711m), in terms of low BER values with the increase in SNR values, as shown in Fig. 14. Moreover, high BER-Gain values are obtained by IAF three time slots protocol, as compared to previous two and three time slots protocols, with the increase in SNR values, as shown in Fig. 15.

Owing to the fact that the IAF protocol has one extra time slot, which increases the degree of broadcasting at destination. Moreover, the IAF three time slots protocol does not remain silent during the 2^{nd} and 3^{rd} time slots and continuously broadcasts to destination. Due to this, diversity order is further increased at destination, which results in low BER and high BER-Gain values in contrast to previous two and three time slots protocols.

The proposed protocol has been evaluated statistically by using Global Percentage Error Decrease (GPED) and Local Percentage Error Decrease (LPED) methods [31-32] to find the accuracy of the proposed protocol. The GPED indicates the average percentage error decrease for the total SNR taken, while, LPED shows the percentage error decrease for each SNR ratio taken individually, is contrast to previous two and three time slots protocols. The high LPED and GPED in BER mean better performance of the IAF three time slots protocol, in terms of low BER values over PPAF two and three time slots protocols. These statistical methods are defined by eq. [30-31] as:

$$LPED = \left| \frac{\bar{E}_0 - \bar{E}_1}{\bar{E}_0} \right| \times 100 \qquad (30)$$

$$GPED = \frac{\sum \left| \frac{\bar{E}_0 - \bar{E}_1}{\bar{E}_0} \right| \times 100}{N} \qquad (31)$$

where $\bar{E}_0$ is the average BER of the IAF three time slot protocol and $\bar{E}_1$ is the average BER of PPAF two time slots and three time slots protocols and N is the total number of SNR values taken.

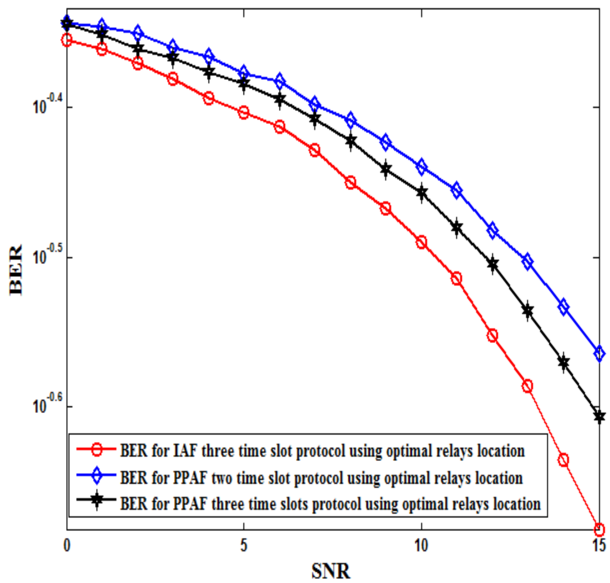

Fig. 14. BER comparisons of IAF three time slots with PPAF two time slots and three time slots protocols

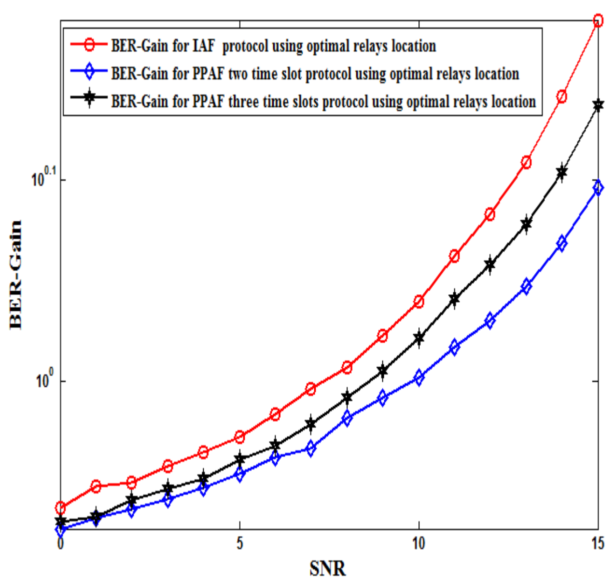

Fig. 15. BER-Gain comparison of IAF three time slots with PPAF two time slots and three time slots protocols

The GPED and LPED values are obtained by using low to medium SNR values (e.g. 0-14dB) and for fading conditions (e.g. K=1, 3 and 5), as shown in Fig. 16.

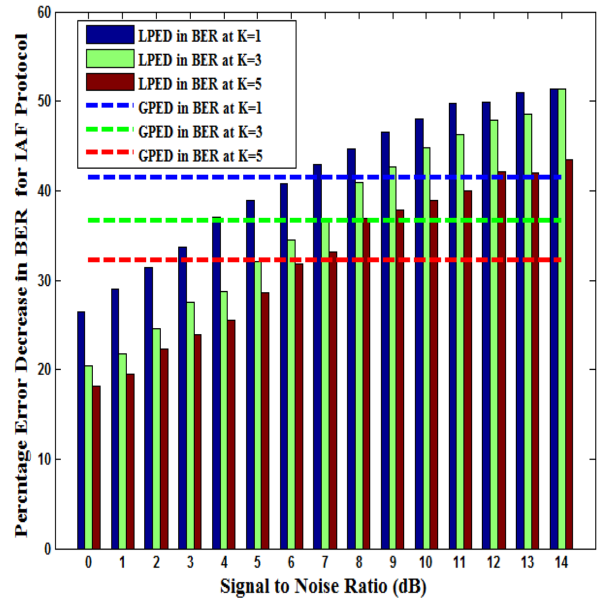

Fig. 16. Percentage error decrease in BER for IAF three times slots protocol, as compared to PPAF two time slots protocol, using different K values and SNR 0 to 14dB

It is shown from GPED results that the IAF protocol performs better over PPAF two time slots protocol, with 41.4% GPED at K=1, 36.58% at K=3, and 32.27% at K=5. It is indicated from GPED values that the IAF three time slot protocol showed enhancement over PPAF two time slots protocol, in terms of improved GPED in BER at severe fading i.e. at K=1, as compared to the GPED values at K=3 and 5. It is due to the fact that the PAF protocol has high diversity order at destination and high broadcasting degree at the source, as compared to PPAF two time slots protocol.

It is also indicated from Figure 16 that the IAF protocol showed better performance over PPAF two time slots protocol, in terms of increase in LPED values with the increase in SNR values e.g. from 0dB to 14dB. For 0dB SNR, the IAF protocol indicated LPED in BER of 26.50% at K=1, 20.50% at K=3 and 18.20% at K=5, as compared to PPAF two time slots protocol. However, the performance of IAF is further improved by increasing SNR value to 14dB, with 51.40% LPED at K=1, 51.50% at K=3 and 43.50% at K=5, as compared to PPAF two time slots protocol.

From the performance comparison of IAF protocol with PPAF three time slots protocol, it is indicated that the IAF protocol performed better, with GPED values of 28.57% at K=1, 29.36% at K=3 and 29.57% at K=5, as shown in Fig. 17. It was indicated from GPED values that the IAF three time slots protocol showed improvement over PPAF three time slots, both at severe and low fading. It is because the IAF three time slots protocol does not have much effect when the LOS component of K dominates.

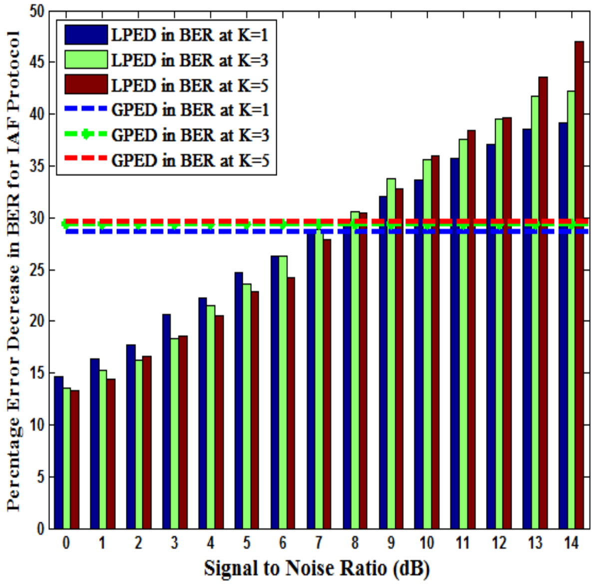

Fig. 17. The GPED and LPED in BER for IAF three times slots protocol, as compared to PPAF three time slots protocol, at different K values and SNR 0 to 14dB

It is also indicated that the IAF three time slots protocol showed improvement over PPAF three times slots protocol, in terms of increase in LPED values, with the increase in SNR values e.g. from 0dB to 14dB, as shown in Fig. 17. For 0dB SNR, the PAF protocol showed LPED in BER of 14.70% at K=1, 13.40% at K=3 and 13.30% at K=5. However, the IAF protocol showed further improvement, in terms of increase in LPED values with the increase in SNR values to 14dB. For 14dB SNR, the PAF protocol showed improvement, by means of 40.10% LPED in BER at K=1, 45.60% at K=3 and 47% at K=5, as compared to PPAF three time slots protocol. It is demonstrated from LPED results that the proposed IAF protocol performed well both at severe and low fading conditions, by showing smaller differences in LPED values at K values 1, 3 and 5. However, the performance of the IAF protocol is sufficiently improved over PPAF three time slots protocol, with the increase SNR values from low to medium.

The GPED and LPED values are also obtained using the optimal relays location with optimal link distances i.e. d_{SR1}=5.59m, d_{R1D}=5.59m, d_{SR2}=5.59, d_{R2D}=5.59, d_{R1R2}=5m and d_{R2R1}=5m. The IAF three time slots protocol showed improvement at optimal relays location, with GPED in BER of 50% at SNR values from 0dB to 15dB as compared to PPAF two time slots protocol, as shown in Fig. 18.

Moreover, the proposed protocol showed high LPED in BER, with the increase in SNR values. For 0dB SNR, the proposed protocol demonstrated 30% LPED in BER, as compared to PPAF two time slots protocol. However, the performance of the proposed protocol further increases, in terms of high LPED values, with the increase in SNR values. For 15dB SNR, the proposed protocol indicated 60% LPED in BER, as compared to PPAF two time slots protocol.

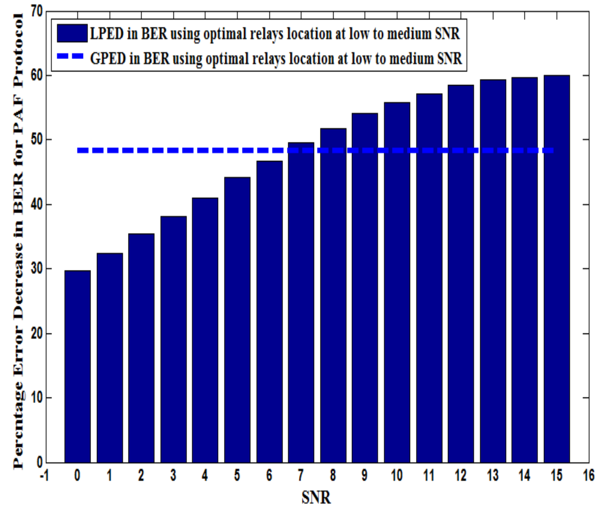

Fig. 18. GPED and LPED values in BER of IAF three time slot protocol as compared to PPAF two time slots protocol at SNR values from 0dB to 15dB

From the performance evaluation of IAF protocol with PPAF three time slots protocol at optimal relays location, it is indicated that the proposed protocol demonstrated improvement with 35.04% GPED in BER at SNR values from 0dB to 15dB, as shown in Fig. 19. Moreover, the proposed protocol showed high LPED values in BER, in contrast to PPAF three time slots protocol, with the increase in SNR values. For 0dB SNR, the PAF protocol indicated LPED in BER of 21%, and for 15dB SNR it showed 43.40% LPED in BER, in contrast to PPAF three time slots protocol.

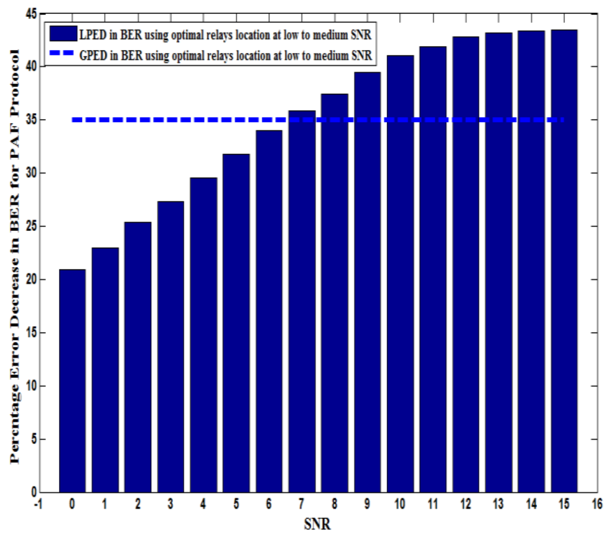

Fig. 19. GPED and LPED values in BER of IAF three time slot protocol as compared to PPAF three time slots protocol at SNR from 0dB to 15dB

IV. CONCLUSIONS AND FUTURE WORK

The IAF three time slots TDMA based protocol has been proposed, and the optimal relays location has been identified using the relay displacement analysis. The IAF protocol demonstrated improved performance, in terms of low BER and BER-Gain values with the increase in SNR values, in contrast to previous two and three time slots protocol. The proposed protocol also showed better performance at optimal relays location, in terms of low BER and high BER-Gain values with the increase in SNR values. The GPED results obtained at optimal relay locations indicated the accuracy of the IAF protocol, with GPED in BER of 50% and 35.04% in contrast to previous two and three time slots protocols respectively, at SNR 0dB to 15dB. Moreover, the proposed protocol indicated improvement, in terms of increase in LPED values, with the increase in SNR values, as compared to previous two and three time slots protocols.

In this work, only two relays in the system model has been used for simplicity. However, multiple relays can used to further demonstrate the performance of the IAF protocol. In addition, the performance of the proposed protocol could be further analyzed using parameters like delay, throughput and outage probability.

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