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OPTIMAL POWER ALLOCATION TO MINIMIZE SER FOR MULTI-RELAY DECODE-AND-FORWARD COOPERATIVE COMMUNICATION SYSTEMS USING EMA ALGORITHM

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ABSTRACT

In the wireless environment, data transfer suffers from several problems such as the Multipath propagation, fading and limited range of transmitters. To solve these problems, a number of solutions have been developed that one of the newest and most efficient of them is cooperative communication techniques. In cooperative communications, one can gain a benefit from numerous advantages such as compensation or coverage of range limitation effects transmitters, overcoming fading and creating spatial diversity. Since most mobile units are fed by power limited batteries, optimal control and allocation of power in these networks is of particular importance. In this paper, a method for allocating a limited power the amount of which is determined by constraints is proposed in a cooperative system of multiple relay Decode and Forward to minimize the symbol error rate with M-QAM modulation using two methods EMA algorithm and Lagrange multiplier. Simulation results show that the symbol error rate performance is the same with both methods. Since the computational complexity of power allocation through Lagrange method, especially when there are a large number of relays, is high, EMA algorithm is an effective method for power allocation in cooperative networks.

Keywords: decode and forward, multi-relaying, power allocation, cooperative network, EMA algorithm, symbol error rate.

1. INTRODUCTION

Wireless network in recent years have attracted much attention. The most important reasons for using these networks are mobility, fast installing and ease of use compared with networks with wire. Of the main problems of these networks is fading channels. One way to deal with fading wireless channels is to use diversity techniques in sending or receiving signals. In diversity practices, independent signal samples will reach the receiver and the receiver can attempt to compensate for the fading effects by using independent samples.

On the other hand, wireless environment can also make independent channels from each other in space in case the sender or receiver antennas are at the right distance from each other. It can be shown that there will be very low dependence between channels (antennas transmitter and receiver antennas). In other words, it can be assumed fading quantities for the two channels are independent of each other. This distance for wireless network nodes must be equal to about half the wavelength of transmitted signal. For high antennas, this amount increases to ten times of the wavelength of the transmitted signal[1].

This feature of wireless environment introduces a new type of spatial diversity. In this method, the transmitter and receiver antennas are placed at appropriate intervals from each other in such a way that their channels can be recognized as independent of each other. At the receiver, using independent fading coefficient signals, we can reach the maximum ratio of signal to noise by combining them.

To use spatial diversity, there should be more than one antenna available at the transmitter and receiver. However, in many cases, due to limited physical dimensions and other constraints, mobile terminals are not able to use multiple antennas. The use of cooperative networks is a new solution to this problem. It means mobile units of single antenna enable a multi-user network, using each other's antennas and forming a virtual array of antennas from adjacent users, to achieve the spatial diversity.

Relay Channel was first described in 1971 by Van-der Meulen [2].In 1979, Cover and EL Gamal, after working on the properties of channel information theory, reached the basic idea of cooperative Networks[3]. In cooperative networks, each transmitted message passes through multiple relay routes and the probability that the message does not reach its destination is significantly reduced. Types of relay performance on these networks include Amplify and Forward protocol (AF), Decode and Forward protocol (DF) and Compress and Forward protocol (CF).In Amplify and forward the relays, the incoming signal is multiplied by a coefficient and re-transmit. The relay, in this method, behaves like an analog repeater. During a time slot, it sends data source to the destination and the relay. Then, the relay amplified version of transmitted signal from the source to the destination without any decoding and sends it to the destination [4]. Decode and Forward protocol, the relayed codes the received signal and re-transmit it to the destination. When the source and relay are close together, this method is close to the optimal mode[4]. In Compress and Forward protocol, when the relay channel-destination is good, it is useful. In this case, the relay sends an estimate of the source signal to the destination. The signal that has been estimated by the relay is sent to the destination as side information so that the destination uses this side

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information to decode the transmitted signal from the source[5].

In cooperative networks, users coordinate and share their resources to enhance the quality of transmitting. In these networks, nodes are powered by batteries. So, power allocation methods can be used to saving transmitted power and improving the lifetime of the system. Reference[6], studying wireless sensor networks, showed that the total energy consumption in data transmission can be reduced by using cooperative system. In [7] it is shown that equal distributions of signal energy between direct links and relay are used for cooperative communication, optimal allocation is not for power. In [8]it has been stated that optimized power allocation in the fading environment leads to an increasing in the capacity of the system. Analysis of the symbol error rate (SER) and optimal power allocation for Decode and Forward cooperative systems have been investigated in[9].Optimal power allocation method for Amplify and Forward multiple relays have been proposed in[10]that is based on the signal-to-noise ratio (SNR) and outage probability. In [11], cooperative multi-relay networks has been investigated. In[12],optimizing power distribution for a single-relay Decode and Forward cooperative network using the particle swarm optimization algorithm (PSO) has been investigated.

As noted, the issues of improving system performance and reducing the possibility of error in cooperative systems have been the focus of high concentration. On the other hand, the issue of transmitter power is raised. So we should seek methods and algorithms that can lead to improving the quality of transmission with a minimum transmit power and increase lifetime system. A lot of pieces of work in this regard have been conducted by the conventional optimization Lagrange method[13, 14]. However, the disadvantage of this method is that in systems in which there are large numbers of relays, expressions are very complex and solving them is so difficult. So in this paper, EMA algorithm is proposed as a good way to minimize the symbol error rate and power allocation in cooperative systems. In this paper, a Multi-Relay Decode and Forward cooperative system in wireless networks is taken into consideration. At first, a closed-form expression for the symbol error rate with M-QAM signal is obtained. Since this is a complex formula, an approximation expression is derived for SER to demonstrate the performance of a cooperative system. Based on the symbol error rate performance analysis, optimal power allocation method using the EMA algorithm and Lagrange method (OPA) is proposed. The paper is organized as follows. After the introduction, system model for Multi-Relay Decode and Forward cooperative wireless network is introduced in section two. In section three, power allocation algorithm based on minimizing the symbol error rate is given by Lagrange multipliers. In section four, based on the symbol error rate performance analysis, optimal power allocation method using the EMA algorithm is recommended. In the fifth part, the simulation results will be expressed and conclusions are presented in Section VI.

2. SYSTEM MODEL

We consider a N-relay wireless network, where information is transmitted from a source to a destination. Due to the inherent nature of wireless channel, relays eavesdrop to the transmitted information and in this way it cooperates with the source to send its data. Wireless link between any two nodes is modeled by a Rayleigh fading channel in the presence of Additive white Gaussian noise. The fading channel for different paths is assumed to be statistically independent because the relays are usually spatially separated. Additive noise in incoming terminals has been modeled by a Gaussian random variable with zero mean and $\mathcal{N}_0$variance. Assume that the relays transmit in an orthogonal channel so there will be no between-relay interference.

In the cooperative strategy of Decode and Forward scheme, each relay can decode the received signal from source with transmitted signals by the previous relay combination and send them to the receptor after re-encoding. A common cooperative scenario that is shown with C(m)(1 ≤ m ≤ N-1) is implemented in which each relay combines received signals from m previous relays with the received signal from the source.

Multi-Relay Decode and Forward strategy is shown in Figure-1 in which each relay combine received signals from previous relays with the received signals from the source.

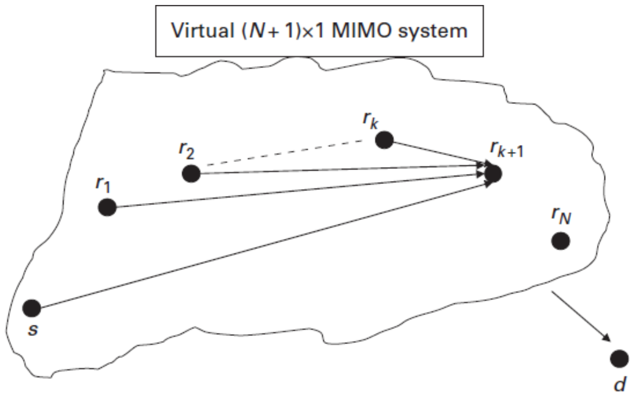

Figure-1. Illustrating cooperation under *C(N-1)*: the *(k+1)*-th relay combines the signals received from the source and all of the previous relays[14].

In all mentioned cooperative methods, the destination steadily and coherently combines the received signals from the source and relays. Now we propose a system model for a common cooperative system C(m) (1 ≤ m ≤ N-1) in a way that each relay decodes the information after combining received signals from m previous relays with the received signals from the source.

Normally, multi-node cooperative strategy has N+1 phase. In the first phase, the source sends the message signal to both the first relay and the destination, which is modeled according to the following equation:

$$Y_{s.d} = \sqrt{P_0}\, h_{s.d}\, x + n_{s.d}$$

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$$Y_{s.r_i} = \sqrt{P_0}\, h_{s.r_i} x + n_{s.r_i} \quad 1 \leq i \leq N \qquad (1)$$

Where, $P_0$is the transmit power from the source, X is the transmitted symbol, $h_{s.d}$and $h_{s.ri}$are the channel coefficients between source and destination and source and$i$-th relay, respectively. Moreover, $n_{s.d}$and $n_{s.ri}$are defined as AWGN channel noise. In the second phase, if the first relay correctly decodes the signal reached from source to the relay, it then recodes the signal and sends it to other relays as well as the destination with P_1power. Otherwise, it will idle. The second relay combines received signals from the first relay and the source signals as follows:

$$Y_{r2} = \sqrt{P_0}\, h^*_{s.r2} Y_{s.r2} + \sqrt{P_1}\, h^*_{r1.r2} Y_{r1.r2} \qquad (2)$$

Where $h_{r1.r2}$is the channel coefficient between the first and second relays. In addition, $Y_{r1.r2}$is defined as the signal received at the second relay from the first relay, which can be obtained from the following equation:

$$Y_{r1.r2} = \sqrt{P_1}\, h_{r1.r2}\, x + n_{r1.r2} \qquad (3)$$

In which $P_1$is the transmit power of the first relay.The received signal at the destination in the second phase is as follows:

$$Y_{r_i.d} = \sqrt{\hat{P}_i}\, Y_{s.r_i}\, h_{r_i.d}\, x + n_{r_i.d} \qquad (4)$$

Where$\hat{P}_i$is the power of ith relay. If the relay is able to correctly decode the signal received from phase one, then, $\hat{P}_i = P_i$. Otherwise, $\hat{P}_i = 0$. Furthermore,. $h_{ri.d}$is the channel coefficient between ith relay and the destination, and $n_{ri.d}$is defined as AWGN channel noise.

In lth Phase (2≤l≤N),the lth relay combines the incoming signals from the source and from the previous relays,$min\{1.l-m\}$, with the MRC method, which can be expressed as follows:

$$Y_{r_l} = \sqrt{P_0}\, h^*_{s.r_l} Y_{s.r_l} + \sum_{i=\max(1.l-m)}^{l-1} \sqrt{\hat{P}_i}\, h^*_{r_i.r_l} Y_{r_i.r_l} \qquad (5)$$

$max(1.l-m)$Expression is to ensure that for $l < m$, combining signals begins from the first relay, is considered. Also in the above expression, $h_{r_i.r_l}$is the channel coefficient between the ith relay and lth relay and $Y_{r_i.r_l}$is the signal received to ith relay from the lth relay, which is defined by the following equation:

$$Y_{r_i.r_l} = \sqrt{\hat{P}_i}\, h_{ri.r_l}\, x + n_{ri.r_l} \qquad (6)$$

In which, $\hat{P}_i$is the transmit power of$i$th relay in$i+1$ phaseso that if ith relay correctly decode the transmitted signal from the source, the following equation is established: $\hat{P}_i = P_i$. Otherwise, power will be equal to zero, $\hat{P}_i = 0$.

In equation (5), if the lth relay can decode the received signal in $l+1$phase, then it sends that signal with a power equal to$\hat{P}_l = P_l$. Otherwise, the relay idle. Finally, in Phase N+1, the destination coherently combines all received signals together by using MRC technique, according to the following equation:

$$Y_d = \sqrt{P_0}\, h^*_{s.d} Y_{s.d} + \sum_{i=1}^{N} \sqrt{\hat{P}_i}\, h^*_{r_i.d} Y_{r_i.d} \qquad (7)$$

3. POWER ALLOCATION FOR COOPERATIVE RELAYING NETWORKS

In this part, a closed expression for the symbol error rate for a Multi-Relay Decode and Forward system with M-QAM modulation is proposed. Moment SNR of the signal combined in the destination with MRC method, which is developed by the sum of SNR of the direct path and the relay path, considering the average transmitted power from the source(P_0) and the transmitted power from the j-th relay (P_j), is obtained from the following equation [14]:

$$SNR_d = \frac{P_0|h_{s.d}|^2 + \sum_{j=1}^{N} P_j B_{i.N[j]} \left|h_{r_j.d}\right|^2}{\mathcal{N}_0} \qquad (8)$$

In which $B_{i.N}[j]$ gets a value of 1 or 0. If the relay has been able to decode the signal correctly, it will be equal to 1. Otherwise it will be zero. Also, $h_{s.d}$ and $h_{r_j.d}$are the source-destination channel coefficient and the j-th relay of the destination, respectively. The K-th relay coherently combines the signal coming from the source with the m previous relays. So SNR is equal to k-th relay:

$$SNR^m_{r_k} = \frac{P_0\left|h_{s.r_k}\right|^2 + \sum_{j=\max(1.k-m)}^{k-1} P_j B_{i.N[j]} \left|h_{r_j.r_k}\right|^2}{\mathcal{N}_0} \qquad (9)$$

In which $h_{r_j.r_k}$ and $h_{s.r_k}$are the channel coefficient of j-th relay and k-th relay and source and K-relay, respectively. SER for an N relays scheme with a Decode and Forward strategy, C (m) (1 ≤ m ≤ N-1), for M-QAM is expressed as follows:

$$P_{SER}(m) = \sum_{i=0}^{2^N-1} F_q\left[\left(1 + \frac{b_q P_0 \sigma^2_{s.d}}{\mathcal{N}_0 sin^2(\theta)}\right)\prod_{j=1}^{N}\left(1 + \frac{b_q B_{i.N[j]} P_j \sigma^2_{r_j.d}}{\mathcal{N}_0 sin^2(\theta)}\right)\right] \prod_{k=1}^{N} G^m_k\left(B_{i.N[k]}\right) \qquad (10)$$

$$F_q\big(x(\theta)\big) = \frac{4C}{\pi}\int_0^{\pi/2} \frac{1}{x(\theta)}\, d\theta - \frac{4C^2}{\pi}\int_0^{\pi/4} \frac{1}{x(\theta)}\, d\theta \qquad (11)$$

$$b_q = b_{QAM}/2$$
$$b_{QAM} = 3/(M-1)$$
$$C = 1 - 1/\sqrt{M} \qquad (12)$$

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$$G_k^m(x) = \begin{cases} F_q\left[\left(1+\frac{b_q P_0 \sigma_{s.r_k}^2}{\mathcal{N}_0 sin^2(\theta)}\right)\prod_{j=\max(1.k-m)}^{k-1}\left(1+\frac{b_q B_{i.N[j]} P_j \sigma_{r_j.r_k}^2}{\mathcal{N}_0 sin^2(\theta)}\right)\right] \\ if\ x=0 \\ 1-F_q\left[\left(1+\frac{b_q P_0 \sigma_{s.r_k}^2}{\mathcal{N}_0 sin^2(\theta)}\right)\prod_{j=\max(1.k-m)}^{k-1}\left(1+\frac{b_q B_{i.N[j]} P_j \sigma_{r_j.r_k}^2}{\mathcal{N}_0 sin^2(\theta)}\right)\right] \\ if\ x=1 \end{cases} \tag{13}$$

In the expression above, $\sigma_{s.d}^2$, $\sigma_{s.r_k}^2$, $\sigma_{rj.d}^2$, $\sigma_{r_j.r_k}^2$are Variance of source-destination channels, source and K- relay, the destination j-th relay and j-th relay and k-th relay, respectively. In what follows, we will continue:

The above equation is an exact unconditional expression for the SER. Because of the complexity of the above equation, we can consider an upper bound for SER in high SNR. If all channel coefficients are available, upper bound of SER is derived as follows[14]:

$$P_{SER} \simeq \left(\frac{P}{\mathcal{N}_0}\right)^{-(N+1)} \frac{1}{b_q^{N+1}\sigma_{s.d}^2}\sum_{j=1}^{N+1}\frac{g_q(N-j+2)g_q^{j-1}(1)}{a_0^j\prod_{i=j}^{N}a_i\sigma_{r_i.d}^2\prod_{k=1}^{j-1}\sigma_{s.r_k}^2} \tag{14}$$

$$g_q(x) = \frac{4C}{\pi}\left[\int_0^{\pi/2} sin^{2x}(\theta)d\theta - C\int_0^{\pi/4} sin^{2x}(\theta)d\theta\right]$$

$$P_0 = a_0 P$$

$$P_i = a_i P\,.\ \ 1 \le i \le N$$

In which P is the total power and a_0 is the source power allocation coefficient and a_i is the power allocation coefficient of the i-th relay, 1 < i<N.

Finally, the amount of P_{SER}in equation 14 is used as the evaluation criterion to optimize system performance.

$$a_i \ge 0\ (0 \le i \le N).\ \ \sum_{i=0}^{N} a_i = 1\ ;\ a_i = \frac{P_i}{P} \tag{15}$$

$$a_{\text{opt}} = \arg\min_{a} P_{SER}$$

$$subject\ to\quad a_i \ge 0\ (0 \le i \le N).\ \ \sum_{i=0}^{N} a_i = 1 \tag{16}$$

For efficient power allocation, P_{SER} should minimize. Because the upper bound of the obtained symbol error rate in SNR in equation 14 is asymptotic to the exact equation, hence in the high SNR regime it is enough to minimize the asymptotically tight approximation 14 by considering power constraint in equation 15. Using appropriate Lagrange multipliers, optimal values are obtained as follows:

$$P_0 = \frac{1+\kappa}{1+\kappa+N}\,P\,.\ \ P_i = \frac{1}{1+\kappa+N}\,P\,.\quad 1 \le i \le N \tag{17}$$

So that $\kappa$is obtained from the following equation[14].

$$\kappa(1+\kappa)^N = (N+1)\frac{g_q^{N+1}(1)\prod_{i=1}^{N}\sigma_{r_i.d}^2}{g_q(N+1)\prod_{i=1}^{N}\sigma_{s.r_i}^2} \tag{18}$$

4. EMA ALGORITHM (Exchange Market Algorithm)

EMA algorithm (Exchange Market Algorithm) is a strong, robust and efficient algorithm to extract the global optimum points of optimization problems. This optimization algorithm has been introduced by Nasser Ghorbani and Ebrahim Babaei with the inspiration of human intelligence and how the stock traded in the stock market[15]. Because of enjoying two searching operators and two absorbing operators, production and organization of random numbers in this algorithm is done in the best possible way. Therefore, this algorithm has improved the limitations and problems of other algorithms to an acceptable level. Such limitations and problems are as follows: getting stuck in local optimum and consequently premature convergence (exploration problem) or insufficient ability to find points in the vicinity of optimum point (the problem of extraction) and converging to non-identical answers every time you run the program.

Reviewing the performance of the elite in stock market has led to the formation EMA algorithm. How successful people perform in the stock market, in the case of non-oscillation market and oscillation market, are different. In this algorithm, it is assumed that in each iteration there two different modes of the market. Elite behavior in the stock market when their property value is high, medium and low has been appraised. And these characteristics have been used for the proposed algorithm. In EMA, there are two modes of the market in each of iterations. And after each market mode, the suitability of people is studied and people are arranged based on the value of their assets. At the end of every market mode, elementary, middle and end people of the population are known under the name of group one, two and three people, respectively. People in group one have been reluctant to do business in all iterations and people in groups two and three commence to trade their shares, with separate ties. In a non-oscillation market, the algorithm is in charge of attracting people toward the elite and in case of an oscillation market the algorithm is responsible for searching. With regard to the mentioned issues, this algorithm in case of a non-oscillation market or an oscillation one has two absorbing operators (members of Group Two and Group Three) and two search operators, which leads to the fact that production and organization of random numbers in EMA is done in the best possible way. Also the speed of reaching the optimal solution in the existing algorithm is more than that of available algorithms such as PSO and GA [15].

Since optimal power allocation in cooperative networks is of particular importance, in this article, it is attempted that optimal values for power in a Multi-Relay

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Decode and Forward system in order to minimize the symbol error rate using EMA algorithm is obtained. In this method, the initial population must be first determined, which is assumed 80here, and the number of iterations is also considered to be 300 and the equation 16 is considered as the objective function.

5. SIMULATION

In this section, numerical results of recovery rate of the proposed method of distribution are checked. For this purpose, a participatory system of three relaying Decode and Forward system is taken into consideration. It is assumed that channels have Rayleigh fading. In all the simulations it is assumed that the noise variance is equal to one, ($\mathcal{N}_0 = 1$). Also, in all the simulations, 4-QAM modulation has been used.

In this section, the method of equal power allocation (EPA) and optimal power allocation (OPA) by the usual method of Lagrange as well as EMA algorithm for the three modes are compared. The first case is when the relays are located exactly in the middle of the origin and the destination. In this case, the channel coefficients are defined as follows: $\sigma^2_{ri.d} = \sigma^2_{ri.rj} = \sigma^2_{si.r} = \sigma^2_{s.d} = 1$. The second case is when the relays are located near the source. In this case, the channel coefficients are defined as follows: $\sigma^2_{si.r} = \sigma^2_{ri.rj} = 10$; $\sigma^2_{ri.d} = \sigma^2_{s.d} = 0.1$. And in the end, the third case is when the relays are located near the destination. In this case, the channel coefficients are defined as follows: $\sigma^2_{ri.d} = \sigma^2_{ri.rj} = 10$; $\sigma^2_{si.r} = \sigma^2_{s.d} = 0.1$. Equal power allocation (EPA) in all three modes for the source and the relays is considered to be equal to 0.25.The values for power in optimal power allocation obtained by using EMA algorithm is shown in Table-1. And optimized power allocation is also shown in Table-2 using Lagrange multipliers.

Table-1. The values for power in optimal power allocation obtained by using EMA algorithm.

Using EMA algorithm					
Power Ratios	$[\sigma^2_{ri.d}\sigma^2_{s.ri}\sigma^2_{s.d}\sigma^2_{ri.rj}]$	$a_0 = \frac{P_0}{P}$	$a_1 = \frac{P_1}{P}$	$a_2 = \frac{P_2}{P}$	$a_3 = \frac{P_3}{P}$
First case	[1 1 1 1]	0.30104	0.23301	0.23302	0.23302
Second case	[0.1 10 0.1 10]	0.25001	0.25001	0.25001	0.25001
Third case	[10 0.1 0.1 10]	0.90451	0.031825	0.031826	0.031826

Table-2. Optimized power allocation using Lagrange multipliers.

Using Lagrange multipliers					
Power Ratios	$[\sigma^2_{ri.d}\sigma^2_{s.ri}\sigma^2_{s.d}\sigma^2_{ri.rj}]$	$a_0 = \frac{P_0}{P}$	$a_1 = \frac{P_1}{P}$	$a_2 = \frac{P_2}{P}$	$a_3 = \frac{P_3}{P}$
First case	[1 1 1 1]	0.31	0.23	0.23	0.23
Second case	[0.1 10 0.1 10]	0.25	0.25	0.25	0.25
Third case	[10 0.1 0.1 10]	1	0	0	0

In Figure-2, the symbol error rate performance in different SNR of equal power allocation method and optimized power allocation using Lagrange method (OPA)and EMA algorithm in a cooperative system of three relaying Decode and Forward system when the relays are located in the middle of the source and destination has been shown. It can be observed that when we use optimized power allocation, symbol error rate performance improves as much as 3 dB.

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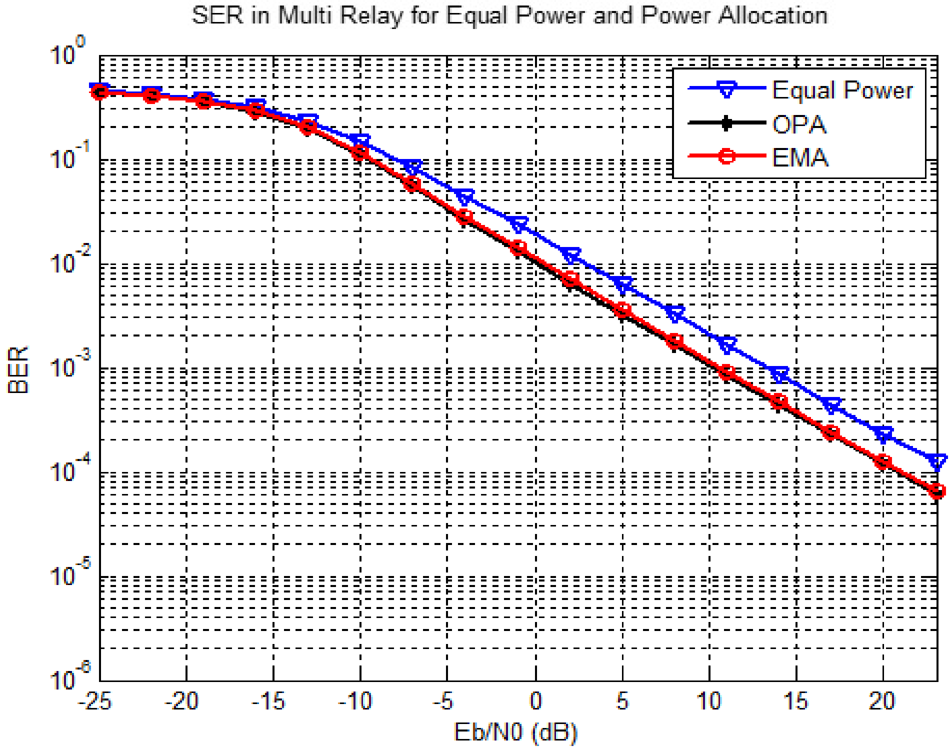

Figure-2. The symbol error rate performance.

In Figure-3, a comparison of the SER performance in different SNRs between equal power allocation and optimized power allocation using EMA algorithm and Lagrange method in the same system, in case that the relays are close to the destination, has been done. It can be demonstrated that if you use optimized power allocation, then system performance improves as much as 11 dB.

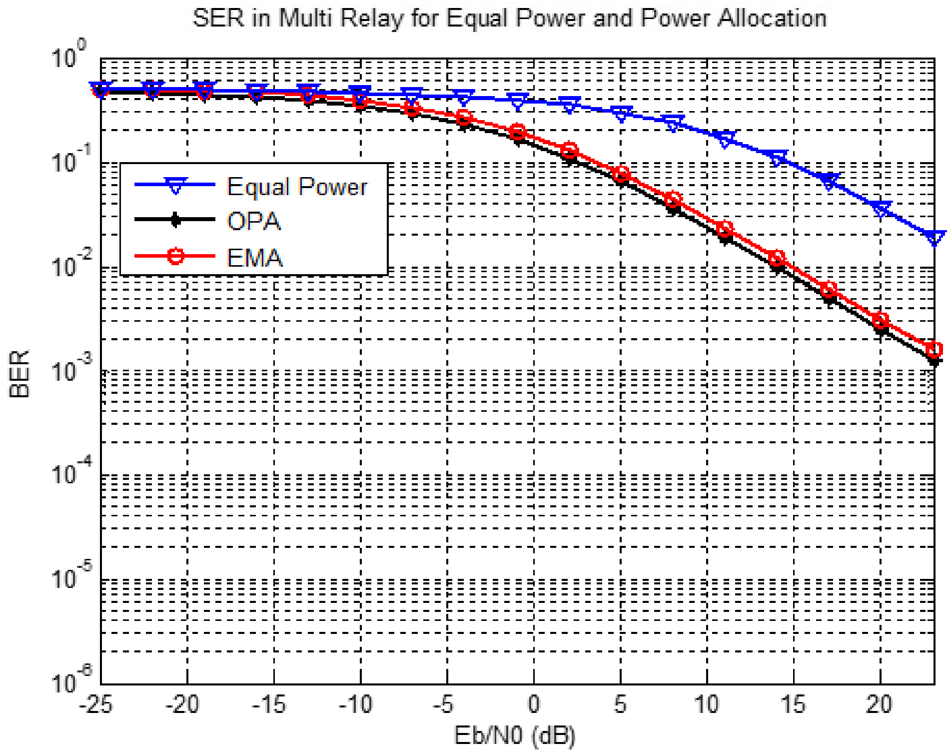

Figure-3. A comparison of the SER performance in different SNRs.

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In Figure-4, the SER performance in different SNRs in a three-relay cooperative network when the relays are close to the source has been shown. It can be seen that the optimal power allocation is, in fact, equal power allocation between the source and the relays. Hence, no significant change in this case can be recognized between the equal and optimal power allocation.

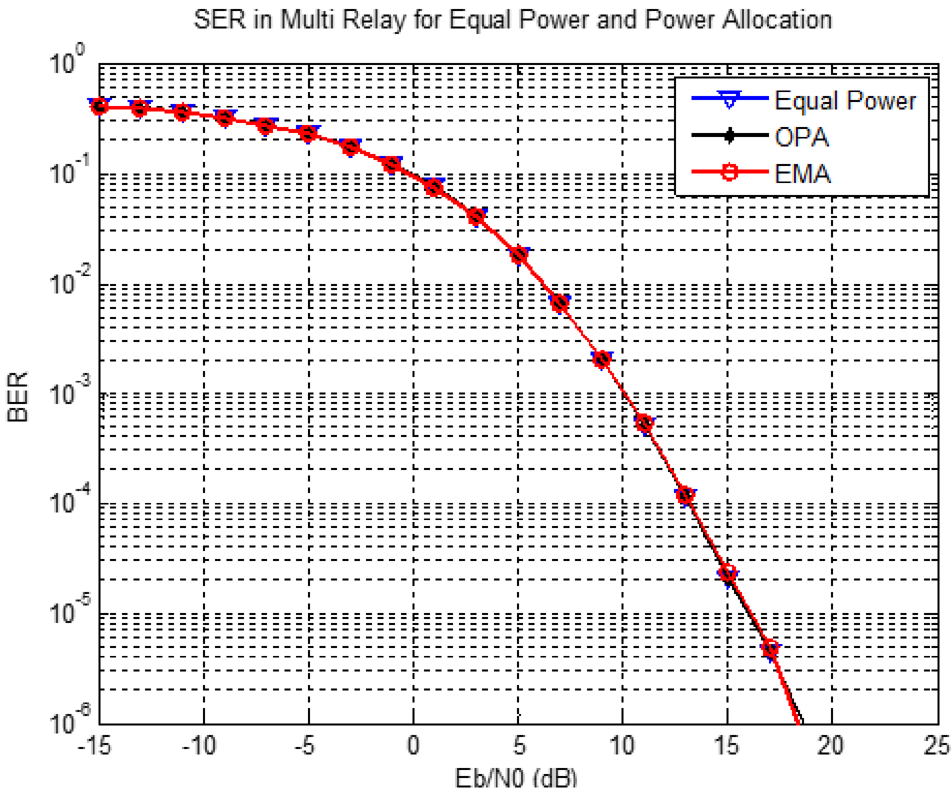

Figure-4. SER in Multi Relay for equal Power and power Allocation.

6. CONCLUSIONS

In the present paper, power allocation algorithm in Multi-Relay Decode and Forward cooperative systems to minimize the symbol error rate was explored and a simple new method for power allocation through EMA algorithm was proposed. Given that using Lagrange method has high computational complexity, especially when there are a large number of relays, optimal power allocation method by EMA algorithm is an appropriate alternative to this end. We also drew a comparison between the equal power allocation and optimal power allocation and got power values from the two methods of Lagrange method (OPA) and EMA algorithm. Numerical simulations indicate that the proposed power allocation method depends on channel quality links. Finally, simulation results prove the effectiveness of this algorithm.

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