Near-Optimal Joint Routing and Power Allocation for Amplify-and-Forward Multi-Hop Networks

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Abstract— **In this paper we developed a sub-optimal algorithm for joint routing and power allocation for an amplify-and-forward multi-hop relay network. The objective function for the optimization is the received signal-to-noise ratio (SNR) at the destination. Higher SNR would cause for lower bit error rate consequently. The joint problem of power allocation and relay selection is formulated with respect to maximizing received SNR at the destination while the channel state information (CSI) of all links is available and constant during the transmissions. Formulating the problem, we would separate the problem into two sub-problems, the routing and power allocation problems. The power allocation problem is solved sub-optimally for high SNR regime. The solution of power allocation problem induces a new routing metric causing to our desired goal, maximizing received SNR at the destination, and then the relay selection algorithm could be solved by some dynamic programming methods like Dijkstra. Our new metric asymptotically become optimal in high SNR regime. Simulation results show a significant performance gain against the traditional routing and power allocation schemes.**

***Keywords*— power allocation, routing, cross-layer relaying, multi-hop, amplify-and-forward**

I. INTRODUCTION

Since the introduction of relay networks, high promises and technology trends involved in wireless multi-hop relaying system to increase the scalability and capacity of wireless networks. Power source as one of the most important resources in wireless communication has to be managed among relay nodes to minimize the energy consumption and maximize the network life time. Along with power management, correct relay selection for routing from source to destination is one of the other important issues in wireless networks which can improve the power efficiency of the relay network; so the problem of joint routing and power allocation has obtained a large attention in recent studies like [1-5]. In some works like [1] the power allocation problem for dual-hop Amplify-and-Forward (AF) networks has been considered, but the rout is constant and there would be no routing algorithm. In [2] and [3] some joint routing and power allocation problem for Decode-and-Forward (DF) with the objective function of outage probability has been discussed. Though various cross-layer design algorithms addressed the problem of joint routing and power allocation, none of them has investigated the routing and power allocation jointly in the AF relaying networks.

In this paper we have modeled the amplify-and-forward target SNR and then applied an approximation for high target SNR to get to a closed form target SNR through single branch multi-hop path. This approach has been used in [4] and [5] respectively to allocate power in single [4] and multi branch [5] multi-hop AF relay system. None of them has considered the route selection problem in AF system. Based on the approximated metric used in [4] we have defined the routing problem with new metric and proposed a dynamic programming algorithm which is similar to Dijstera's shortest path algorithm. Since the metric hasn't been claimed to be optimal for low SNR regimes, some simulation results at the end compares our algorithms performance with respect to other approaches.

The reminder of this paper is arranged as follow; in section II the network model will be introduced. Having the goal of achieving maximum received signal-to-noise ratio (SNR) the joint problem of power allocation and routing is presented and solved in section III. In section IV there would be some numerical results to evaluate our new suboptimal scheme and compare it with conventional routing algorithms and power allocation strategies. The discussions and conclusion are presented in section V.

II. SYSTEM MODEL

First we considered the system model introduced in [4]. We considered a cooperative system with a single branch as depicted in Fig. 1. This branch is composed of $K-1$ relays $R_1, R_2, \ldots R_{K-1}$. We assume that each node is equipped with only one antenna. Moreover, half-duplex constraints are imposed on the relay nodes (i.e. the relay nodes cannot transmit and receive simultaneously). The channels between all the nodes are assumed to be random, independent, frequency-flat and constant over the transmitted block of data. The channel between the relays R_{k-1} and R_k of the branch is denoted by α_k, which is assumed to be a zero mean, circularly symmetric complex Gaussian random variable (r.v) with variance $\sigma_{k,l}^2$. The noise r.v on all links is assumed to be zero mean, independent, additive Gaussian distributed. Since each links transmission's is orthogonal to the other links, there is no interference in the system.

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Considering AF relaying strategy, each relay amplifies the signal received from the immediate preceding node and then forwards to the next node in the next time slot. Although exploiting all the signals transmitted by previous hops can greatly improve the power efficiency, here we assume that a specific receiving node only use signal transmitted by its neighboring relay cluster. The amplification factor at the k^{th} relay is adopted based on the instantaneous fading amplitude over the channel between the terminals R_{k-1} and R_k , α_k , to result in a power P_k at the relay output and is given by[3]:

$$G_k^2 = \frac{P_k}{P_{k-1}\left|\alpha_k\right|^2 + N_{0_k}} \qquad k = 1,2,...,K-1 \tag{1}$$

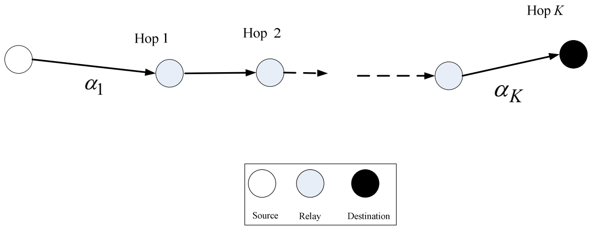

Fig. 1. Network model with K hops

Where power of transmitter source is P_0 and N_{0_k} is the k^{th} power of additive white Gaussian noise (AWGN) at the relay terminal. It is assumed that the total available power for the system is P_T . In a single-branch multi-hop system with uniform power allocation scheme, equal portions of the total power P_T are assigned to each transmitting node, i.e. $P = \frac{P_T}{K}$. In order to optimize power allocation in this paper we consider that the allocated power to the k^{th} relay terminal P_{k-1} is as follow:

$$P_{k-1,l} = \beta_{k-1,l}P \tag{2}$$

Where $\beta_{k-1} \geq 0$ is the k^{th} relay's portion of power, P , and β_0 is the source node power coefficient. So, we can explain all nodes power portions as:

$$P_{k-1} = \beta_{k-1}P \qquad k = 1,...K \tag{3}$$

$$\sum_{k=1}^{K} \beta_{k-1} = K \tag{4}$$

III. JOINT ROUTING AND POWER ALLOCATION PROBLEM

Here we develop a new routing metric for the end-to-end SNR at the destination node with AF protocol. Based on this approximation [5] has formulated the target SNR. Neglecting the direct link between source and destination, the received SNR at the destination is [4], [3];

$$\gamma_{AF} = \left[\prod_{k=1}^{K}\left(1 + \frac{1}{\beta_{k-1}\gamma_k}\right) - 1\right]^{-1} \tag{5}$$

Where $\gamma_{k,l} \triangleq \frac{P}{N_{0_{k,l}}}\left|\alpha_{k,l}\right|^2$. The above can be approximated due to [4] for high SNR as

$$\gamma_{AF} \approx \left[\sum_{k=1}^{K} \frac{1}{\beta_{k-1}\gamma_k}\right]^{-1} \tag{6}$$

In [5] it is shown that with the approximation formula of(6), the optimal power allocation can maximize target SNR to

$$\text{Max}\left(\gamma_{AF}\right) = K\Gamma_l \tag{7}$$

Where

$$\Gamma_l = \left(\sum_{k=1}^{K} \frac{1}{\sqrt{\gamma_k}}\right)^{-2} \tag{8}$$

And the total power constraint along the selected branch is as assumed in (4). According to (7) and (8), the best route has to minimize the value of $\left(\sum_{k=1}^{K} \frac{1}{\sqrt{\gamma_k}}\right)$ which is accumulative inverse square root of each node's SNR along the selected branch. This key relation has the ability to enable the route search algorithm to be computed by dynamic programming. Assigning the link cost of $\frac{1}{\sqrt{\gamma_{n_1,n_2}}}$ to each of the edges of the graph (edge between node n_1 and node n_2), we can run Dijkstra shortest path algorithm. The detail of Dijkstra algorithm has been omitted here for brevity, though the proposed algorithm is very similar to its original version proposed by Dijkstra.

After running the proposed shortest path, we can apply the power allocation proposed in [4] or [5] to the selected branch and compute each node's power coefficient as computed in [4] and [5]

$$\beta_{k-1} = \gamma_k^{-\frac{1}{2}} K \left[\sum_{k'=1}^{K} \gamma_{k'}^{\frac{-1}{2}}\right]^{-1} ,k = 1,2,..K \tag{9}$$

IV. NUMERICAL RESULTS

To evaluate our joint routing and power allocation scheme we consider two scenarios to compare it with the common schemes. We consider a rectangle with side length of 60 unit of length as the environment of the example and there are 'n' nods distributed on it randomly with a uniform distribution.

The source and the destination are located on the opposite corners of rectangle with side length of 20 units of length. So there would be a large choice for the routes.

In the first scenario we want to just compare our routing scheme compare with Hop-Count routing, to do this, first we should choose a measure of connectivity for the nodes of the network for Hop-Count routing. There are two measures considered in Hop-Count routing, the distance metric and the received SNR metric, we compare our new scheme with the both metrics and to have a fair comparison we run some precise simulations to choose optimal metrics for Hop-Count routing not to just choose some heuristic one. Fig.2 shows the optimal distance metric versus the number of nodes

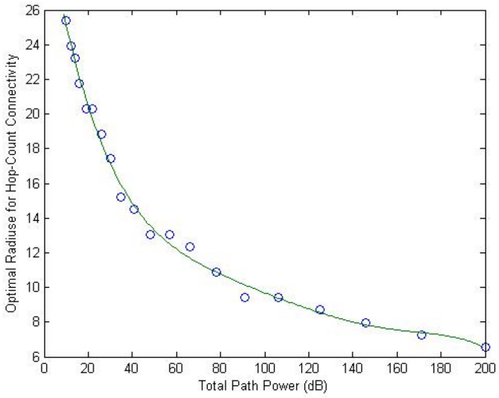

Fig. 2 Optimal Connectivity Radius for Hop-Count Algorithm

As it was expected the optimal radius has been decreased as the number of nodes increases and either for the small number of nodes the optimal radius is near the distance between the source and destination, which is the diameter of the rectangular. Fig. 4 shows the optimal received SNR metric versus the number of nodes.

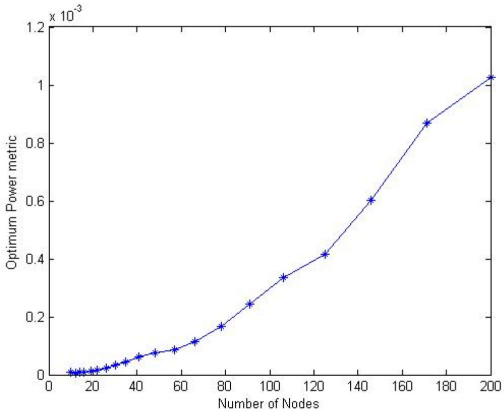

Fig. 3 Optimal Connectivity SNR measure for Hop-Count Algorithm

The optimal received SNR metric has been increased as the number of nodes increased, as it was expected, because when we have more neighbors we could choose one who received the message with higher SNR.

After this, in our simulations for any number of nodes, we choose the optimum metrics for the Hop-Count routing from these results to be compared with our scheme. In the Fig. 4 you can see a sample of nodes distributions and the three paths found with different routing schemes.

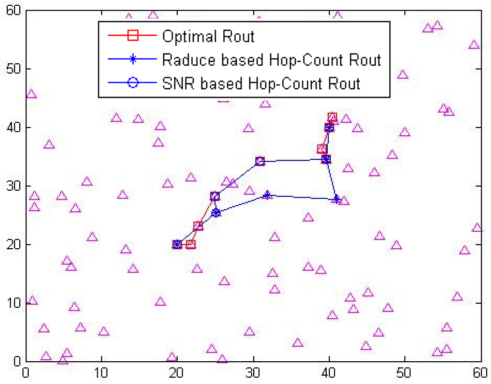

Fig. 4 Sample of nodes distributions and the three paths found with different routing schemes.

In the first scenario we evaluate our routing scheme by comparing it with available routings, so we chose the uniform power allocation for both Hop-Count routing and our routing scheme, the received SNR versus total power consumed over the path is depicted in Fig. 5.

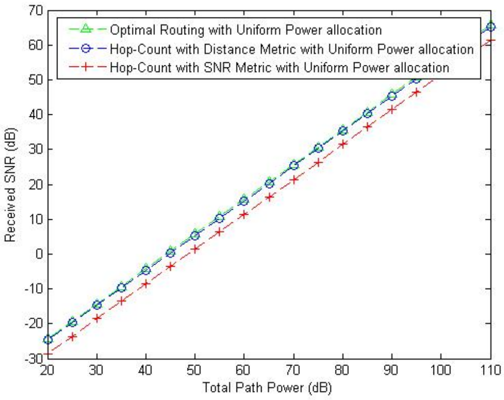

Fig. 5 Received SNR versus Total path power when uniform power allocation is applied either for the new routing scheme

As you can see in the figure our routing scheme acts better than the two Hop-Count scenarios.

As it is clear in Fig. 5 the new scheme obtains more than 4 dB performance gain compare with the Hop-Count scheme with SNR metric and less than 1 dB (0.3) compare with the

Hop-Count scheme with distance metric at the receiver even when the non optimal uniform power allocation is applied.

In the second scenario we want to apply the optimal power allocation to our new scheme. Although the advantage of the hop-count routing is simplicity and no need to total CSI and this new sub-optimal power allocation could not be applied over it but Because of having a comparison, we apply the optimal power allocation either to the Hop-Count routing with both metrics. The result is depicted in Fig. 6.

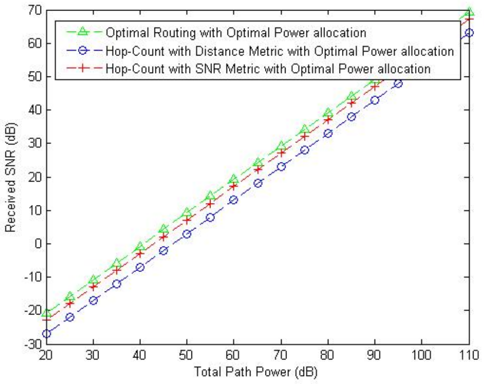

Fig. 6 Received SNR versus Total path power when sub-optimal power allocation is applied

As it is clear in Fig. 6 the new scheme obtains more than 2.5 dB performance gain compare with the Hop-Count scheme with SNR metric and about 7 dB compare with the Hop-Count scheme with distance metric at the receiver when the optimum power allocation is applied.

The next simulations compare the new scheme with optimal power allocation and the Hop-Counts algorithms with uniform power allocation. You can see the results in Fig. 7.

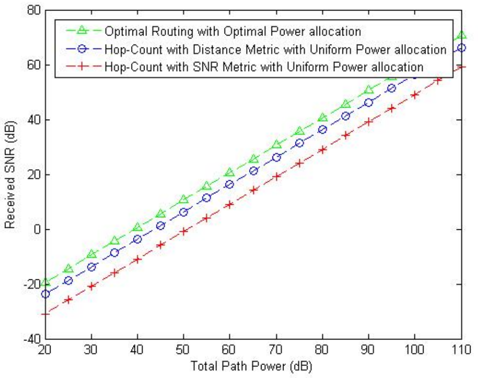

Fig. 7 Received SNR versus Total path power when sub-optimal power allocation is applied

As it is clear in Fig. 6 the new scheme obtains about 11.5 dB performance gain compare with the Hop-Count scheme with SNR metric and more than 4.2 dB compare with the Hop-Count scheme with distance metric at the receiver when the optimum power allocation is applied.

As it was mentioned in section III we consider the high SNR regime to achieve some simplifications to solve the power allocation problem. Here we want to compare the received SNR from both the exact, (5), and used approximation equation (6). You can see the result in Fig. 8.

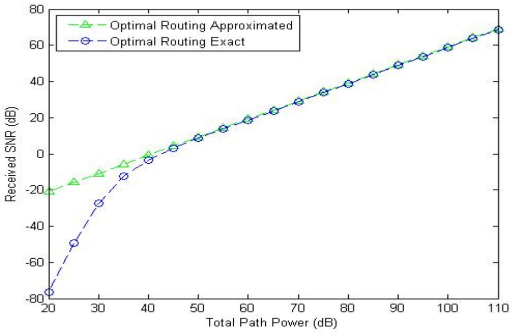

Fig. 8 The difference between achieved SNR from the exact equation and the high SNR approximation

As it is clear in the Fig., the approximation in the high SNR situation is close enough to the exact value and as the links SNR decreases the difference increases.

V. CONCLUSION

A sub-optimal joint power allocation and routing scheme was presented in this paper. The objective function was the received SNR at destination. Introducing the joint problem, we separate it into tow sub-problems for routing and power allocation. Solving the power allocation problem we use the solution to find a new metric for routing problem which is a dynamic programming. To evaluate the new scheme we run some simulations to compare it with traditional algorithm and numerical results show a significant performance gain by the cost of overheads for gathering CSI over the network.

VI. ACKNOWLEDGMENT

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REFERENCES

[1] A. P. T. Lau and S. Cui, “Joint power minimization in wireless relay channels," IEEE Trans. Wireless Commun., vol. 6, no. 8, pp. 2820-2824, Aug. 2007.

[2] Ramin Babaee and Norman C. Beaulieu , “Joint Routing and Power Allocation Optimization for Multi-Hop Wireless Networks”

[3] Lu Zhang and Leonard J. Cimini, Jr.”Hop-by-Hop Routing Strategy for Multihop Decode-and-Forward Cooperative Networks”

[4] G. Farhadi and N. C. Beaulieu, “Power-Optimized Amplify-and-Forward Multi-Hop relaying systems,” IEEE. Trans. Wireless commun., vol. 8, no. 9, pp. 4634–4643, Sept. 2009.

[5] M. Mohammadi, B. Mahboobi and M. Arebilipour “Power-Optimized Multi-Hop Multi-Branch Amplify-and-Forward Cooperative Systems” accepted in International conference on wireless Pervasive Communication 2010 in Italy

[6] M.O.Hasan and M.S.Alouini , “Outage probality of multi-hop transmission over Nakagami fadin channels,” IEEE. commun. Lett, vol. 7, pp. 216–218, May 2003.

[7] J. Boyer, D.D.Folconer, and H. Yanikomeroglu, “Multihop diversity in wireless relaying channels,” IEEE. Trans. commun., vol. 52, no. 10, pp. 1820–1830, Oct.