Power Allocation Scheme for Decode-and-Forward Cooperative Communications in Rician Fading Channels

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Abstract. Given to the performance of the resource utilization in the cooperative communication systems, the paper proposed a novel power allocation scheme in the Decode and Forward cooperative communication scenario. Based on the analysis of the system model and the fading channel model, the paper proposed an optimized power allocation scheme using optimization theory to minimize the outage probabilities of the communication system, for the accuracy and reliability of each link's transmission. Simulation results are presented to illustrate that optimized power allocation in terms of minimum outage probabilities offers better outage performance than common power allocation in cooperative diversity systems.

Keywords: Cooperative communication · Rician fading · Decode-and-Forward (DF) · Outage probability · Power allocation

1 Introduction

Cooperative communication technique in fading channel environments has been a hot research area for several years, because of its perfect performance in wireless communication environments [1, 2]. The principle of this technique is to make use of the broadcasting transmission characteristics of wireless signals in the channel, thus all nodes in the system can help their partners transmit information while sending their own information, thus forming a system that can obtain the same performance gain as MIMO (Multiple Input Multiple Output). Its basic idea is to share and transmit information by sharing partners' antennas and channels, so as to combat channel fading, improve communication reliability and reduce terminal burden.

Outage probability is another expression of link capacity. When the link capacity is lower than the data rate required by the user, outage events will occur, resulting in transmission errors. Outage probability is often used to measure the frequency of communication system outage events, so as to evaluate the performance of wireless systems.

Many papers have been published to deal with the resource allocation schemes to improve the performance of the cooperative communication systems under different cooperative communication schemes conditions (e.g., [3, 4]). In practice, Doppler

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effect, shadow effect and multipath effect exist in satellite mobile communication. These effects affect the performance of communication system and even cause communication interruption. They are typical fading channels. Cooperative communication technology is an effective technology to mitigate fading channels and enhance communication quality, and the cooperative relay networks can be deployed in line-of-sight (LOS) environment [5]. Therefore, it is very necessary to study the property of the power allocation scheme in such fading environment. In this paper, we proposed an optimized power allocation algorithm in the three-node Decode and Forward (D-F) cooperative communication scenario.

2 Models and Formulas

2.1 System Model

In wireless networks, there are many system models of cooperative communication, and different definitions correspond to different system models. For example, the number of relay forwarding determines whether it is a two-hop or multi-hop model, and the number of relays determines whether it is a single-relay or multi-relay model. In order to facilitate the research, we simplify the model and only consider single source and single destination nodes. The three-node system model includes a source node denoted with S, a relay node denoted with R, and a destination node denoted with D. Each node has a single antenna. Figure 1 is the three-node system model.

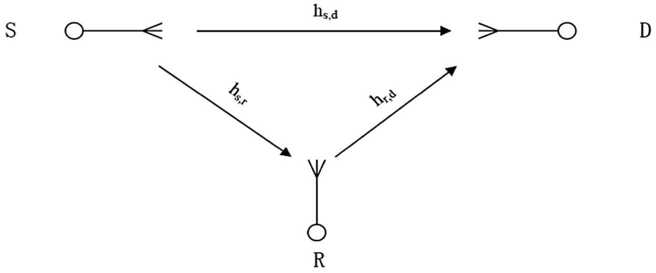

Fig. 1. Cooperative communication system model.

In the terrestrial wireless circumstances, the S and the R operate in the same frequency band and use the half duplex mode like reference [6]. There are two stages in the process of signal transmission: the first stage is that the R receives the signals sent by the S and the D receives the signals sent by the S too, and the expressions of the signals they receive are as follows

$$y_{s,d} = \sqrt{P_s} h_{s,d} x_s + n_{s,d} \tag{1}$$

$$y_{s,r} = \sqrt{P_s} h_{s,r} x_s + n_{s,r} \tag{2}$$

where P_s is the transmitted power of S, x_s is the transmitted signal. $h_{s,d}$ and $h_{s,r}$ are the corresponding link channel coefficients of link S → D and link S → R, $n_{s,d}$ and $n_{s,r}$ are Gauss white noise (AWGN) of direct link S → D and link S → R, which have zero-mean and variance N_0 [3].

In the next stage, the relay node receives the signal sent by the source node, and then performs the decoding operation. And only when the decoding is correct will the next step be carried out. At this point, the destination node receives a signal that is

$$y_{rd} = \sqrt{P_r} h_{r,d} x_s + n_{r,d} \tag{3}$$

where P_r is the relay transmitted power, $h_{r,d}$ is the channel coefficients of link R → D.

The instantaneous average signal-to-noise ratio (SNR) of source node-relay node and relay node-destination node are set as

$$\Gamma_1 = \left|h_{s,r}\right|^2 P_s/N_0, \Gamma_2 = \left|h_{r,d}\right|^2 P_r/N_0 \tag{4}$$

$$\bar{\Gamma}_1 = \Omega_{s,r} P_s/N_0, \bar{\Gamma}_2 = \Omega_{r,d}/P_r N_0 \tag{5}$$

where Γ_1 is the instantaneous SNR of link S → R and $\bar{\Gamma}_1$ is the average SNR of link S → R, while Γ_2 is the instantaneous SNR of link R → D and $\bar{\Gamma}_2$ is the average SNR of link R → D. $\Omega_{s,r} = E[h_{s,r}]$, $\Omega_{s,d} = E[h_{s,d}]$, in which $E[g]$ denotes expectation.

The instantaneous SNR of the link S → D is given in (6), and the average SNR of the link S → D is described as (7).

$$\Gamma_0 = \left|h_{s,d}\right|^2 P_s/N_0 \tag{6}$$

$$\bar{\Gamma}_0 = \Omega_{s,d} P_s/N_0 \tag{7}$$

where Γ_0 is the average SNR of link S → D, $\bar{\Gamma}_0$ is the average SNR of link S → D $\Omega_{r,d} = E[h_{r,d}]$.

2.2 Channel Model

In Rician fading channel, assuming that $h_{s,d}$, $h_{s,r}$ and $h_{r,d}$ are unrelated coefficients, non-central χ^2 is the basis of its power distribution, and the degree of freedom is two. Each resulting SNR (i.e., Γ_0, Γ_1 and Γ_2) has the same distribution. In a Rician fading channel, SNR's probability density function (PDF) is defined as

$$p(\gamma) = [(1+K)/\bar{\gamma}] \exp[-K - (1+K)x/\bar{\gamma}] \times I_0(2\sqrt{K(1+K)x/\bar{\gamma}}) \tag{8}$$

Where $\bar{\gamma}$ is an average SNR per symbol. K is the Rician K-factor defined as the ratio of the power in the LOS component to the power in the other (non-LOS) multipath components, is the zero-order modified Bessel function of the first kind.

According to reference [7], the instantaneous SNR's cumulative distribution function (CDF) is given in (9).

$$P(\gamma) = 1 - Q(\sqrt{2K}, \sqrt{2(1+K)\gamma/\bar{\gamma}}) \tag{9}$$

where $Q(\alpha, \beta)$ is the first-order Marcum Q function.

3 Optimized Power Allocation Scheme

In information theory, channel capacity rest with the received signal' SNR. Hence, for the system, the Γ_0, Γ_1 and Γ_2 is closely related to the outage probability. In the system model assumed in this paper, the destination node will receive two sets of signals, one from the relay link and the other from the direct link. Two sets of signals are combined based on the choice of merging mode. When the SNR threshold is fixed, for direct link, outage occurs when the instantaneous received SNR drops below the threshold, for relay link, outage occurs when the instantaneous received SNR of any single hop link is less than the threshold. When the SNR of two links is lower than the threshold SNR at the same time, the outage state of the whole system occurs [8]. Therefore, if the probability of making wrong decisions at the destination node can be reduced, then the transmission accuracy and reliability of each link can be guaranteed.

As shown in (4) and (6), it is important to allocate the source transmit power and the relay transmit power for minimizing outage probability.

As mentioned above, when the SNR of direct link and relay link is lower than the threshold SNR γ_{th} at the same time, the whole cooperative diversity system will be interrupted, and the probability of outage is

$$P_{out} = \Pr\{\Gamma_{0,} \min(\Gamma_1, \Gamma_2) < \gamma_{th}\} \tag{10}$$

where $\min(g)$ returns the minimum value.

In the direct link, the outage probability of the direct link is

$$P_{out1} = \Pr(\Gamma_0 < \gamma_{th}) \tag{11}$$

As was mentioned before, in the relay link, outage probability is a complementary event with more than two thresholds. Hence, the outage probability is given by

$$P_{out2} = 1 - \Pr\{\Gamma_1 > \gamma_{th}\} \Pr\{\Gamma_2 > \gamma_{th}\} \tag{12}$$

Combined with the (9), we have

$$\begin{aligned} P_{out} = P_{out1} \times P_{out2} = 1 - Q(\sqrt{2K_{sr}}, \sqrt{2(1+K_{sr})\gamma_{th}/\bar{\Gamma}_1}) \times Q(\sqrt{2K_{rd}}, \sqrt{2(1+K_{rd})\gamma_{th}/\bar{\Gamma}_2}) \\ \times [1 - Q(\sqrt{2K_{sd}}, \sqrt{2(1+K_{sd})\gamma_{th}/\bar{\Gamma}_0})] \end{aligned} \tag{13}$$

where $K_{s,d}$ is the Rician K-factor of the channel from the S to the D, $K_{s,r}$ from the S to the R, and $K_{r,d}$ from the R to the D.

The Marcum Q function is defined by [7]

$$Q(\alpha,\beta)=\exp(-(x^2+\alpha^2)/2)\sum_{k=0}^{\infty}(\alpha/\beta)^k I_k(\alpha\beta) \tag{14}$$

Its first-order formula is given as follows:

$$Q(\alpha,\beta)=\int_{\beta}^{\infty}x\exp(-(x^2+\alpha^2)/2)I_0(\alpha x)dx \tag{15}$$

As is shown in (15), we can't use the integral form without upper bound to express the outage probability function that with closed form directly. For simplicity of calculation, under the condition of upper bound is limited, the closed form approximation of outage probability CDF is obtained. Therefore, its closed-form is given in (16).

$$\begin{aligned}P_{out}=&\{1-\exp(-[(1+K_{sr})\gamma_{th}/\bar{\Gamma}_1+K_{sr}])\sum_{k=0}^{20}[K_{sr}\bar{\Gamma}_1/(1+K_{sr})\gamma_{th}]^{k/2}I_k(2[K_{sr}(1+K_{sr})\gamma_{th}/\bar{\Gamma}_1]^{k/2})\\&\times\exp(-[(1+K_{rd})\gamma_{th}/\bar{\Gamma}_2+K_{rd}])\sum_{k=0}^{20}[K_{rd}\bar{\Gamma}_2/(1+K_{rd})\gamma_{th}]^{k/2}I_k(2[K_{rd}(1+K_{sd})\gamma_{th}/\bar{\Gamma}_2]^{k/2})\}\\&\times\{1-\exp(-[(1+K_{sd})\gamma_{th}/\bar{\Gamma}_0+K_{sd}])\sum_{k=0}^{20}[K_{sd}\bar{\Gamma}_0/(1+K_{sd})\gamma_{th}]^{k/2}I_k(2[K_{sd}(1+K_{sd})\gamma_{th}/\bar{\Gamma}_0]^{k/2})\}\end{aligned} \tag{16}$$

In this paper, we study the optimal power allocation problem with minimum outage probability under two constraints: the maximum power allowed to be consumed by a given packet in the whole propagation process from source to destination and the power provided by each relay node. The two constraints are total power constraints p_{tot} and maximum power $p_{\max}$ per hop. We should note that $p_{\max} < p_{tot} \leq 2p_{\max}$.

Therefore, the problem is formulated is that under the condition of $p_1+p_2=p_{tot}$, $0 \leq p_n \leq p_{\max}\, n=1,2$, get the minimum value of P_{out}.

The problem formulated is an optimization problem. When drawing in linear proportion, the outage probability function is convex. Furthermore, they form a convex set because of all the constraints are linear [9], this is the cause of an optimization problem which has a unique optimal solution.

We use Lagrange multiplier maximization method, the modified objective function can be written as

$$P_{opt}=P_{out}+\eta(p_1+p_2-p_{tot})+\mu_1(p_1-p_{\max})+\mu_2(p_2-p_{\max})+\delta_1 p_1+\delta_2 p_2 \tag{17}$$

where η, μ_1, μ_2, δ_1 and δ_2 are constants.

4 Simulation Evaluation and Discussion

In this part, numerical results are used to show the optimal power allocation scheme. Assume the system channels are mutually independent identical Rician fading channels, and we have $K_{s,d} = K_{s,r} = K_{r,d} = K$. Set data rate R to 1 bits/Hz, so $\gamma_{th} = 2^{2R} - 1 = 3$. Set $p_{\max}/p_{tot}$ to 0.8. Define the ratio of the fading powers of the corresponding channels, $\Omega_{s,d} : \Omega_{s,r} : \Omega_{r,d}$. Considering whether the K factor and the fading power ratio are the same, we can divide them into two cases: one is that the K factor is the same but the fading power ratio is different, the other is opposite to the first case, and has different K factor and the same fading power ratio.

4.1 Optimal Power Allocation with Different Power Fading Ratios

Set $K = 3$. Figures 2 and 3 show the performance of the optimized power allocation scheme when the outage probability varies with the ratio. The outage performance is compared with the following two situations: 1. Uniform power distribution of the system. 2. Only direct links exist.

From Figs. 2, 3 it can be observed that, with high total power, outage probability of the optimal power allocation scheme and the uniform power allocation scheme tend to be identical under same fading power ratio condition. So the optimal power allocation is not necessary when the total power budget is large. It could also be concluded that, referring to the outage probability of direct links, as the ratio of $\Omega_{s,d}$ to $\Omega_{s,r}$ is fixed, with the increase of $\Omega_{r,d}$, outage probabilities of optimized power allocation system are more likely to drop below those of the direct link only case, as the total power budget increases.

In Fig. 2, $\Omega_{s,d} : \Omega_{s,r} : \Omega_{r,d}$ is set to $0.5 : 0.1 : 0.1$, $0.5 : 0.1 : 0.5$, $0.5 : 0.1 : 1$, $0.5 : 0.1 : 5$ and $0.5 : 0.1 : 1000$, respectively, with $\Omega_{s,d} = 0.5$. With the increase of $\Omega_{r,d}$, the outage probability of the system will be increased, and ultimately reach the upper limit with the increase of $\Omega_{r,d}$.

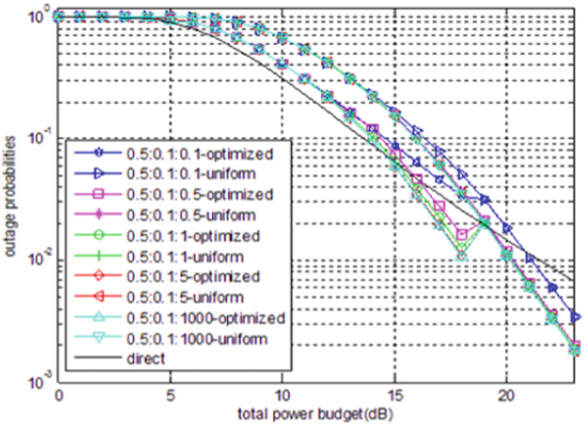

Fig. 2. Outage performances when $\Omega_{sd} > \Omega_{sr}$.

In Fig. 3, also with the same $\Omega_{s,d}$ value, $\Omega_{s,d} : \Omega_{s,r} : \Omega_{r,d}$ is set to 0.5 : 0.1 : 5, 0.5 : 1 : 5 and 0.5 : 5 : 5, respectively. We can see that, when the ratio of $\Omega_{s,d}$ and $\Omega_{s,r}$ increases, the outage probability improvements get less obvious with high $\Omega_{s,r}$.

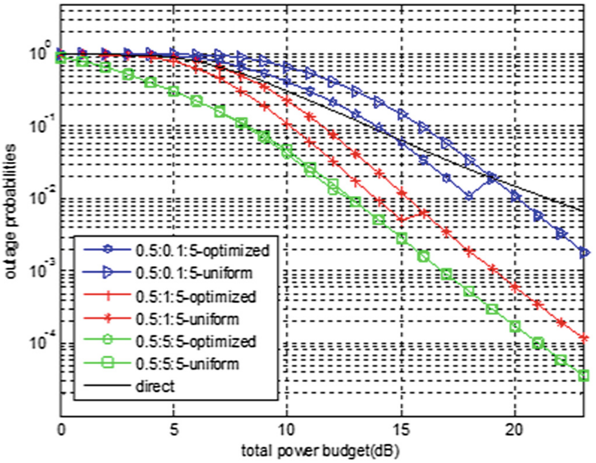

Fig. 3. Outage performances with different power fading ratios.

5 Optimal Power Allocation with Different Rician K- Factors

Set $\Omega_{s,d} : \Omega_{s,r} : \Omega_{r,d} = 0.5 : 1 : 5$. Figure 4 illustrates the outage probability difference of the direct link only case and the optimized power allocation case under different Rician *K*-factors. It is shown that, when the abscissa is small, more LOS improves the outage probability performance. When the abscissa is large, the outage probability differences approach 0, regardless of the *K* values.

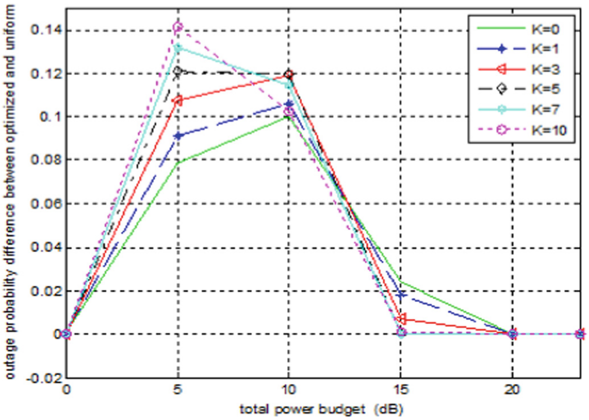

Fig. 4. Outage performance difference with different K-factors.

6 Conclusions

Cooperative communication technology is an effective technology to mitigate fading channels and enhance communication quality. So, it is very necessary to evaluate the performance of the power allocation scheme in such fading environment. We proposed a novel power allocation algorithm in the D-F cooperative communication scenario under different channel fading environments. Through the simulation results, it can be seen that with high total power, outage performances of the optimal power allocation case and the uniform power allocation case tend to be identical under same fading power ratio condition. So it can be seen that the optimal power allocation is not necessary when the total power budget is large. It could also be concluded that, referring to the outage probability of direct links, as the ratio of $\Omega_{s,d}$ to $\Omega_{s,r}$ is fixed, with the increase of $\Omega_{r,d}$, outage probabilities of optimized power allocation system are more likely to drop below those of the direct link only case, as the total power budget increases.

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