THE LONG RANGE AMPLIFY-AND-FORWARD THREE TIME SLOTS TDMA-BASED PROTOCOL WITH INTER-RELAY COMMUNICATION OVER RICIAN FADING

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ABSTRACT *—The two time slots and three time slots amplify-and-forward protocols Time Division Multiple Access (TDMA) based protocols have been investigated previously by various researchers. However, the low diversity order reduces the performance of these TDMA based protocols and has several limitations. Moreover, the previous two time slots and three time slots protocols have not been investigated by using longer distances between source to relays and relays to destination, and for the particular target environment. Therefore, the Long Range Amplify-and-Forward (LRAF) three time slots TDMA based protocol has been proposed for the target open urban environment with flat terrain. Moreover, the Lee path loss model has been identified from theoretical analysis, and the path loss values have been estimated for the target environment (i.e. open urban with flat terrain). Furthermore, the composite signal has been derived at destination using Maximum Ratio Combining (MRC) and the channel conjugates. The results indicated better performance of LRAF protocol in terms of low Bit Error Rate (BER) values, as compared previous two time slots and three time slots protocols, both for longer distances and shorter distances. In addition, the LRAF protocol showed improved Global Percentage Error Decrease (GPED) and Local Percentage Error Decrease (LPED) in BER over previous two time slots and three time slots protocols, both for shorter as well as longer distances, at low to medium and medium to high SNR values.*

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 and to send the same data over independent fading paths, diversity communication has been used. To achieve diversity communication several communication techniques, for instance, macro diversity, space diversity, frequency diversity and time diversity have been used [1]. However, these methods tend to increase the size, complexity and total power of the wireless network devices. In order to solve these issues, recently cooperative diversity communication has been introduced.

In cooperative diversity communication, cooperation among users or relays ensures the diversity at destination. Each user or relay transmits their own information data to destination along with the information of their partner, virtually seeking the advantages of Multi Input Multi Output (MIMO) spatial diversity [2-5].

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. In DF mode, the relay decodes the received signal from the source and forwards to destination. However, in AF mode, the relay amplifies the received signal from the source and forwards to destination [3],[6-8]. Cooperative communication solves the issues of size, cost, and hardware limitations of multiple antennas [9]. 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[10-11]. Different multiple access techniques such 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 [12-13].

Three different TDMA based two time slots protocols have been proposed [14]. The three protocols are operated with respect to the degree of broadcasting at the source and diversity order at destination. The performance of two time slots protocol with single and multiple relay networks using Nakagami-m fading channels has been analyzed [15]. The novel scheme of cooperative network using three time slots protocol has been analyzed [16]. Data exchange between relays is used over the third time slot, 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 [17]. The BER, outage probability and Gain have been used as the performance metrics. Three time slots TDMA based protocol is proposed [17-19]. In this protocol, the source broadcasts to relays and destination over the first time slot. In the second time slot, the relays broadcast to destination. The relays also exchange their data in the 2^{nd} time slot. In the 3^{rd} time slot, the relay broadcasts the data to the destination, which was previously exchanged by the relays, in the 2^{nd} time slot. In [20], the authors analyzed the performance of single relay and multiple relay cooperative network. 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 the previous AF two time slots and three times slots TDMA-based protocols and has several limitations. Moreover, the previous TDMA-based protocols have not been analyzed by using longer distances between the source and relays as well as between the relays to destination. Path loss prediction issues arise for the particular target environment, with respect to the increase is distances between the source to relays and relays to destination links.

In this paper, the LRAF Amplify-and-Forward (LRAF) three time slots TDMA based protocol using inter-relay communication has been proposed. The contribution of this work is that the source has been activated over the 2nd and 3rd time slots, and diversity order has been improved at the destination to get low BER and high BER-Gain values. Moreover, the theoretical analysis has been performed, and the Lee path loss model has been identified for the target open urban environment with flat terrain. Furthermore, the path loss estimation for the target environment has been carried out, with respect to the increase in link distances using the Lee path loss model. Simulation results indicated that the proposed LRAF three time slots protocol demonstrated low BER and high BER-Gain values as compared to Previous Proposed Amplify-and-Forward (PPAF) two time slots [14] and three time slots protocols [18].

This paper is organized as follows: Section 2 describes the theoretical analysis of different path loss models. Moreover, the system model and signal models for the proposed LRAF protocol has been described in this section. Section 3 illustrates the analysis, performance evaluation of the proposed protocol, with the comparison of previous two time slots and three time slots TDMA-based protocols. Section 4 concludes the paper followed by future work as well as acknowledgement.

II. THE LONG RANGE MPLIFY-AND-FORWARD (LRAF) THREE TIME SLOTS PROTOCOL USING INTER-RELAY COMMUNICARTION

In the LRAF three time slots protocol, the source broadcasts to destination, relay1 and relay2 over 1st time slot. In the second time slot, both the relays transmit to destination and also exchange their data. 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 by Tanoli et al., [18]. Furthermore, the proposed protocol with one extra time slot makes the proposed protocol superior, in terms of less BER and high BER-Gain at destination, as compared to two time slots protocol proposed by Nabar et al., [14]. The summary of the proposed protocol is shown in Table 1.

TABLE I: The Iaf Three Time Slots Tdma Based Transmission Protocol

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

A. System model for the LRAF three time slots TDMA based protocol

The system model for the proposed LRAF three time slots protocol is shown in Figure 1. The system model consists of wireless cooperative network with source, two relays and destination.

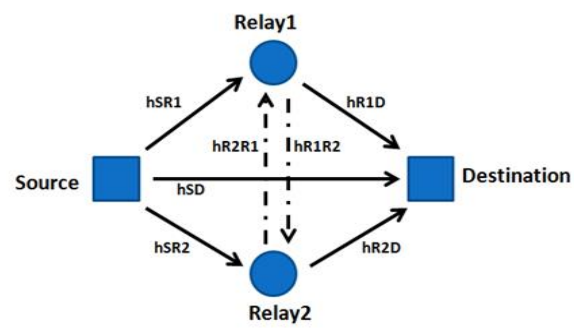

Fig. 1. Inter-relay communication using LRAF TDMA- based three times slots protocol

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. Amplify-and-Forward communication is used by the relays.

B. Selected Path loss models and their application in different environments

When the distance between the source and relays as well as between relays to destination increases, the path loss prediction issue arise, for the particular target environment. Therefore, different path loss models have been analyzed theoretically to find out a particular path loss model, for the open urban environment with flat terrain, as shown in Table II [21-29].

Various researchers have used different selected path loss models to determine a particular path loss model, for path loss predictions in a particular target environment. For example, the comprehensive measurement has been taken in Cambridge UK to validate the applicability of the three path loss models i.e. COST-231 Hata, SUI and ECC-33 model [21]. Field strength data in Cyberjaya Malaysia was used to calculate the path loss indicated by WiMAX signals [28]. Path loss measurement has been carried out in 3.5GHz band in rural macro-cellular environment in Italy [30]. Four empirical path loss models namely, SUI, Cost 231 Hata, Macro model and Ericsson model have been investigated for path loss prediction in mobile fixed wireless system such as WiMAX in Osijek Croatia city [25]. The simulation of the various path loss models namely, Cost-231, Hata-Okumura Extended Model, Cost-231 WI mode, SUI model, and Ericsson mode have been performed in [31]. The performance comparison between Cost-231-Hata and SUI models has been presented, for the Amazon Cities environment at 5.8 GHz frequency in [32]. The path loss measurement from Terrestrial Trunked Radio System (TETRA) in Riyadh city Saudi Arabia, has been performed by Alotaibi and Ali [33]. Four empirical models namely, Lee

Table Ii: Descrition Of The Selected Path Loss Models

S/No	Models	Mathematical Formulae with Adjustment and Correction factors
1	Free Space Model [21]	$PL_{FSPL} = 32.45 + 20\log_{10}(d) + 20\log_{10}(f)$
2	HATA Model[21]	$PL = 69.55 + 26.16\log_{10}(f_c) - 13.82\log_{10}(h_t) - a(h_r) + 44.9 - 6.55\log_{10}(h_t)\log_{10}(d)$ $a(h_r) = (1.1\log_{10}(f_c) - 0.7)h_r - (1.56\log_{10}(f_c) - 0.8)dB$
3	SUI Model [21]	$PL = A + 10\,\gamma\log_{10}\left(\frac{d}{d_o}\right) + X_f + X_h + S, \quad for\ d > d_o$ $A = 20\log_{10}\left(\frac{4\pi d_0}{\lambda}\right) \quad \gamma = a - b h_b + \left(\frac{C}{h_b}\right) \quad X_f = 6.0\log_{10}\left(\frac{f}{2000}\right)$ $X_h = \begin{cases} -10.8\log_{10}\left(\frac{h_r}{2000}\right) & for\ terrain\ type\ A\ and\ B \\ -20.0\log_{10}\left(\frac{h_r}{2000}\right) & for\ terrain\ type\ C \end{cases}$
4	COST-231HATA Model [24]	$PL = 46.3 + 33.9\log_{10}(f) - 13.82\log_{10}(h_b) - ah_m + (44.9 - 6.55\log_{10}(h_b))\log_{10} d + c_m$ $ah_m = 3.20(\log_{10}(11.75h_r))^2 - 4.79, \quad for\ f > 400MHz$
5	ECC-33 Model [26]	$PL = A_{fs} + A_{bm} + G_b - G_r$ $A_{fs} = 92.4 + 20\log_{10}(d) + 20\log_{10}(f)$ $A_{bm} = 20.41 + 9.83\log_{10}(d) + 7.894\log_{10}(f) + 9.56[\log_{10}(f)]^2$ $G_b = \log_{10}\left(\frac{h_b}{200}\right)\{13.958 + 5.8[\log_{10}(d)]^2\}, G_r = [42.57 + 13.7\log_{10}(f)][\log_{10}(h_r) - 0.585]$
6	Egli Model [28]	$PL = G_B G_M \left[\frac{h_B}{d^2} h_M\right]^2 \left[\frac{40}{f}\right]^2$
7	LEE Model [29]	$PL = L_0 + \gamma\log d - 10\log F_A$ $L_0 = G_B + G_M + 20(\log\lambda - \log d) - 22,\ F_F = \left(\frac{f}{900}\right)^{-n},\ F_{MG} = G_M$ $F_A = F_{BH}F_{BG}F_{MH}F_{MG}F_F,\ F_{BH} = \left(\frac{h_B}{30.48}\right)^2,\ F_{BG} = \left(\frac{G_B}{4}\right)\ F_{MH} = \begin{cases} \frac{h_M}{3} & if,\ h_M > 3 \\ \left(\frac{h_M}{3}\right)^2 & if,\ h_M \le 3 \end{cases}$
8	Ericsson Model [34]	$PL = a_o + 30.2\log_{10}(d) + 12\log_{10}(h_b) + 0.11\log_{10}(h_b).\log_{10}(d) - 3.2(\log_{10}(11.75h_r)^2) + g(f)$ $g(f) = 44.49\log_{10}(f) - 4.78(\log_{10}(f))^2$

model, SUI model, Cost-231 Hata model and Egli model have been investigated by Lwas et al., [34].

It is indicated from the theoretical analysis that the Lee model is the most appropriate model for the prediction of path loss effects in an open urban environment. It is because, the correction and adjustment factors in LEE model can be easily adjusted for the open urban environment with flat terrain. Therefore, the Lee path loss model has been selected for the path loss predictions, and to propose LRAF three time slots protocol for wireless cooperative network for the target environment (i.e. open urban envionment with flat terrain)

C. Signal models for the LRAF 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]

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

$$y_{SR2} = (PL)^{-1} E_S h_{SR2} s + n_{SR2} \quad (2)$$

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

Where h_{SR1}, h_{SR2} and h_{SD} are the complex Rician multipath fading channels of source to relay1, source to relay2 and source to destination links respectively. The parameters n_{SR1}, n_{SR2} and n_{SD} are the AWGNs, which are added to source to relay1, source to relay2 and source to destination channels respectively. The subscript PL indicates the path loss predictions, which is obtained from Lee path loss model.

In the second time slot, the relay1 and relay2 receive the signals from the source, normalize the received signals and broadcast to destination. Similarly, the relay1 and relay2 also exchange their data, over the 2nd time slot. The received signals at the destination, from relay1, relay2 and source over the 2nd time slot are y_{R1D}, y_{R2D} and $y_{SD,2}$ respectively and given by eq. [4-6]

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

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

$$y_{SD,2} = (PL)^{-1} E_S h_{SD} + n_{SD} \quad (6)$$

Where h_{R1D} and h_{R2D} are the complex Rician multipath fading channels of relay1 to destination and relay2 to destination links respectively. The parameters n_{R1D} and n_{R1D} are the AWGNs, which are added to relay1 to destination and relay2 to destination channels respectively.

The received signals at relay2 from relay1 and at relay1 from relay2, over the 2nd time slot, are y_{R1R2} and y_{R2R1} respectively and given by eq. [7-8]

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

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

Where h_{R1R2} and h_{R1R2} are the complex Rician multipath fading channels of relay1 to relay2 and relay2 to relay1 links respectively. In the 3rd time slot, both the relay1 and relay2 normalize the exchange data received during 2nd time slot and broadcast to destination. The received signals at destination from relay1 and relay2 as well as from the source are y_{R1D}, y_{R2D} and $y_{SD,3}$ respectively and given by eq. [9-11]

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

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

$$y_{SD,3} = (PL)^{-1} E_S h_{SD} + n_{SD} \quad (11)$$

The MRC technique is used at destination, in order to extract the required information. The derived received information signal at destination using MRC is y_D and given by eq. [12]

$$y_D = y_{R1D}h^*_{R1D}h^*_{SR1} + y_{R2D}h^*_{R2D}h^*_{SR2} + y_{SD}h^*_{SD} + y_{R2D}h^*_{R2D}h^*_{R1R2}h^*_{SR1} + y_{R1D}h^*_{R1D}h^*_{R2R1}h^*_{SR2} + y_{SD}h^*_{SD} + y_{SD}h^*_{SD} \qquad (12)$$

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 LRAF three time slots protocol, in term of low BER and high BER-Gain values.

III. SIMULATION RESULTS AND DISCUSSION

The simulation model for the LRAF three time slots protocol is shown in Figure 2. At the source, 10^5 symbols are generated. The BPSK modulation technique is used to modulate the signals, at the source. 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 path loss predicted by LEE path loss models is added to each Rician multipath channel. Moreover, the input signal from the source is passed across each Rician multipath channel, in order to create Rician multipath signals with path loss effects, for each of the source to relay1, source to relay2 and source to destination link respectively. Furthermore, the AWGN's are included to each Rician multipath channel, to make the multipath path channels noisy as well. The noisy signals, along with multipath and path loss effects are received at relay1, relay 2 and destination, over the first time slots.

The signals received at relays are normalized by pre-existing normalization factor. 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. Moreover, the path loss from LEE path loss models is added to each of the Rician multipath channels (i.e. h_{r1d}, h_{r2d}, h_{r1r2} and h_{r2r1}). Furthermore, the normalized signals along with average energy per symbol are passed across each Rician multipath channel, in order to create multipath signals along with path loss effect, for each of the relay1 to destination, relay2 to destination, relay1 to relay2 and relay2 to relay2 link, over the 2nd time slot.

In addition, the AWGN's are also included to each Rician multipath channel (i.e. h_{r1d}, h_{r2d}, h_{r1r2} and h_{r2r1}) to make each multipath signal noisy as well. These noisy signals along with Rician multipath and path loss effects are received at destination, from relay1, relay2 and destination, over the 2nd time slot. Moreover, the destination also receives a copy of Rician multipath fading signal along with path loss effect from the source directly, over the 2nd time slot. Furthermore, the relay1 receives Rician multipath noisy signal along with path loss effect from relay2, and relay2 receives Rician multipath noisy signal along with path loss effect from relay1, over the 2nd time slot.

The signals received at relay1 from relay2, and at relay2 from relay1 are again normalized by normalization factor, for the 3rd time slot. The path loss from LEE model is added to each

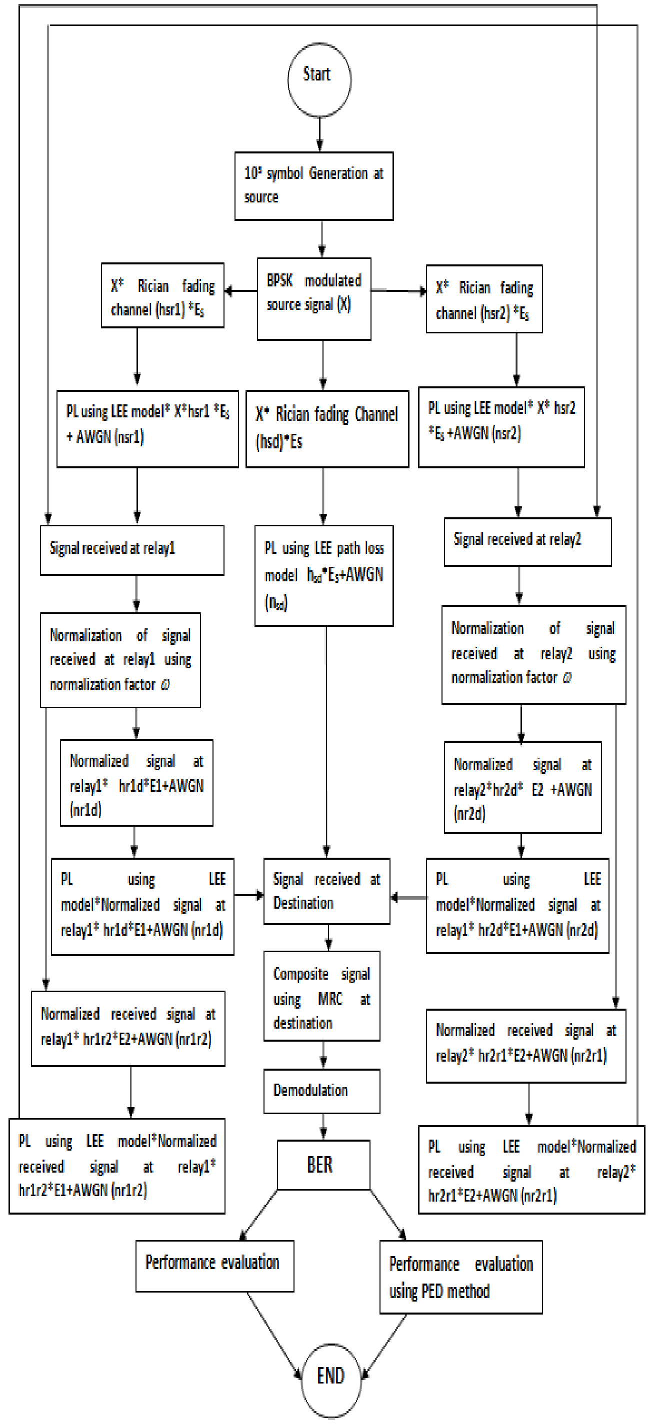

Fig. 2. Simulation model for the LRAF three time slots protocol

Rician multipath channels (i.e. h_{r1d} and h_{r2d}), for the 3rd time slots. The normalized signals at both relays along with average energy per symbol are passed through each Rician fading multipath channels (i.e. h_{r1d} and h_{r2d}), for the relay1 to destination and relay2 to destination links respectively. Moreover, the AWGN's are also included to each Rician multipath channel, in order to create signals with Rician multipath and path loss effect, for the 3rd time slots. The destination receives these Rician multipath noisy signals along with path loss from relay1 and relay2, over the 3rd time slot. In addition, the destination also receives a copy of Rician multipath noisy signal along with path loss effect from the source, over the 3rd time slot. The MRC is used to get the composite signal at destination. Demodulation and xoring are used, in order to get BER at destination. Finally, the performance evaluation and performance evaluation using PED method has been carried out.

The performance analysis and evaluation of the proposed LRAF protocol has been accomplished with the comparison of PPAF two time slots protocol [14] and three time slots protocol [18]. The proposed LRAF protocol and the previous protocols are evaluated by taking shorter distances as well as longer distances. For shorter distances, the source to destination distance (d_{SD}) is assumed 100m, and for longer distances it is assumed 1000m. The purpose of taking these assumed distances was to calculate BER values with low path loss effect from the Lee path loss model [21]. Moreover, for distance d_{SD}=100m, the link distances calculated are i.e. $d_{SR1}=d_{SR2}=d_{R1D}=d_{R2D}$=55.9m and $d_{R1R2}=d_{R2R1}$=50m

Furthermore, for distance d_{SD}=1000m, the link distances calculated are i.e. $d_{SR1}=d_{SR2}=d_{R1D}=d_{R2D}$=559m and $d_{R1R2}=d_{R2R1}$=500. The link distances are calculated using the following eq. [13-18] as:

$$d_{SR1} = \sqrt{(0.1\times i\times d_{SD})^2 + (d_{SD}/4)^2} \tag{13}$$

$$d_{SR2} = \sqrt{(0.1\times i\times d_{SD})^2 + (-d_{SD}/4)^2} \tag{14}$$

$$d_{R1D} = \sqrt{((d_{SD}-i)/(10\times d_{SD}))^2 + (d_{SD}/4)^2} \tag{15}$$

$$d_{R2D} = \sqrt{((d-i)/(10\times d_{SD}))^2 + (-d_{SD}/4)^2} \tag{16}$$

$$d_{R1R2} = \sqrt{(d_{SD}/2)^2 + (0.1\times i\times d_{SD})^2} \tag{17}$$

$$d_{R2R1} = \sqrt{(-d_{SD}/2)^2 + (0.1\times i\times d_{SD})^2} \tag{18}$$

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

The source and destination antenna heights were taken 3m each, in order to maintain low installation cost. The operating frequency for the Lee path loss model was fixed i.e. 1500MHz [24].

The performance evaluation of LRAF protocol for shorter distances (i.e. d_{SD}=100m, $d_{SR1} = d_{SR2} = d_{R1D}=d_{R2D}$ =55.9m and $d_{R1R2}=d_{R2R1}$ =50) is carried out at severe fading condition i.e. at K=1 and for SNR values e.g. from 0dB to 20dB as well as from 21dB to 60dB. The purpose of taking SNR values from 0dB to 20 dB and from 21dB to 60 dB was to observe the LRAF protocol at low, medium and high SNR values. The LRAF three time slots protocol showed low BER values, as compared to PPAF two time slots and three time slots protocols, with the increase in SNR values i.e. from 0dB to 20dB, as shown in Figure 3.

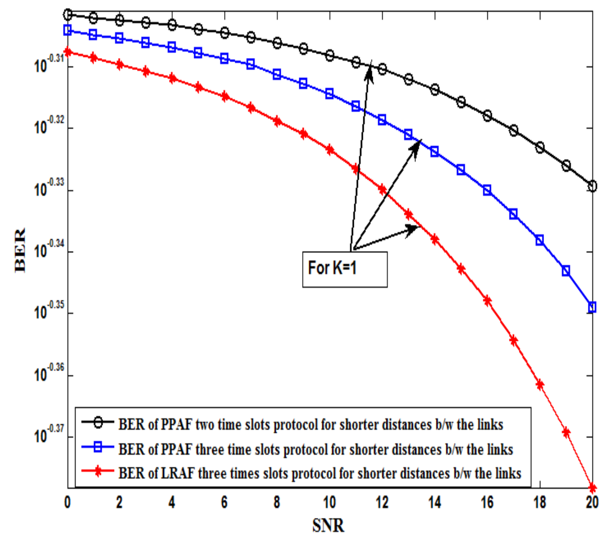

Fig.3. BER for shorter distances and low to medium SNR values

Moreover, the LRAF three time slots protocol showed further improvement over PPAF two time slots and three time slots protocols, in terms of low BER values, with the increase in SNR values from 21dB to 60dB, as shown in Figure 4. It is due to the fact that LRAF three time slots protocol has high diversity order, as compared to PPAF two time slots and PPAF three time slots protocols. It is also indicated from the results in Figure 3 and 4 that the LRAF three time slots protocol demonstrated significant improvement over PPAF two time slots and three time slots protocols, in terms of low BER values at medium to high SNR values from 21dB to 60dB, as compared to the low to medium SNR values from 0dB to 20 dB. Moreover, the proposed LRAF protocol showed significant improvement over PPAF two time slots protocol, as compared to PPAF three time slots protocol, in terms of low BER values with the increase in SNR values from low to high. It is due to the fact that one extra time slot makes the proposed protocol superior, as compared to PPAF two time slots protocol.

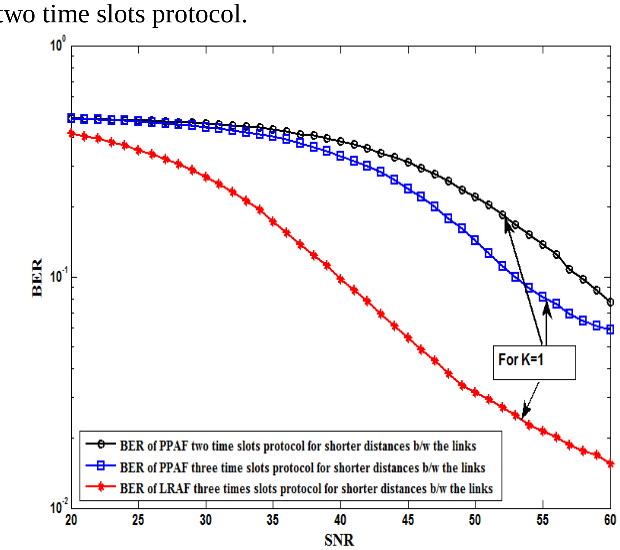

Fig.4. BER for shorter distances and medium to high SNR values

The performance evaluation of LRAF protocol for longer distances (i.e. d_{SD} = 1000m, d_{SR1} =d_{SR2} =d_{R1D} =d_{R2D} = 559m and d_{R1R2} = d_{R2R1} = 500) is also accomplished at severe fading condition i.e. at K=1 and for SNR values e.g. from 0dB to 20dB as well as from 21dB to 60dB. The LRAF protocol showed better performance over PPAF two time slots and three time slots protocols, in terms of low BER values with the increase in SNR values from 0dB to 20dB, as shown in Figure 5.

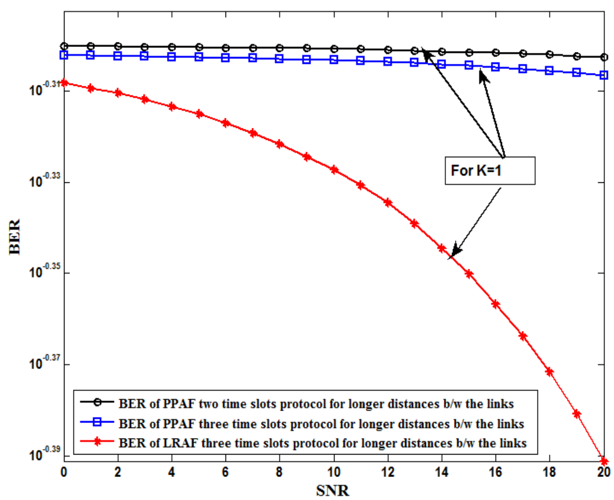

Fig. 5. BER for longer distances and low to medium SNR values

The proposed LRAF protocol also demonstrated improvement over PPAF two time slots and three time slots protocols, in terms of low BER values with the increase in SNR values from 21dB to 60dB, as shown in Figure 6.

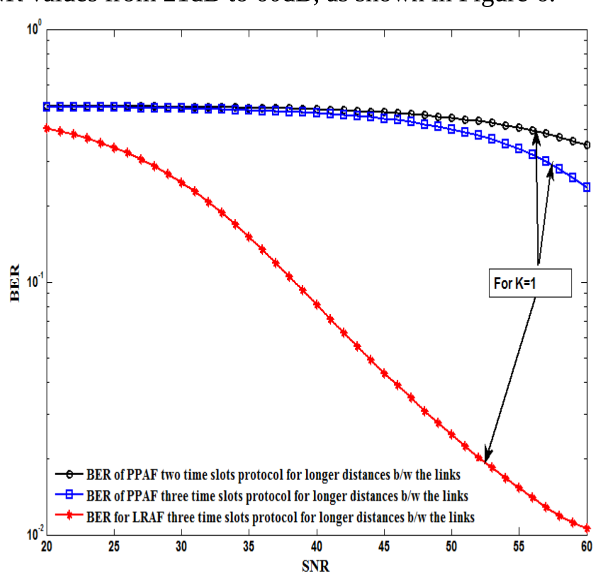

Fig .6. BER for longer distances and medium to high SNR values

It is also shown from results in Figures 5 and 6 that the proposed LRAF protocol indicated low BER values over PPAF two time slots and three time slots protocol, with the increase in SNR values from 21 dB to 60dB, as compared to the increase in SNR values from 0dB to 20dB. Moreover, low BER values are indicated by LRAF protocol over PPAF two time slots protocol, in contrast to the BER values demonstrated from the assessment with the PPAF three time slots protocol. Furthermore, the LRAF protocol illustrated better performance for longer distances, as compared to shorter distances, in terms of low BER values both for low to medium i.e. 0dB to 20dB, and medium to high i.e. 21dB to 60dB SNR values.

The accuracy of LRAF three time slots protocol was evaluated statistically by using the GPED and LPED methods [35-36]. The scientists use these methods to express the magnitude of the error between two measurements. The high LPED and GPED values mean better performance of LRAF three times slots protocol, in terms of low BER at destination. The eq. [19-20] define these statistical methods, as shown below

$$LPED = \left| \frac{\overline{E}_0 - \overline{E}_1}{\overline{E}_0} \right| \times 100 \tag{19}$$

$$GPED = \frac{\sum \left| \frac{\overline{E}_0 - \overline{E}_1}{\overline{E}_0} \right| \times 100}{N} \tag{20}$$

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

Moreover, the performance evaluation by using PED method has been accomplished for shorter distances and longer distances, at low to medium (e.g. at 0dB to 20dB) and medium to high (e.g. at 21dB to 50dB) SNR values. The performance evaluation of the proposed LRAF protocol by using PED method, for shorter distances (i.e. d_{SD}=100m, d_{SR1}=d_{SR2}=d_{R1D}=d_{R2D}=55.9m and d_{R1R2}=d_{R2R1}=50) is shown in Figures 7-10. First, the GPED and LPED values are obtained using low to medium SNR values e.g. from 0dB to 20dB and at severe fading condition e.g. at K=1. Secondly, the GPED and LPED values were obtained using high SNR values e.g. from 21dB to 50dB and at severe fading conditions. The proposed protocol indicated improvement over PPAF two time slots protocol, with GPED in BER of 5% using SNR values from 0dB-20dB, as shown in Figure 7.

Moreover, the proposed protocol demonstrated better performance, in terms of increase in LPED values, with the increase in SNR values e.g. from 0dB to 20dB. For 0dB SNR, the proposed protocol showed LPED in BER of 1.19%, as compared to two time slots protocol. However, the performance is further improved with the increase in LPED values. For 20dB SNR, the proposed protocol showed 12.01% LPED in BER, as compared to two time slots protocol.

The proposed LRAF protocol showed better performance over PPAF two time slots protocol, with GPED in BER of 46.98% at SNR values from 21dB-50dB, as shown in Figure 8.

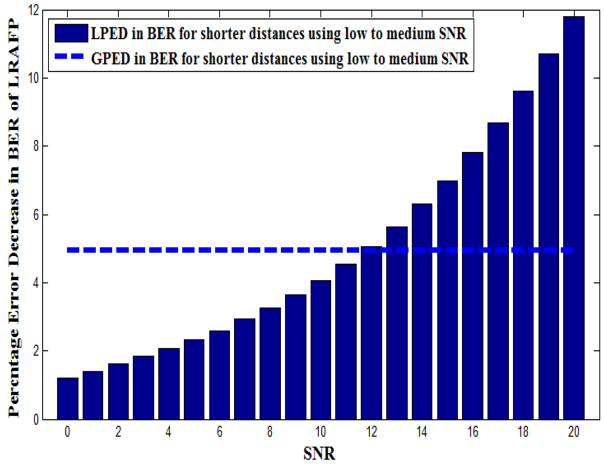

Fig .7. The PED comparison with PPAF two time slots protocol for shorter distances and low to medium SNR values

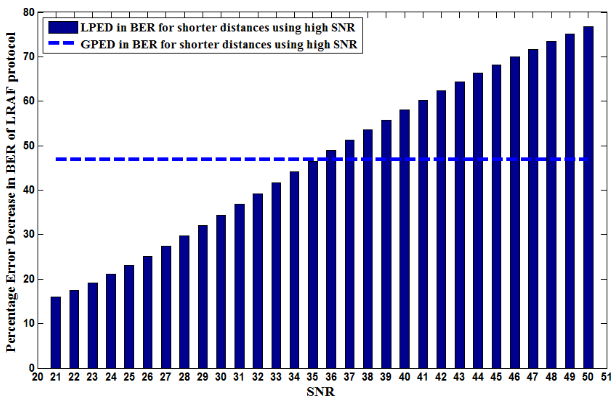

Fig .8. The PED comparison with PPAF two time slots protocol for shorter distances and medium to high SNR values

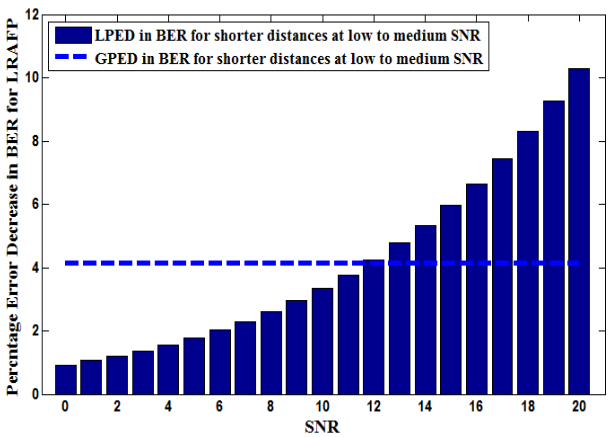

Fig .9. The PED comparison with PPAF three time slots protocol for shorter distances and at low to medium SNR values

In addition, the proposed protocol indicated increase in LPED values with the increase in SNR values from 21dB to 50dB. For 21dB SNR, the proposed protocol showed the LPED in BER of 15.90%. However, the performance is further improved with the increase in SNR value until 50dB. For 50dB SNR, the proposed protocol showed LPED in BER of 76.70%, as compared to two time slots protocol.

From the performance evaluation of LRAF three time slots protocol with PPAF three time slots protocol, it is indicated that LRAF protocol demonstrated better performance over PPAF three time slots protocol, with GPED in BER of 4.52 % at 0dB-20dB SNR, as shown in Figure 9.

Moreover, the proposed protocol demonstrated LPED in BER of 1.36% at SNR 0dB and LPED in BER of 10.70% at SNR 20dB, as compared to three time slots protocol. It is also indicated from results that the LRAF protocol showed significant improvement over PPAF three time slots protocol, in terms of GPED in BER of 40.44% at 21dB-50dB SNR, as shown in Figure 10.

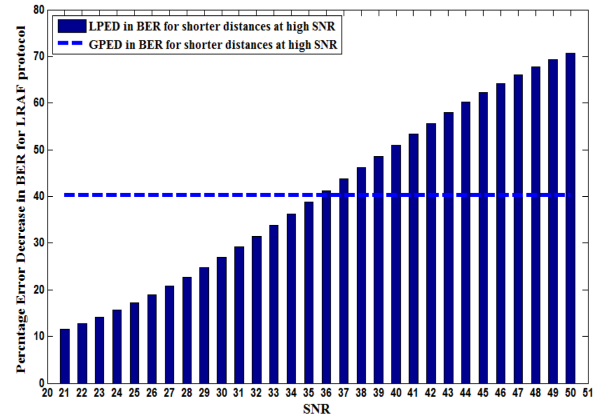

Fig .10. The PED comparison with PPAF three time slots protocol for shorter distances and medium to high SNR values

In addition, the proposed protocol demonstrated better performance, in terms of increase in LPED in BER, with the increase in SNR values from 21dB to 50dB. With respect to the 21dB SNR value, the proposed protocol indicated 11.70% LPED in BER. However, the performance is further improved over PPAF three time slots protocol, by achieving increase in LPED in BER with the increase in SNR e.g. until 50dB. For 50dB SNR, the proposed protocol showed LPED in BER of 70.60%.

The performance evaluation of the proposed LRAF protocol by using PED method, for longer distances (i.e. d_{SD} = 1000m, d_{SR1} =d_{SR2} =d_{R1D} =d_{R2D} = 559m and d_{R1R2} = d_{R2R1} = 500) is shown in Figures 11-14.

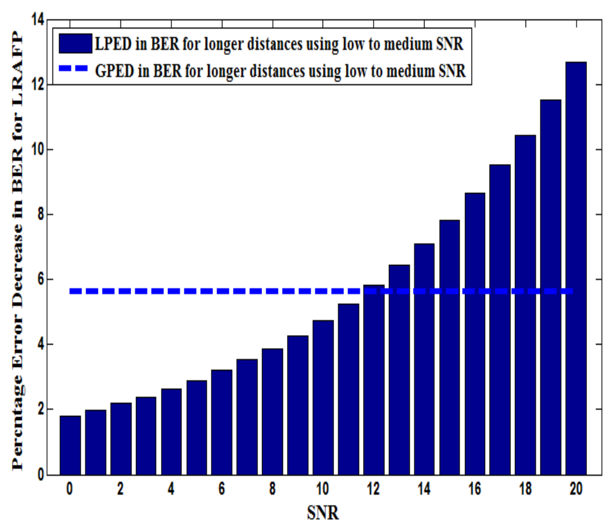

Fig. 11. The PED comparison with PPAF two time slots protocol for longer distances and low to medium SNR values

The low to medium (e.g. 0dB-20dB) and medium to high (e.g. 21dB to 50dB) SNR values are used to get the GPED and LPED values at severe fading conditions i.e. at K=1. The proposed protocol showed improvement over PPAF two times slots protocol, with GPED values in BER of 5.76% at SNR from 0dB to 20dB, as shown in Figure 11. Moreover, the protocol showed increase in LPED in BER of 1.20% at SNR 0dB and 12.76% at SNR 20dB, as compared to two time slots protocol.

It is also indicated from results that the LRAF protocol showed improvement over PPAF two time slots protocol, in terms of GPED in BER of 35.35% at SNR 21dB to 50dB, as illustrated in Figure 12.

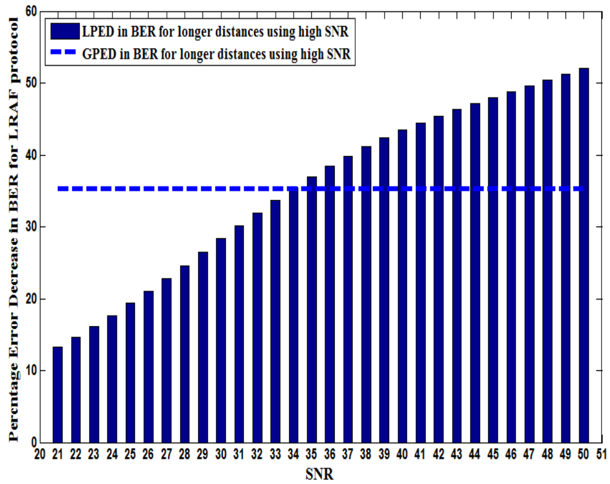

Fig. 12. The PED comparison with PPAF two time slots protocol for longer distances and medium to high SNR values

Moreover, the proposed LRAF protocol demonstrated increase in LPED values, with the increase in SNR values e.g. from 21 dB to 50dB. With respect to the 21 dB SNR, the LPED in BER of 13.30% is shown by the proposed protocol. However, the performance of the proposed protocol is further enhanced, in terms of increase in LPED until 50dB. For 50dB SNR, the proposed protocol pointed out LPED in BER of 52%, in contrast to PPAF two time slots protocol.

The performance comparison of LRAF protocol with PPAF three time slots protocol indicated that the proposed protocol showed better results, in terms of GPED in BER of 3.56% at SNR 0dB to 20dB, as shown in Figure 13. Moreover, the proposed protocol demonstrated LPED in BER of 1.20% at SNR 0dB and LPED in BER of 8.50% at SNR 20dB, as compared to PPAF three time slots protocol. It is also shown from results that the LRAF protocol performed better over PPAF three time slots protocol, in terms of GPED in BER of 30% at SNR 21dB to 50dB, as shown in Figure 14. However, the performance of LRAF protocol is further improved over PPAF three time slots protocol, in terms of increase in LPED values in BER, with the increase in SNR values from 21 dB to 50dB. Regarding the 21 dB SNR, the proposed protocol illustrated 9.42% LPED in BER. However, the proposed protocol indicated further improvement with the increase in SNR value until 50dB. With respect to the 50dB SNR, the proposed protocol showed improvement, in terms of LPED in BER of 46.60%, as compared to PPAF three time slots protocol.

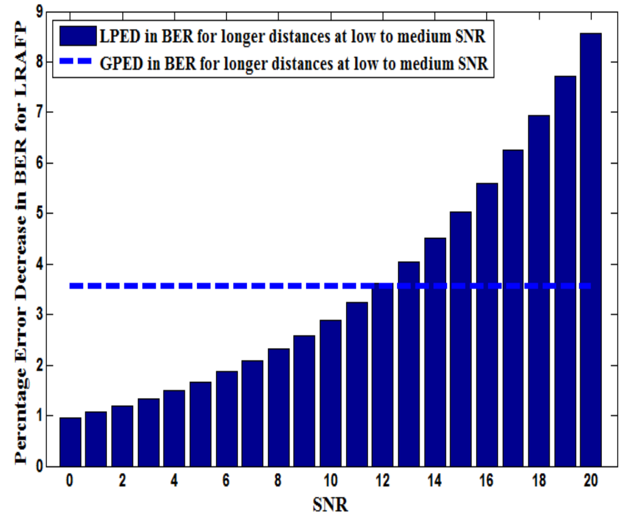

Fig. 13. The PED comparison with PPAF three time slots protocol for longer distances and low to medium SNR values

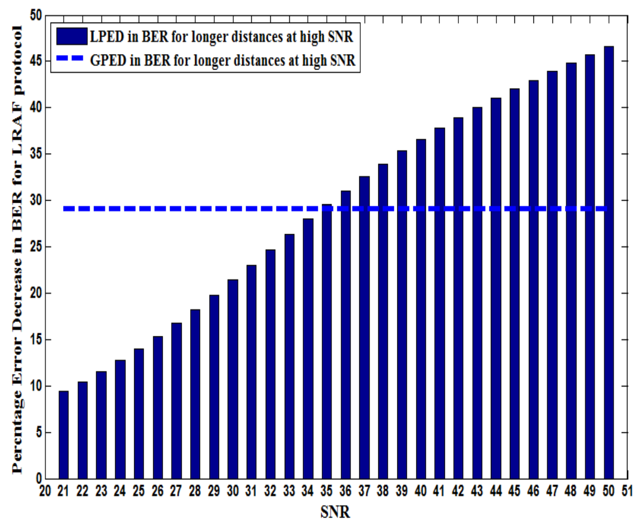

Fig. 14. The PED comparison with PPAF three time slots protocol for longer distances and medium to high SNR values

VI. CONCLUSIONS AND FUTURE WORK

The LRAF three time slots TDMA based protocol has been proposed for the target open urban environment with flat terrain. Moreover, from theoretical analysis the Lee path loss models have been identified, and the path loss values have been estimated for the open urban environment with flat terrain.

It is demonstrated from results that the LRAF protocol showed low BER values as compared to previous two time slots and three time slots protocols, both for longer distances and shorter distances using low to medium and medium to high SNR values. For shorter distances, the GPED and LPED results indicated the improvement of LRAF protocol, with GPED in BER of 5% and 4.52% over PPAF two time slots and three time slots protocols respectively, at SNR 0dB to 20 dB. However, the performance of the proposed protocol is further improved to GPED in BER of 46.98%, and 40.44% in contrast to PPAF two time slots and three time slots protocols respectively, at SNR 21dB to 50dB. Moreover, for shorter distances, the LRAF protocol also showed improvement with the increase in LPED in BER values, as compared to PPAF two time slots and three time slots protocols, with respect to the increase in SNR values. For longer distances, the LRAF protocol showed improvement over PPAF two time slots and three time slots protocols, with GPED in BER of 5.76% and 3.56% respectively, at SNR 0dB to 20dB. However, the performance is further enhanced to GPED in BER of 35.35% and 30%, as compared to PPAF two time slots and three time slots protocols respectively, with GPED, at SNR 21dB to 50dB. Moreover, the LRAF three time slots protocol also demonstrated increase in LPED in BER values for longer distances, with the increase in SNR values.

In this work, we have used only two relays with source and destination in the system model for simplicity. However, the performance of the proposed protocol can be further enhanced by using multiple relays. Moreover, the performance of the proposed protocol could be further analyzed by using parameters like delay and throughputs.

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