RELAY ASSUMPTION BASED OPERATIONAL COMPLEXITY AND COMPUTATIONAL TIME REDUCTION OF TWO TIME SLOTS TDMA-BASED PROTOCOL

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ABSTRACT; *The two time slots TDMA-based algorithms has been proposed by various researchers. However, the high operational complexity and computational time reduces the performance of these algorithms and has several limitations. Therefore, the Relay Assumption-based Operational Complexity Reduction Algorithm (RAOCRA) has been proposed. It is assumed that the relay is stationary and completely normalizes the incoming signal from the source. The average probability of bit error rate has been derived at destination, using the products of MGFs of the source to destination and relay to destination links. The performance analysis and evaluation has been carried out, with the comparison of previous proposed algorithm. The proposed algorithm demonstrated better performance, in terms of low BER and high BER-Gain values, with the increase in SNR values. Moreover, the RAOCRA showed improvement, in terms of low operational complexity and computation time with the increase in SNR values, in contrast to previous proposed algorithm. Furthermore, the Global-Percentage-Error-Decrease (GPED) and Local-Percentage-Error (LPED) methods have been used, to evaluate the accuracy of the proposed algorithm.*

Index Terms— Operational complexity, computational time, two time slots AF protocol, 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). To achieve diversity communication, several communication techniques, for instance, micro diversity, macro diversity, space diversity, frequency diversity and time diversity have been used [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 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 [5],[8-14]. Cooperative communication solves the issues of size, cost, and hardware limitations of multiple antennas [15]. 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 [16-17]. 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 [18-19].

The performance analysis of wireless cooperative networks using amplify-and-forward and decode-and-forward based algorithms over fading channels has been carried out by various researchers [20-21] . Different approaches like Probability Density Function (PDF), Moment Generating Function (MGF), Cumulative Distributive Function (CDF), Gamma function and Gauss hyperbolic functions have been used to achieve bit error rate (BER) and outage probability of bit error rate at destination. For instance, the PDF, CDF and MGF using the harmonic mean of two independent exponential random variables have been derived using single relay wireless cooperative network [22]. The derivations are then used to derive the average BER and outage probability at destination. The performance analysis of multiple relays wireless cooperative network using amplify-and-forward based algorithm over independent non-identical Nakagami-m fading channels has been carried out [23]. The closed form approximations for PDF and MGF have been derived to get BER and outage probability at destination. The average symbol error probability for general multi-relay wireless cooperative links using AF based algorithm has been derived [24]. The performance analysis of dual hop multiple relay wireless cooperative network using AF based algorithm has been performed [25]. The closed form expressions for the PDF using cooperative network are derived to get symbol-error-rate at destination. The performance of dual hop single relay wireless cooperative network has been investigated over Rician fading channel using different K factors [26] . The MGF based approach has been used to derive the closed form expression for PDF and to get outage probability at destination.

The high operational complexity and high computational time reduces the performances of the two time slots protocols and has several limitations. The probability distribution $p_{\gamma\Sigma}(\gamma)$ used is often not in the closed form. It is normally in the form of closed form of an infinite integral, which is difficult to evaluate numerically to get BER and BER gain. The MGF approach along with the Gauss's hyper-geometric, Gauss's hyperbolic and Gamma functions has been used, to eliminate these kinds of integration difficulties. However, the operational complexity (number of operations) and the computational time increase, due to the use of these techniques.

In this work, the Relay Assumption based Operational Complexity Reduction Algorithm (RAOCRA) has been proposed. The main contribution of this work is that the average probability of bit error rate (BER) has been derived using normalization factor assumption at relay. Simulation results indicated that the proposed algorithm demonstrated low operational complexity and less computational time, in contrast to Previous Proposed Algorithm (PPA) [26].

II. THE RELAY ASSUMPTION BASED OPERATIONAL COMPLEXITY REDUCTION ALGORITHM

System model

The system model used for RAOCRA consists of source (S), single relay (R) and destination (D), as shown in figure 1. In the 1st time slot, the source broadcasts to relay and destination in the first time slot. In the 2nd time slot, the relay broadcasts to the destination. The relay assists the source to provide a copy of the original signal to the destination. The source, relay and destination all are equipped with single antenna. Moreover, the Rician fading model is considered as the fading model.

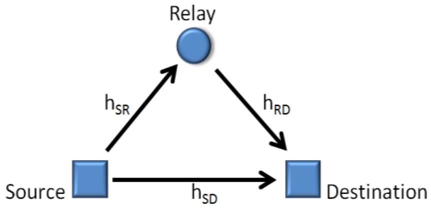

Fig. 1. Single relay wireless cooperative network

The parameters h_{SR}, h_{RD} and h_{SD} are the Rician fading channels from source to relay, relay to destination and source to destination links respectively.

The received signals at relay and destination, over the 1st time slot are given by eq. [1-2] as:

$$y_{SR} = E_S\, h_{SR}\, x + n_{SR} \qquad (1)$$

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

The relay receives the signal from the source, normalizes the received signal and retransmits to destination in the second time slot. The received signal at the destination from relay is y_{RD} and is given by eq. [3] as:

$$y_{RD} = h_{RD} \frac{y_{SR}}{\sqrt{E_s |h_{SR}|^2 + 1}} + n_{RD} \qquad (3)$$

The received signal to noise ratios at relay and destination over the first time slot is given by eq. [4-5] as:

$$\gamma_{SR} = x\, h_{SR} E_S / N_{SR} \qquad (4)$$

$$\gamma_{SD} = x\, h_{SD}\, E_S / N_{SD} \qquad (5)$$

Where E_S is the average transmit energy per symbol by the source. The parameters h_{SR} and h_{SR} are random complex multipath fading channels of the source to relay and source to destination channels respectively. The parameters N_{SR} and N_{SD} are the noise variances of the source to relay and source to destination links respectively, and are modeled as with zero mean. The received signal to noise ratio of relay to destination link at destination, over the 2nd time slot is given as by eq. [6] as:

$$\gamma_{RD} = y_{SR}\, h_{RD} / N_{RD} \qquad (6)$$

Where y_{SR} is the signal obtained from source to relay link. The parameters h_{RD} is the random complex multipath fading channel of the source to destination link. The parameter N_{SD} is the noise variance of the source to destination link and is modeled as with zero mean. The received signal to noise ratio at the destination due to S→R→D links is given as by eq. [7] as:

$$\gamma_{eq} = \frac{\gamma_{SR}\gamma_{RD}}{\gamma_{SR} + \gamma_{RD}} \qquad (7)$$

Using the Maximum Ratio Combining (MRC) at destination, the total signal to noise ratio using the direct and two hops paths can be represented by eq. [8] as:

$$\gamma_{MRC} = \gamma_{SD} + \gamma_{eq} \qquad (8)$$

Substituting the eq. (6) and (4.7) into eq. (4.8), the total signal to noise ratio can be determined by eq. [9] as:

$$\gamma_{MRC} = \gamma_{SD} + \frac{\gamma_{SR}\gamma_{RD}}{\gamma_{SR} + \gamma_{SD}} \qquad (9)$$

Hence, the probability of bit error rate, using the approach in [1] can be expressed by eq. [10] as:

$$P_e^{(AF)} = Q\sqrt{2(\gamma_{MRC})} \qquad (10)$$

Where the Q-function Q (z) =1/2 erf (z /√2).

Alternative expression for probability of bit error rate

The probability density function of Rician distributed random variable X can be expressed as [20]:

$$p_X(x) = \frac{x}{\sigma^2} e^{-\frac{x^2+A^2}{2\sigma^2}} I_0\left(\frac{Ax}{\sigma^2}\right),\ x \geq 0 \qquad (11)$$

Where A is the peak amplitude of the line of sight (LOS) component and $I_0(.)$ is the 0th order modified Bessel function of the first kind and σ is the standard deviation of real and imaginary Gaussian variables. Similarly, the probability distribution function of the signal to noise ratio (γ) per symbol over a single Rician fading channel is expressed as [26]:

$$p_\gamma(\gamma) = \frac{(1+K)e^{-K}}{\bar{\gamma}} \exp\left(-\frac{(1+K)\gamma}{\bar{\gamma}}\right) \times I_o\left[2\sqrt{\frac{K(K+1)\gamma}{\bar{\gamma}}}\right] \qquad (12)$$

Where $\bar{\gamma}$ is the average SNR per symbol. The $K=A^2/2\theta^2$, is the ratio of the power of the LOS component to that of the scattered signals. Using the eq. (6.26) [1], the MGF of the received signal to noise ratio over Rician fading can be shown by eq. [13] as:

$$M_\gamma(s) = \int_0^\infty e^{s\gamma} p_\gamma(\gamma) d\gamma \qquad (13)$$

Similarly, using eq. (6.64) [1], the moment generation function can be expressed by eq. [14] as:

$$M_\gamma(s) = \frac{(1+K)}{(1+K) - s\bar{\gamma}_{SD}} \exp\left[\frac{sK\bar{\gamma}_{SD}}{(1+K) - s\bar{\gamma}_{SD}}\right] \qquad (14)$$

Substituting $s = -g/\sin^2\phi$ [1], the moment generating function can be shown by eq. [15] as:

$$M_\gamma\left(\frac{-g}{\sin^2\phi}\right)=\frac{(1+K)\sin^2\phi}{(1+K)-g\bar{\gamma}_{SD}}\exp\left[\frac{gK\bar{\gamma}_{SD}}{(1+K)\sin^2\phi-g\bar{\gamma}_{SD}}\right] \quad (15)$$

Using eq. (6.74) [1], the average error probability rate for non-cooperative source to destination link over the Rician fading channel can be expressed by eq. [16]as:

$$\bar{P}_{SD}^{NC}=\frac{1}{\pi}\int_0^{\pi/2}\frac{(1+K)\sin^2\phi}{(1+K)-g\bar{\gamma}_{SD}}\exp\left[\frac{gK\bar{\gamma}_{SD}}{(1+K)\sin^2\phi-g\bar{\gamma}_{SD}}\right]d\phi \quad (16)$$

It is assumed that the relay is stationary and completely normalizes the incoming signal from the source. In this case, the probability of bit error rate is affected because of the variation in the source to destination and relay to destination links. Therefore, using eq. (7.49) [1], the average probability of bit error rate for cooperative single relay to destination and source to destination links is given by eq. [17] as:

$$\bar{P}^{C}=\frac{1}{\pi}\int_0^{\pi/2}\frac{(1+K)\sin^2\phi}{(1+K)-g\bar{\gamma}_{SD}}\exp\left[\frac{gK\bar{\gamma}_{SD}}{(1+K)\sin^2\phi-g\bar{\gamma}_{SD}}\right]\times$$

$$\frac{(1+K)\sin^2\phi}{(1+K)-g\bar{\gamma}_{RD}}\exp\left[\frac{gK\bar{\gamma}_{RD}}{(1+K)\sin^2\phi-g\bar{\gamma}_{RD}}\right]d\phi \quad (17)$$

Furthermore, using eq. (7.46) and (7.51) [1], the average probability of bit error rate for multiple cooperative links can be expressed by eq. [18] as:

$$\bar{P}=\frac{1}{\pi}\int_0^{\pi/2}\frac{(1+K)\sin^2\phi}{(1+K)-g\bar{\gamma}_{SD}}\exp\left[\frac{gK\bar{\gamma}_{SD}}{(1+K)\sin^2\phi-g\bar{\gamma}_{SD}}\right]$$

$$\times\prod_{i=1}^{M}\frac{(1+K)\sin^2\phi}{(1+K)-g\bar{\gamma}_{i}}\exp\left[\frac{gK\bar{\gamma}_{i}}{(1+K)\sin^2\phi-g\bar{\gamma}_{i}}\right]d\phi \quad (18)$$

Finally, the BER gain for wireless cooperative network with single source, single relay and one destination can be determined by eq. [19] as:

$$Average\,BER\,gain=\frac{\bar{P}_{SD}^{NC}}{\bar{P}^{C}} \quad (19)$$

Where $\bar{P}_{SD}^{NC}$ and $\bar{P}^{C}$ indicates the average probability of bit error rate in non-cooperative and cooperative scenarios respectively.

III. SIMULATION AND RESULT DISCUSSION

The simulation model for the RAOCRA is shown in figure 2. At the source, 10^5 symbols are generated. The BPSK modulation technique is used to modulate the signal at the source.

The Rician multipath fading channels h_{sr} and h_{sd} are created for the source to relay and source to destination links respectively, over the 1st time slot. Moreover, the input signal or information signal from the source along with average symbol energy per symbol is passed across each Rician multipath fading channel. In addition, the AWGN is included to Rician multipath channel h_{sr}, to create noisy Rician multipath fading signal for the sourc to relay link. The relay receives the Rician multipath nosiy signal over the 1st time slots. For the 2nd time slot, the signal received at relay during the 1st time slot is normalized. The normalized signal is considered as the input signal for the relay e to destination link and is passed through the Rician multipath channel (h_{sr}). Moreover, the absolute value of the Rician multipath channel h_{sr} is created and divided by the noise variance (N_{RD}), to create the signal to noise ratio (γ_{RD}) for the relay to destination link. The destination receives the signal to noise ratio, over the 2nd time slot.

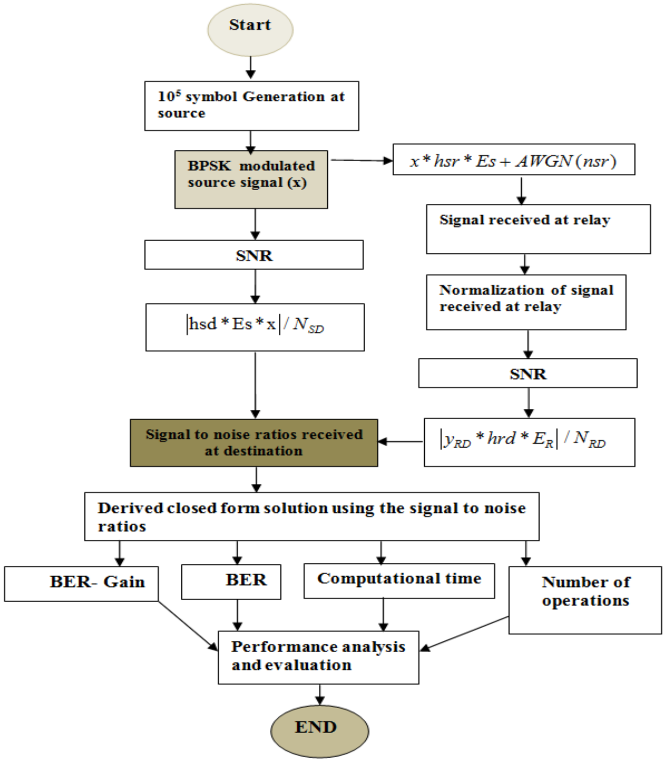

Fig. 2. Simulation model for the proposed RAOCRA

The signal to noise ratio (γ_{SD}) and noise variance (N_{SD}) are obtained for the source to destination link. Moreover, the absolute value of the Rician multipath channel h_{sd} is obtained and divided by the noise variance (N_{SD}), to create the signal to noise ratio for the source to destination link. The destination receives the signal to noise ratio, over the first time slot.

The BER and BER-Gain are obtained from the derived closed form solution using the signal to noise ratios i.e. γ_{RD} and γ_{SD} of the relay to destination and source to destination links respectively. The γ_{RD} and γ_{SD} are used as random variables for the derived closed form of BER and BER-Gain at destination. Moreover, the number of operations and the computational time are obtained for the proposed RAOCRA algorithm. Finally, the performance analysis and evaluation are carried out with the comparison of previous proposed algorithm.

The performance analysis and evaluation of RAOCA has been presented, with respect to the increase in signal to noise ratio values. The BER and BER-Gain are used as performance metrics and are obtained at severe as well as low fading conditions i.e. at K=0, 2 and 3. In addition, the proposed protocol has been tested using low to medium SNR values e.g. 0dB to 15dB, at both the severe as well as low fading conditions,

The RAOCRA indicated better performance, in terms of decrease in BER and increase BER-Gain values, with the increase in SNR values, as shown in figures 3 and 4 respectively.

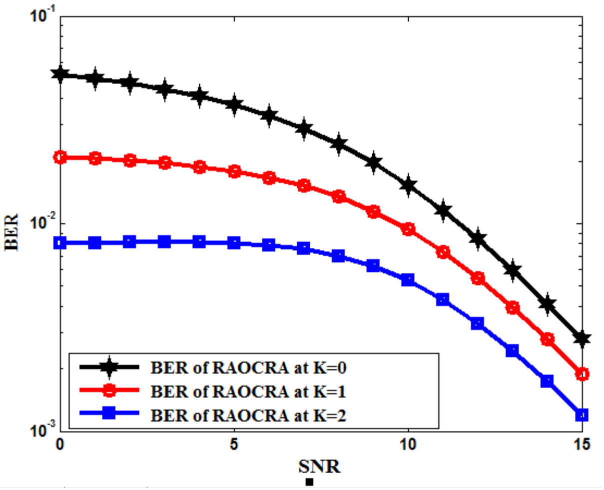

Fig. 3. BER of RAOCRA at different K values

Moreover, the proposed algorithm demonstrated improved performance, in terms of low BER and high BER-Gain values, at low fading conditions i.e. at K=2 and 2, in contrast to severe fading conditions i.e. at K=0. It is because at severe fading conditions, there is weak LOS channel behavior, while, at low fading conditions the channel shows strong LOS behavior. Due to the strong LOS behavior, the low BER and high BER-Gain values have been observed by the proposed algorithm.

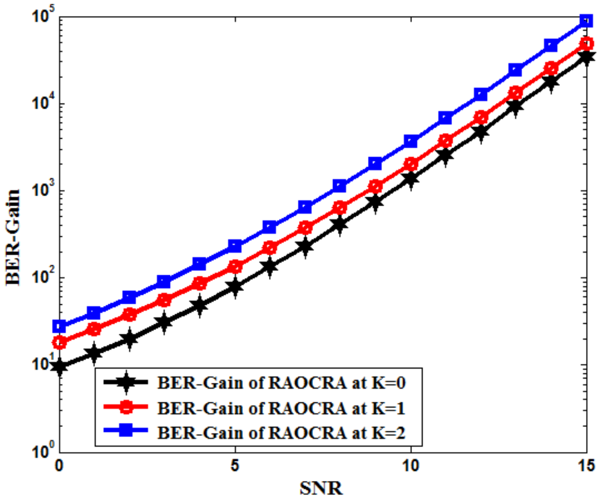

Fig. 4. BER-Gain of RAOCRA at different K values

The RAOCRA is evaluated with the comparison of Previous Proposed Algorithm (PPA) [26]. The low to medium SNR values (e.g. 0dB to 15dB) have been used for the performance evaluation. The RAOCRA showed improved performance, in terms low BER values as compared to PPA, with respect to the increase in SNR values, as shown in figure 5. Owing to the fact that the relay assumption used greatly simply the closed form solution for the BER and the BER is derived by using only the product of MGFs of SNRs of source to destination and relay to destination links. Due to this, the BER is affected only by noises of source to destination and relay to destination links and is independent of the noise of source to relay link.

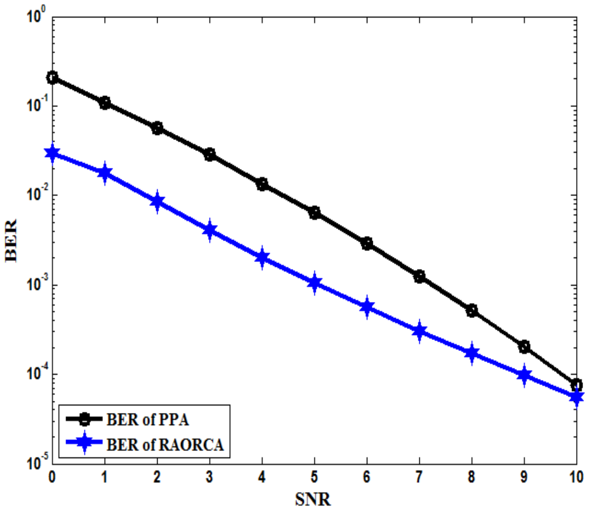

Fig. 5. BER comparisons of RAOCRA and PPA

The computational time and the number of operations for both the RAOCRA and PPA are obtained by using low to medium SNR values e.g. from 0dB to 15 dB, and at severe fading condition. The RAOCRA demonstrated less computational time as compared to PPA, with the increase in SNR values i.e. 0 dB to 15dB, as shown in figure 6.

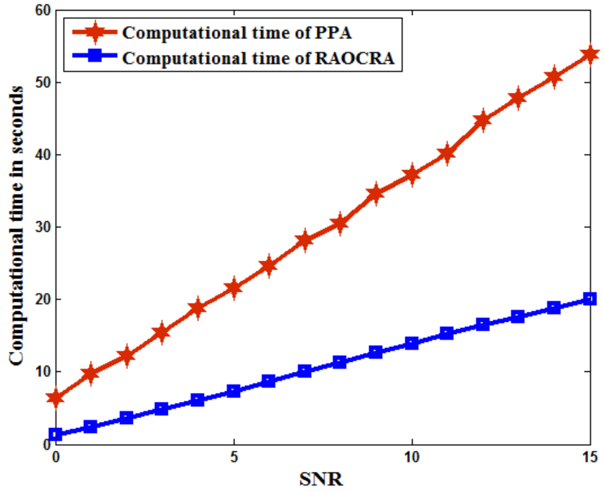

Fig. 6. Computational time comparison of RAOCRA

Moreover, the RAOCRA showed low operational complexity (i.e. less number of operations) in contrast to PPA, with respect to the increase in SNR values, as shown in figure 7. It is because of the fact that the RACRA uses simple MGF technique, due to which the average BER is obtained by evaluating single integral, with the products of MGFs of SNRs of source to destination and relay to destination links. Comparatively, in PPA the closed from solution of the probability of the average BER has been derived by using the complex techniques like Gauss hyper-geometric and Gamma functions. The Gauss hyper geometric and Gamma functions increase the operational complexity (i.e. number of operations) as well as the computational time of the PPA.

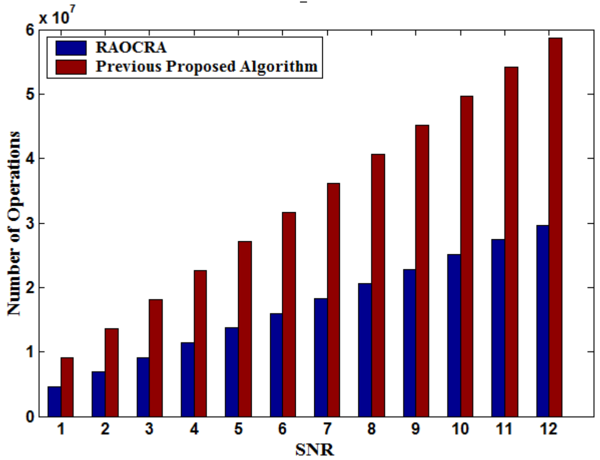

Fig. 7. Operational complexity comparison of RAOCRA

The accuracy of the RAOCRA has been evaluated statistically by using Local Percentage-Error-Decrease (LPED) and Global Percentage-Error-Decrease (GPED) methods [27-28]. The high LPED and GPED values mean better performance of the RAOCRA, in terms of low operational complexity (i.e. less number of operations). These statistical methods are defined by the eq. [20-21].

$$LPED = \left|\frac{\bar{E}_0 - \bar{E}_1}{\bar{E}_0}\right| \times 100 \qquad (20)$$

$$GPED = \frac{\sum \left|\frac{\bar{E}_0 - \bar{E}_1}{\bar{E}_0}\right| \times 100}{N} \qquad (21)$$

Where $\bar{E}_0$ is the average number of operations RAOCRA and $\bar{E}_1$ is the average number of operations of PPA and N is the total number of SNR values taken. Moreover, the low to medium SNR values e.g. 0dB to 12 dB are used for the evaluation using PED methods.

The RAOCRA showed improved performance, in terms of 79.54% GPED in number of operations, in contrast to PPA, with the increase in SNR values, as shown in figure 8.

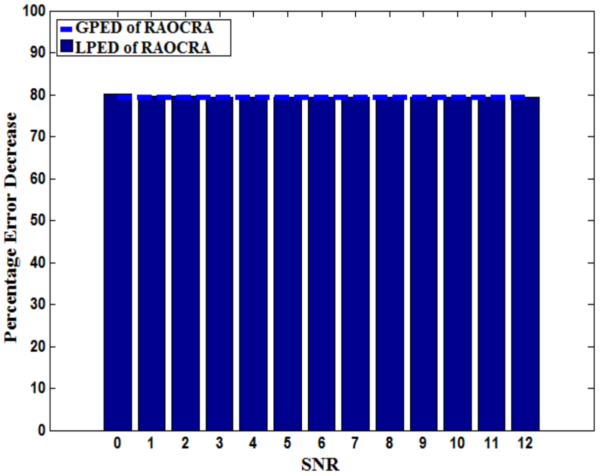

Fig. 8. GPED and LPED comparison of RAOCRA.

Moreover, the proposed algorithm indicated 80.06% LPED at SNR=0dB and 79.34% at SNR=12dB, as compared to PPA, as shown in figure 8. The LPED values illustrated that the proposed algorithm showed 80.06% low operational complexity at SNR 0dB and 79.34% at SNR 12dB, in contrast to PPA. It is also observed from figure 8 that the proposed algorithm demonstrated almost the same LPED in operational complexity for the SNR 0dB to 12dB. It is because the proposed algorithm shows almost the same number of operations for each signal to noise ratio iteration.

IV. CONCLUSIONS AND FUTURE WORK

The Relay Assumption-based Operational Complexity Reduction Algorithm has been proposed. Using the normalization factor assumption at relay, the average probability of bit error rate has been derived at destination. The products of MGFs of the source to destination and relay to destination links have been used to derive the average bit error rate. The proposed algorithm demonstrated better performance, in terms of low BER and high BER-Gain values, with the increase in SNR values. Moreover, the RAOCRA showed improvement, in terms of low operational complexity and computation time with the increase in SNR values, in contrast to previous proposed algorithm. The Global-Percentage-Error-Decrease and Local-Percentage-Error further verifies the accuracy of the proposed algorithm. The RAOCRA demonstrated 79.54% GPED in number of operations, in contrast to previous proposed algorithm, with the increase in SNR values. Moreover, the 80.06% LPED in operational complexity at SNR=0dB and 79.34% at SNR=12dB has been demonstrated, in contrast to previous proposed algorithm.

In this work, a single relay is used for simplicity. However, the performance of the proposed algorithm can be further enhanced by using multiple relays. Moreover, the performance of the proposed algorithm could be further analyzed by using parameters like delay, throughputs.

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