High Power Efficiency Transmission Based on Game Theory for AF Cooperative Communication

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***Abstract*—Cooperative communication has been studied as a way to improve reliability of networks compared to conventional direct transmission scheme. We consider amplify-and-forward (AF) cooperative communication with multiple relays. In this system, there is a problem that which relay nodes should be selected and how much power should be allocated to the selected relay nodes. Most of conventional researches on this model have focused on only improving channel capacity or reliability, rather than saving power consumption in all over the network with maintaining such communication qualities. In this paper, we propose a new power allocation scheme for multiple relay nodes using game theory that focuses on transmission power efficiency. With computer simulation, we show that our proposed game theoretical approach has superiority to some conventional schemes from the viewpoint of transmission power efficiency.**

I. INTRODUCTION

RECENTLY, the expansion of coverage area of a mobile environment is required and the number of wireless mobile terminals have been increasing exponentially. Cooperative communication focusing on such requests have been moved into the limelight with the one of the emerging transmission strategies for future wireless networks [1].

Relay nodes play two roles in distributed wireless networks with nodes that help each other by relay transmissions. First, they are used to extend the coverage area. This is realized by passing packet through one or more nodes as relay in between source node and destination. Such “multi-hop network” was discussed in [2][3]. Second, they are used to obtain a spatial diversity gain. Prior works of this “cooperative communication” are [1]-[11]. In this paper, we study the latter. As its name suggests, cooperative communication is the technology for increasing reliability by neighboring multi-nodes cooperate mutually. The most popular forwarding schemes are decode-and-forward (DF) and AF. We assume the latter scheme. DF cooperative communication was studied in [3]-[6], while AF was studied in [1][2][7]-[11]. It is well known that error rate performance in DF cooperative communications depend on the encoding and decoding techniques at relay nodes. In [5][6], such coding techniques are discussed. Capacity of “all-participate” AF cooperative communication network, in which R received data participate in relaying the data, can be upper-bounded by optimal power allocation (OPA) scheme assuming perfect knowledge of all channel state information (CSI) of all links. OPA for all-participate AF cooperative communication has been studied recently in [1]-[11]. In [1][2], power allocation based on the OPA algorithm for AF network with multiple relay nodes to minimize outage probability. In [7]-[9], authors focus on the single-relay case. OPA for multi-relay case was studied in [10][11]. In [11], authors proposed a distributed game-theoretical framework over cooperative networks to achieve optimal relay selection and power allocation without knowledge of CSI.

Along with advancing of mobile terminals like smart phones, power consumption at terminals increases, too. The more the terminals advance, the more the battery is consumed. From viewpoint of end-user’s aspect, this is undesirable. We have ideas to reduce such increasing power consumption at terminals according to development of terminals. That is, it is requested that not only the improvement of the communication qualities but also the reduction of the power consumed. However, most existing works about cooperative communications have focused on resource allocation aimed at improving only the communication qualities, rather than saving transmission power or improving transmission power efficiency.

In this paper, we propose a new power allocation scheme among relay nodes for cooperative communication system considering transmission power saving based on game-theoretical approach. The basic idea of our proposal is that if certain relay nodes could reduce own transmission power without degrading channel capacity performance, each node saves the transmission power. The objective of this study is to improve the transmission power efficiency. To show the effectiveness of this idea, using computer simulation, we discuss the comparison of transmission power efficiency. Although the idea of using game theory in cooperative communication is the same as that in [11], the objective of the research is different: Objective of research in [11] is to make signaling lighter.

The rest of the paper is organized as follows: We start with explanation of system model and some conventional schemes in section II. In section III, we bring up the issues of the conventional scheme and set up our study’s objective. In section IV, our proposed scheme is presented. In section V, simulation results are shown. Finally, VI contains our conclusions.

II. SYSTEM MODEL

A. *SYSTEM MODEL AND PROTOCOL*

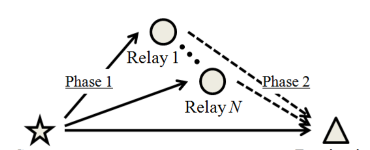

Fig. 1. Cooperative communication with N relay nodes.

As shown in Fig. 1, we consider a cluster of nodes consisting of a source node ‘S’, a destination node ‘D’ and N relay nodes ‘R_i’ ($i = 1, \cdots, N$). We suppose that time is slotted and each node is all half-duplex. Thus, it cannot transmit and receive simultaneously in the same time slot. AF is used as a relay strategy. Protocol of this model consists of two phases;

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data-sharing phase (Phase 1) and relaying phase (Phase 2). Synchronization among each node is ideal, and thus packet collision and hidden node problem are not assumed.

In Phase 1, S transmits to not only D but also each R. The signals received at D and R_i are expressed as respectively

$$y_{\mathrm{S,D}} = \sqrt{P_{\mathrm{S}}} h_{\mathrm{S,D}} x + n_{\mathrm{S,D}}, \tag{1}$$

$$y_{\mathrm{S,R}_i} = \sqrt{P_{\mathrm{S}}} h_{\mathrm{S,R}_i} x + n_{\mathrm{S,R}_i}, \tag{2}$$

where x denotes the (unit energy) transmitted signal at S, and $y_{\mathrm{S,D}}$ and $y_{\mathrm{S,R}_i}$ denote the received signals at S-D and S-R_i transmissions, respectively. $h_{\mathrm{S,D}}$ and $h_{\mathrm{S,R}_i}$ are channel coefficients of S-D and S-R_i channels, respectively. P_{S} is the average power transmitted. $n_{\mathrm{S,D}}$ and $n_{\mathrm{S,R}_i}$ are additive white Gaussian noise (AWGN) in the corresponding channels, with variance $\sigma^2_{0\mathrm{S,D}}$ and $\sigma^2_{0\mathrm{S,R}_i}$, respectively, i.e., $n_{\mathrm{S,D}} \sim \mathcal{CN}(0, \sigma^2_{0\mathrm{S,D}})$, $n_{\mathrm{S,R}_i} \sim \mathcal{CN}(0, \sigma^2_{0\mathrm{S,R}_i})$. Then, without the relay nodes' help (i.e. in direct transmission), the signal-to-noise ratio (SNR) that results from S to D can be expressed by $\Gamma^{\Delta}_{\mathrm{S,D}} = \frac{|h_{\mathrm{S,D}}|^2 P_{\mathrm{S}}}{N_{0\mathrm{S,D}}}$, where $N_{0\mathrm{S,D}}$ is noise power on the S-D transmission and thus $N_{0\mathrm{S,D}}/2 = \sigma^2_{0\mathrm{S,D}}$. In Phase 2, R_i amplifies the received signal $y_{\mathrm{S,R}_i}$ and forwards it as $x_{\mathrm{R}_i,\mathrm{D}}$ to D with transmitted power P_{R_i}. The received signal at D is

$$y_{\mathrm{R}_i,\mathrm{D}} = \sqrt{P_{\mathrm{R}_i}} h_{\mathrm{R}_i,\mathrm{D}} x_{\mathrm{R}_i,\mathrm{D}} + n_{\mathrm{R}_i,\mathrm{D}}, \tag{3}$$

where $x_{\mathrm{R}_i,\mathrm{D}} = y_{\mathrm{S,R}_i} / \sqrt{\varepsilon\{|y_{\mathrm{S,R}_i}|^2\}}$. $\varepsilon\{\cdot\}$ denotes the expectation operator. Hence, the SNR for S, which is helped by R_i, is given by

$$\Gamma^{\Delta}_{\mathrm{S,R}_i,\mathrm{D}} = \frac{P_{\mathrm{S}} \frac{|h_{\mathrm{S,R}_i}|^2}{N_{0\mathrm{S,R}_i}} P_{\mathrm{R}_i} \frac{|h_{\mathrm{R}_i,\mathrm{D}}|^2}{N_{0\mathrm{R}_i,\mathrm{D}}}}{P_{\mathrm{R}_i} \frac{|h_{\mathrm{S,R}_i}|^2}{N_{0\mathrm{S,R}_i}} + P_{\mathrm{R}_i} \frac{|h_{\mathrm{R}_i,\mathrm{D}}|^2}{N_{0\mathrm{R}_i,\mathrm{D}}} + 1}. \tag{4}$$

In this paper, we assume maximum ratio combining (MRC) at D. If R_i are available to help S at a certain time constituting a set, denoted by $L = \{\mathrm{R}_i, \cdots, \mathrm{R}_{\tilde{N}}\}$, we have

$$C_{\mathrm{S,R,D}} = \frac{1}{\tilde{N}+1} \log_2 \left[1 + \Gamma^{\Delta}_{\mathrm{S,D}} + \sum_{\mathrm{R}_i \in L} \Gamma^{\Delta}_{\mathrm{S,R}_i,\mathrm{D}} \right] \tag{5}$$

where $\tilde{N} (\leq N)$ denotes the number of relay nodes that actually help forwarding in Phase 2. If all relays participate in helping forwarding, $\tilde{N} = N$.

B. CONVENTIONAL SCHEME

1) Optimal Power Allocation Scheme (OPA): We rewrite $C_{\mathrm{S,R,D}}$ as C for simplicity. From [10][11], we can model and formulate the all-participate ($\tilde{N} = N$) OPA problem among relays as follows:

$$\begin{aligned} &E^{\mathrm{OPT}}_{\mathrm{R}_i} = \arg\max_{E_{\mathrm{R}_i}} C \\ &\text{s.t. } \forall\, i,\ \sum_{i=1}^{N} E_{\mathrm{R}_i} = E^{\mathrm{TOT}}, E^{\mathrm{MIN}} \leq E_{\mathrm{R}_i} \leq E^{\mathrm{MAX}} \end{aligned} \tag{6}$$

where E^{TOT} is the total energy constraints for all nodes, and E^{MIN} and E^{MAX} are individual energy constraint: these denote maximum and minimum transmission energy. Solution of (6) can be obtained from the following equation [10]:

$$E^{\mathrm{OPT}}_{\mathrm{R}_i} = \left[\lambda \sqrt{\frac{E^2_{\mathrm{S}} a_i^2 + E_{\mathrm{S}} a_i}{b_i}} - \frac{E_{\mathrm{S}} a_i + 1}{b_i} \right]^{E^{\mathrm{MAX}}}_{E^{\mathrm{MIN}}}. \tag{7}$$

where $a_i = |h_{\mathrm{S,R}_i}|^2 / N_{0\mathrm{S,R}_i}$, $b_i = |h_{\mathrm{R}_i,\mathrm{D}}|^2 / N_{0\mathrm{R}_i,\mathrm{D}}$ and λ is a constant chosen to meet the total energy constraint ($\tilde{E}^{\mathrm{TOT}}$), and $[x]^u_l$ is defined as $[x]^u_l = l\ (x < l), x\ (l \leq x \leq u), u\ (u < x)$. This solution can be considered as an extended water-filling process, with each vessel having both a bottom and a lid.

2) Selection Amplify-and-Forward Scheme (SAF): In the previous section, we showed AP-OPA system. However, performance might not be necessarily improved by participation of all relays. To realize orthogonal transmissions, every node can only transmit in a slot with length $1/(N+1)$ of the entire block. Although this orthogonal transmission can achieve full diversity order, the TDMA factor $1/(N+1)$ in (5) has a large adverse effect on throughput when N is large. To solve this problem, [10][11] introduce selection amplify-and-forward (SAF) scheme where the transmission is divided into only two slots. Phase 1 of SAF implements the data-sharing phase as Phase 1 of OPA. In contrast, Phase 2 of SAF contains only one slot unlike OPA that need N time slots, in which R selected by D amplifies-and-forwards its received signal from S by allocating all energy resource (E^{TOT}) to the selected relay ($E_{\hat{\mathrm{R}}_i}$). From (5), the capacity of the S-D channel when R_i is chosen for relaying is

$$\begin{aligned} &C(i) = \frac{1}{2} \log_2 \left[1 + \Gamma^{\Delta}_{\mathrm{S,D}} + \Gamma^{\Delta}_{\mathrm{S,R}_i,\mathrm{D}} \right], \\ &\text{s.t. } \sum_{i=1}^{N} E_{\mathrm{R}_i} = E^{\mathrm{TOT}},\ E_{\hat{\mathrm{R}}_i} = E^{\mathrm{TOT}} \end{aligned} \tag{8}$$

bits per one slot. The maximum capacity is therefore attained when the R with the largest $\Gamma^{\Delta}_{\mathrm{S,R}_i,\mathrm{D}}$ is selected, resulting in a capacity of

$$\begin{aligned} &C^{\mathrm{SAF}} = \frac{1}{2} \log_2 \left[1 + \Gamma^{\Delta}_{\mathrm{S,D}} + \max_i \Gamma^{\Delta}_{\mathrm{S,R}_i,\mathrm{D}} \right] \\ &\text{s.t. } \sum_{i=1}^{N} E_{\mathrm{R}_i} = E^{\mathrm{TOT}},\ E_{\hat{\mathrm{R}}_i} = E^{\mathrm{TOT}}. \end{aligned} \tag{9}$$

D needs only to make the selection and notify the selected R, instead of computing and feeding back the power allocated to every R. Thus, the complexity of SAF is lower than that of OPA. SAF has a higher throughput than OPA, since SAF only repeats information once whereas OPA repeats N times.

III. ISSUES AND OBJECTIVE

As mentioned above, the OPA scheme has a problem as follows; When a signal passing through channel in a very bad state is combined, considering the increment of time slot, capacity of all over the system may be degraded. That is to say, performance might not be necessarily improved by participation of all relays.

As a scheme to solve this problem, we introduce SAF that is a scheme to improve throughput by allocating energy resources to one R intensively and suppressing the increase in required time slots. However, this scheme has another problem; It is an explosion of energy consumption per unit-time (i.e. power consumption), because of allocation of the total energy (E^{TOT}) to one R, or one time slot. That is, by using SAF, while throughput performance improves, capacity (or outage probability) per unit power performance might not improve, and question remains: In perspective of power efficiency, is SAF an excellent scheme?

Under the condition that total energy is constant ($\sum_{i=1}^{N} E_{\mathrm{R}_i} = E^{\mathrm{TOT}}$) in (6) or (9), when the number of time slots of Phase 2 is decreased, power consumption in each time slot in all over the network proportionally increases. For example, when $E^{\mathrm{TOT}} = 3.0$ J, $N = 3$, $\tilde{N} = 3$ and $T = 3.0$ sec (time of Phase 2) in OPA, average transmission power of relay nodes becomes 1.0 W because time is slotted, each node is half-duplex, and one time slot is assumed to be unit duration. On the other hand, when $\tilde{E}^{\mathrm{TOT}} = 3.0$ J, $N = 3$, $\tilde{N} = 1$ and $T = 1.0$ sec in SAF, it becomes 3.0 W. Thus, it is understood that if E^{TOT} is constant, a decrease of time slot must cause an increase in power consumptions. No matter how the improvement of the channel capacity or reliability can be expected, if power consumption increases, the battery of terminals that act as relays is consumed more intensely, and this is not desirable from viewpoint of user's aspect.

As just described, most power allocation schemes in existing works about cooperative communications have focused on resource allocation aimed at improving only the communication qualities, rather than saving transmission power or improving transmission power efficiency. However, we have focused on not only improving the communication qualities, but also improving transmission power efficiency, and this is the novelty of our works. In this paper, we aim to improve the transmission efficiency per unit-power. In other words, the objective of this study is the coexistence of the improvement of channel capacity, reliability and saving of power consumption performance. We try to solve this issue by using game theoretic approach.

IV. PROPOSAL

As previously explained, in allocation problem for equivalent amount of energy resource, reduction of time slots in relaying phase would lead to increase power consumption of relay nodes. Therefore, in our proposal, in order to suppress the increase of power consumption in the relaying phase, like OPA, we assign N slots to relaying phase. From (8), solution of the optimization problem for throughput per unit power seems to solve the following equation (10) as a problem of non-linear programming method:

$$\begin{aligned} E_{\hat{\mathrm{R}}_i} &= \arg\max_{E_{\mathrm{R}_i}} \left[\max_i \frac{C(i)}{P_{\mathrm{R}_i}} \right] \\ \text{s.t. } &\sum_{i=1}^{N} E_{\mathrm{R}_i} \le E^{\mathrm{TOT}},\ E_{-\hat{\mathrm{R}}_i} = \{0\}, \end{aligned} \tag{10}$$

where $E_{-\hat{\mathrm{R}}_i}$ is the transmission energy set of unselected relays. Which is to say,

$$\begin{aligned} E_{\hat{\mathrm{R}}_i} &= \arg\max_{E_{\mathrm{R}_i}} \left[\frac{\log_2 \left[1 + \Gamma^{\Delta}_{\mathrm{S,D}} + \max_i \Gamma^{\Delta}_{\mathrm{S,R}_i,\mathrm{D}} \right]}{2P_{\mathrm{R}_i}} \right] \\ \text{s.t. } &\sum_{i=1}^{N} E_{\mathrm{R}_i} \le E^{\mathrm{TOT}},\ E_{-\hat{\mathrm{R}}_i} = \{0\}. \end{aligned} \tag{11}$$

We can solve uniquely this equation (11) and thus transmission relay node and transmission power are also uniquely determined. However, in this case, the solution becomes $P_{\mathrm{R}_i} = 0$ (i.e. any relay should not participate in relaying received data), and, as it turns out that the problem that how much power should be consumed for transmission could not be resolved. Therefore, we try to solve this issue by introducing a game theoretic framework for studying efficient power saving to a typical AF cooperative communication. Here, game theory is employed as a tool for modeling and understanding the resource allocation problems. We assume that D can perfectly estimate the CSIs of all links, and these CSIs are sent for each R, instantaneously. These assumptions are the same as those in the conventional schemes as OPA and SAF [10].

In general, in game theory, "a game" $\mathcal{G}$ consists of three elements and can be represented as $\mathcal{G} = (\mathcal{K}, \{S_i\}_{i\in\mathcal{K}}, \{U_{\mathrm{R}_i}\}_{i\in\mathcal{K}})$. First, there are parties involved in the resource conflict, which are called "players", which is the first element and defined as $\mathcal{K} := \{1, 2, \cdots, K\}$. Second, the actions or moves that can be taken by the players are called "strategies". They belong to the strategy space $\mathcal{S} := \{S_i\}_{i\in\mathcal{K}}$. The third element is "utility function" $\mathcal{U} := \{U_{\mathrm{R}_i}\}_{i\in\mathcal{K}}$ obtained by the players. Utility depends on their selected strategies, and is a measure of how much something is worth to someone. The players are assumed to be rational and selfish to characterize their objective: to maximize their utility in $\mathcal{G}$.

In our work, we define player as each R and strategy as transmission energy. Utility function U_{R_i} is defined as follows:

$$U_{\mathrm{R}_i} = C - \alpha E_{(\mathrm{R}_i)} \tag{12}$$

where α is a weighting coefficient that emphasizes the channel capacity or energy according to value (small or large). When α is set to a small value, each R selects the strategy, heavy weighing the channel capacity than the energy saving. On the other hand, when α is set to a large value, each R selects the strategy, heavy weighing the energy saving than the channel capacity. For all i, $E^{\mathrm{MIN}} \le E_{\mathrm{R}_i} \le E^{\mathrm{MAX}}$.

To solve this game is to find the strategy profile $s^* \in \mathcal{S}$ defined as:

$$\forall\ i, s_i \in S_i, s_i \ne s_i^* : U_i(s_i^*, s_{-i}^*) \ge U_i(s_i, s_{-i}^*), \tag{13}$$

where each character's meaning is as follows: S_i is the strategy set i-th player can take, s_i is the arbitrary strategy i-th player takes, s_i^* is the strategy i-th player takes at Nash equilibrium (NE) and s_{-i}^* is the strategy set taken by players other than i-th player at NE. (13) means the stable point (i.e. strategy set) in all over the strategy set that each player could select, which is referred to as NE. In NE, no unilateral deviation in strategy by any single player is profitable for that player. A (pure) NE represents a scenario for which no player has an incentive to unilaterally deviate. Therefore, each player attempts to find the strategy set at the NE, and if it was found, player has to select the own strategy in the equilibrium. We find NE brute-forcely with computer simulation. If NE does not exist, resource allocation in relaying phase complies with OPA. Else if only one NE exists, each R selects the strategy of NE, and decides transmission energy in Phase 2. If two or more NEs exist, selected strategy is the one that the sum of the utility function of each R is the maximum.

Solving (12) analytically is very difficult. Hence, in this proposal, for the sake of simplicity, we solved it numerically.

Exactly, we assume that transmission energy is treated as a discrete value which has 0.1 step-size, although in actual, energy takes a continuous value. Therefore, in our proposal, if E^{MIN} and E^{MAX} are decided, the number of strategies is not infinity but finite number. Thus, our game is defined as $\mathcal{G} = (\mathcal{R} = \{\mathrm{R}_1 \cdots \mathrm{R}_N\}, \{E_{\mathrm{R}_i}\}_{\mathrm{R}_i \in \mathcal{R}}, \{U_{\mathrm{R}_i}\}_{\mathrm{R}_i \in \mathcal{R}})$.

V. PERFORMANCE EVALUETION

A. SIMULATION PARAMETERS

Our computer simulation parameters are shown as follows. Network with one source node, one destination node, and three relay nodes ($N = 3$) is assumed. We compared four transmission schemes: "DIR" means direct transmission scheme, which is the simplest and classical transmission scheme when S sends information to D directly without help from R; "EPA" means equal power allocation scheme, which is the simplest conventional allocation scheme in cooperative communications, where all relays use the same energy ($E_{\mathrm{R}_i} = E_{\mathrm{S}} = E^{\mathrm{TOT}}/(N+1)$); "OPA" shows the conventional OPA scheme as explained in section II-B1; "OPSA" means optimal power saving allocation, which is our proposed scheme explained in section IV. We assume that each link experiences i.i.d. block Rayleigh fading, and block length is as long as a time slot (i.e. unit time). Fig. 2 shows the placement of each node. These fading channels have parameters $h_{\mathrm{S,R}_i} \sim \mathcal{CN}(0, g_{\mathrm{S,R}_i})$, $h_{\mathrm{S,D}} \sim \mathcal{CN}(0, g_{\mathrm{S,D}})$ and $h_{\mathrm{R}_i\mathrm{,D}} \sim \mathcal{CN}(0, g_{\mathrm{R}_i\mathrm{,D}})$, respectively, and g indicates the average channel power gain in each link. From Fig. 2, by using path loss exponent γ, each g is expressed as follows: $g_{\mathrm{S,R}_i} = g_{\mathrm{S,D}}\{\sqrt{d^2 + (i/10)^2}\}^{-\gamma}$ and $g_{\mathrm{R}_i\mathrm{,D}} = g_{\mathrm{S,D}}\{\sqrt{(1-d)^2 + (i/10)^2}\}^{-\gamma}$. We set $g_{\mathrm{S,D}}$ to 1.0 dB, $d = 0.1$, and γ to 3. This setting of d means the case where the relays are close to S, thus S-R channels are much better than R-D. Also, we assume that each node knows the noise power in each node and that the channel estimations are ideal. The energy constraints are $E_{(\mathrm{S})} = 1.0$ J, $E^{\mathrm{MIN}} = 0.0$ J, $E^{\mathrm{MAX}} = 3.0$ J, and $\tilde{E}^{\mathrm{TOT}} = 3.0$ J. The target channel capacity is set to be $C^{\mathrm{TAR}} = 1.0$ bps/Hz. N_0 in Fig. 3, Fig. 4 and Fig. 5 (denominator of abscissa axis) is noise power in each node, where $N_0 = N_{0\mathrm{S,D}} = N_{0\mathrm{S,R}_i} = N_{0\mathrm{R}_i\mathrm{,D}}$. As noted

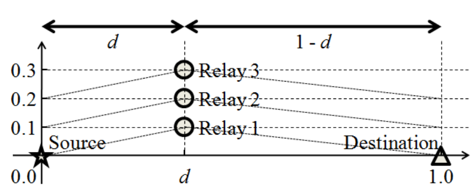

Fig. 2. The placement of each node in our computer simulation.

in the solution of (11), because discussion of the best value of α inevitably conclude that any R should not participate in relaying received data (i.e. α is the smaller the better), it does not make any sense to discuss about it. However, as you can see (12), channel capacity and power saving are expected to have a trade-off depending on α. Thus, α should be set flexibly according to the requirements of target channel capacity of the systems. Here, to verify the existence of this expected trade-off, we have prepared two different values of α; small-value ($\alpha = 0.1$); large-value ($\alpha = 0.5$).

B. SIMULATION RESULTS

Fig. 3 shows the outage probability when target channel capacity is set to 1.0 bps/Hz for the six schemes. In Fig 3, DIR has most poor outage probability in all the schemes; This is owing to no diversity gain. SAF has smaller outage probability than any other schemes; compared with OPA, SAF results in a gain of more than 5 dB. This improvement is owing to the small number of required time slots compared with that in the other conventional cooperative schemes. OPSA has smaller outage probability than OPA. This is because by removing the E^{TOT} constraint, when the channel condition of relay links is bad, more than E^{TOT} (less than NE^{MAX}) is allocated to relay nodes. Although under such circumstances, by using OPSA, it seems to increase power consumption rather than decrease, in fact, it is not. We leave this reason hanging and describe in detail later. In addition, in OPSA, as expected, depending on the value of α, we can understand that outage probability performance changes.

Fig. 4 shows average transmission power of all nodes in all over the network. DIR, EPA and OPA consume equal power. In EPA and OPA, because transmission energy is $E_{\mathrm{S}} + E^{\mathrm{TOT}} = 4.0$ J and the number of required time slots is $N+1$, average transmission power in all over the network per node is 1.0 W. In SAF, because transmission energy is $E_{\mathrm{S}} + E^{\mathrm{TOT}} = 4.0$ J and the number of required time slots is 2, average transmission power in all over the network per node is 1.0 W. Then, we can see that SAF need to increase power consumption compared with OPA. We can also see that OPSA's power consumption performance has the following three characteristics: 1) Under the high noise power conditions, OPSA's power consumption performance is comparable with OPA's and average transmission power is constant about 1.0 W. This is because when noise power is high (in smaller than E^{MAX}) NE does not exist. As mentioned above, because if NE does not exist, resource allocation in relaying phase complies with OPA, power allocation has a higher rate of transmission with OPA scheme (power allocation has a lower rate of transmission with game theoretic approach). 2) Under the low noise power conditions, compared with DIR, EPA or OPA, improvement of OPSA's power consumption performance (i.e. reduction of transmission power) is seen. This is because even if there is no cooperation of each relay node, the target channel capacity is often exceeded. Thus, each relay node selects the strategy that decreases transmission power. From Fig. 4, we can see that power consumption performance of OPSA depends on α. This means that according to α, how much power can be reduced is determined. Here, we discuss the question hanging above; Why power saving is possible? We should take notice of that becasuse, in proposal (OPSA), we removed the E^{TOT} constraint, sometimes total transmission energy becomes more than E^{TOT}, and sometimes it becomes less than E^{TOT}. Therefore, it would appear that if the channel conditions of relay links are good, transmission is done with total energy smaller than E^{TOT} (low-power mode); if the channel conditions of relay links are bad, transmission is done with total energy higher than E^{TOT} (high-power mode). This is the answer of the above question. The rate of these low-power mode and high-power mode depends on α. 3) Under the middle noise power conditions, when α is small (here, $\alpha = 0.2$), OPSA's power consumption performance has slight deterioration compared with OPA and EPA. This can be also explained by the proportion of low-power mode and high-power mode. That is, when α is small, owing to the increased rate of transmission for high-power mode, uplift can be seen as part of the plot.

Fig. 5 shows transmission power efficiency performance of the six schemes, which is defined as $(1 - \mathrm{Pr}^{\mathrm{OUT}})/\bar{P}$, where $\mathrm{Pr}^{\mathrm{OUT}}$ is the outage probability and $\bar{P}$ is the average transmission power in all over the network per node. From Fig. 5, we can see that OPSA provides the best power efficiency for transmission. This is for the following reasons; SAF has advantage of outage probability performance, while it has disadvantage of power consumption performance; OPA has advantage of power consumption performance, while it has disadvantage of outage probability performance; OPSA has better outage probability performance than OPA and better power consumption performance than any other schemes.

From Fig. 3 and Fig. 4, we can see that there is a trade-off between outage probability and power consumption depending on α. This is because the channel capacity is weighed heavier than the energy by setting α small in (12) and thus reliability of transmission could improve. On the other hand, the energy saving is weighed heavier than the channel capacity by setting α large.

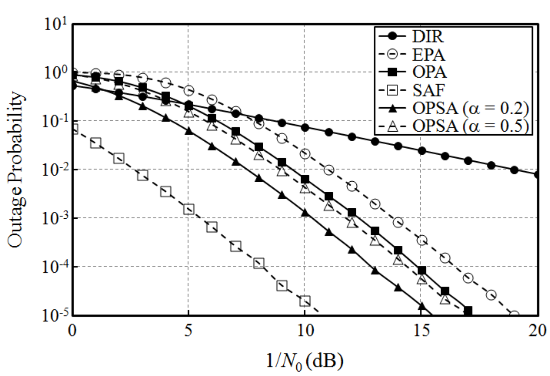

Fig. 3. Outage probability performance for the six schemes when target channel capacity is set to 1.0 bps/Hz.

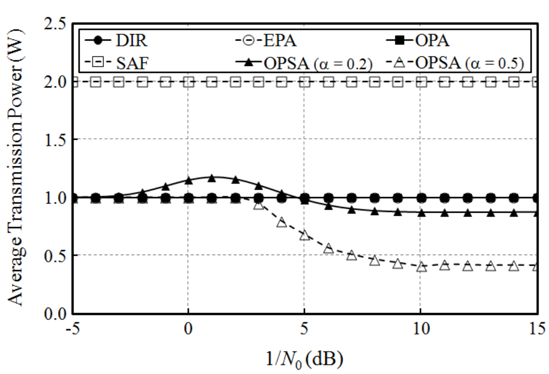

Fig. 4. Power consumption performance: Average transmission power of all nodes in all over the network per node for the six schemes.

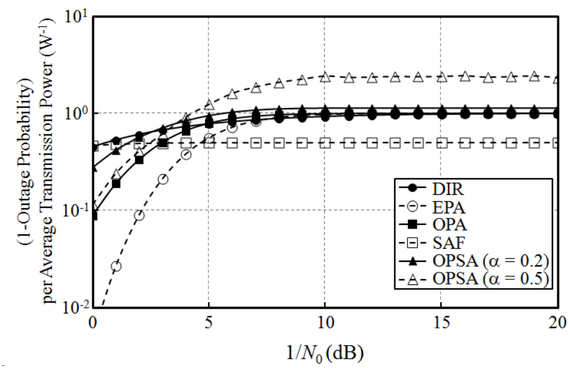

Fig. 5. Transmission power efficiency performance for the six schemes, which is defined as $(1 - \mathrm{Pr}^{\mathrm{OUT}})/\bar{P}$.

VI. Conclusion

In cooperative communication, there is a problem that which relay nodes should be selected and how much power should be allocated to the selected relay nodes. In this paper, for this problem, we propose OPSA using game theory for AF cooperative communication. In this proposal, utility function is set in consideration of the transmission energy of each relay node and the channel capacity in all over the network. We attempt to balance the outage probability with the transmission power of each relay node. By using computer simulations, compared with conventional schemes (EPA, OPA and SAF), we showed that our proposal provides best transmission power efficiency. We also showed that there is a trade-off between reliability and power consumption depending on α.

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