Robust Power Allocation for Selective Relaying Based DF Cellular Wireless System

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***Abstract*—In this paper, we develop a power allocation scheme that works robustly under channel uncertainty for a decode-and-forward (DF) cooperative cellular multi-user network with multiple fixed relays. We propose a method for selective relaying, where cooperation takes place only if it is beneficial for the network in terms of total transmit power minimization or source power savings. Our objective is to provide energy efficiency by minimizing the power consumption of the network while meeting the rate requirements of the users. We consider the probabilistically constrained optimization approach, in which quality of service (QoS) constraint is satisfied for all users with certain probabilities. We transform the probabilistic optimization problem into a deterministic one and derive closed form analytical solutions. Simulation results show the effectiveness of our proposed algorithm.**

I. Introduction

Cooperative relay systems can improve energy efficiency and the achievable transmission rates of a cellular wireless network [1]. By allowing cooperation via relays, it is possible to provide spatial diversity and combat multi-path fading [2]-[3]. Various relaying schemes have already been studied [4]-[5] and among them, decode-and-forward (DF) has attracted considerable attention. Several resource optimization problems have been formulated to improve the performance with DF cooperation further, for example, minimizing transmission power, maximizing capacity, and minimizing outage probability [1]-[3], [6]-[8]. However, if the direct channel is better than the source-relay channel, cooperation may not be beneficial in terms of energy efficiency or spectral efficiency when orthogonal transmission is considered [2]. Therefore, selective relaying, i.e., relaying only when it is beneficial for the system, can improve the performance significantly [5].

Most of the existing literature on power allocation for DF scheme is based on the assumption of the availability of perfect channel state information (CSI) at all the nodes. However, in a practical cellular system, perfect CSI may not be available due to channel fluctuations, limited feedback capacity and channel estimation and quantization errors [7]-[11]. The resource optimization schemes designed based on perfect CSI, will fail to satisfy the quality of service (QoS) constraint which is active, even in the presence of a very small error in CSI. The results of such designs are retransmissions and wastage of energy [9]. Therefore, power allocation algorithms that can work robustly under channel uncertainty are highly desired for practical implementation. Considering channel estimation errors, power allocation schemes for amplify-and-forward (AF) relay networks have been developed in [7]. The optimization problem is formulated as a quasi-convex problem and solved using the bisection method via a sequence of convex feasibility problems in the form of second-order cone programming (SOCP). For DF system, optimal power allocation scheme considering imperfect CSI is developed in [8] for the worst-case optimization approach, in which QoS constraint is satisfied for all channels contained in some bounded uncertainty region. However, the bounded uncertainty region modeling is unsuitable for the cases when CSI error is unbounded, for example, when the CSI is obtained from a training sequence, the channel uncertainty becomes unbounded Gaussian [10]. Moreover, the worst case optimization often leads to overly conservative results. As a result, probabilistically constrained optimization has become an effective approach to provide the robustness when channel uncertainty is modeled as a random process [11].

In this paper, we develop a power allocation scheme that works robustly under imperfect CSI for a DF cooperative cellular multi-user network with multiple fixed relays. We propose a method for selective relaying, where cooperation takes place only if it is beneficial for the network in terms of total transmit power minimization or source power savings. Our objective is to provide energy efficiency by minimizing the power consumption of the network while meeting the rate requirements of the users. We consider the probabilistically constrained optimization approach, in which QoS constraint is satisfied for all users with certain probabilities. Efficient solution for a probabilistic optimization problem is in general very difficult. Our main contribution in the paper is to transform the probabilistic optimization problem into a deterministic one and derive closed form analytical solutions. The rest of the paper is organized as follows. The system model and problem formulation are described in section II. Section III describes the optimization frameworks and solution approaches. Numerical results are presented in section IV and section V concludes the paper.

II. System Model and Problem Formulation

Consider a cellular network, where a set of users, denoted by $\mathcal{S} = \{1, 2, ..., s, ..., S\}$, communicate with a single base station (BS) and a set of fixed relays, $\mathcal{K} = \{1, 2, ..., k, ..., K\}$, are placed in the cell to assist them. Each user is assigned an orthogonal channel over which the uplink communications take place.

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We consider the case of repetition based DF cooperative diversity [4], where cooperation takes place only if it is beneficial for the network in terms of total transmit power minimization or source power savings. In the signaling period, BS (for centralized scheme) or the relays (for distributed scheme) decide whether cooperation or direct transmission is beneficial for a particular user. The decision is taken based on the power requirement to obtain a certain rate by direct transmission and by relay transmission. Our objective is to design a energy efficient scheme, where some QoS is guaranteed to the users with lowest possible power requirement. With the help of the relays, it is also possible to save the source power and prolong the network lifetime.

The communication between a user and BS consists of two transmission phases. In the first phase, user s transmits the signal x_s to BS d and to the relays with power p_s. The received signal at relay k and at BS d is given by

$$\begin{aligned} y_k(n) &= \sqrt{p_s} h_{s,k} x_s(n) + z_k(n), \\ y_{d_1}(n) &= \sqrt{p_s} h_{s,d} x_s(n) + z_d(n), \end{aligned} \tag{1}$$

respectively. Here $h_{s,k}$ and $h_{s,d}$ are the complex channel coefficients for the user s to relay k and user s to BS d links, respectively, which capture the effect of fading and path loss. All channels are statistically modeled as independent and identically distributed (i.i.d.) circularly symmetric complex Gaussian random variables with zero-mean. z_k and z_d denote the i.i.d. circularly symmetric additive white Gaussian noise (AWGN) with zero-mean and unit variance.

The set of relays that is able to decode the messages for a user s is denoted by $k \in \mathcal{K}(s)$. If cooperation is beneficial, we consider that only one of the relays from $k \in \mathcal{K}(s)$, which is decided based on the minimum source power requirement for decoding a message for user s, forwards the received signal in the second phase to the BS with power $p_{k,s}$. The received signal at BS d forwarded by a relay k for user s is given by

$$y_{d_2}(n) = \sqrt{p_{k,s}} h_{k,d} x_k(n) + z_d(n), \tag{2}$$

where $h_{k,d}$ is the channel coefficient between relay k and BS d link.

A. Imperfect Channel State Information

Resource optimization problems depend largely on the CSI among various links. Due to the Gaussian noise in the estimation process, quantization effects in the CSI and mobility of the users, the CSI is often imperfect. We assume that the CSI is obtained from a training sequence and the resulting channel uncertainty is unbounded Gaussian [10]. We model the imperfect channel as $h = \hat{h} + e$, where $\hat{h}$ denotes the estimated channel coefficient and e is the error in CSI which is modeled as i.i.d and distributed as complex normal, $\mathcal{CN}\left(0, \sigma_e^2\right)$. The estimated channel $\hat{h}$ and the error e are assumed to be statistically independent. The variance σ_e^2 of error indicates the quality of CSI.

Using this imperfect channel model, a relay k will be in the set $\mathcal{K}(s)$ if the mutual information between a user s and relay k is greater than some fixed target rate r_s [6], i.e.,

$$I_{s,k} \geq r_s, \tag{3}$$

where $I_{s,k} = \frac{1}{2}\log_2(1 + |\hat{h}_{s,k} + e_{s,k}|^2 p_s)$ and $\hat{h}_{s,k}$ denotes the estimated channel coefficient, $e_{s,k}$ is the error in CSI and $|\hat{h}_{s,k} + e_{s,k}|^2$ is the channel gain between user s to relay k link, respectively. The mutual information between user s and the BS d with and without relay can be expressed as

$$\begin{aligned} I_{s,d_{relay}} &= \frac{1}{2}\log_2(1 + |\hat{h}_{s,d} + e_{s,d}|^2 p_s + |\hat{h}_{k,d} + e_{k,d}|^2 p_{k,s}), \\ I_{s,d_{direct}} &= \log_2(1 + |\hat{h}_{s,d} + e_{s,d}|^2 p_{s,d}), \end{aligned} \tag{4}$$

respectively, where $|\hat{h}_{s,d} + e_{s,d}|^2$ and $|\hat{h}_{k,d} + e_{k,d}|^2$ are the channel gains between user s to BS d and relay k to BS d links, respectively.

Since the instantaneous mutual information with CSI error is a random variable, a capacity outage occurs whenever the data rate of a user exceeds the instantaneous channel capacity. Our goal is now to provide the QoS in a probabilistic manner, such that the outage is less than some predetermined value, p_{out}. With CSI error, no cooperation, i.e., direct transmission is optimal in terms of source power savings or total power consumption, if the required power to obtain Pr.$(I_{s,k} \leq r_s) \leq p_{out}$ is greater than Pr.$(I_{s,d_{direct}} \leq r_s) \leq p_{out}$, where Pr.$(\cdot)$ denotes the probability of the event $(\cdot)$. In this scenario, user s transmits directly to the BS and the optimal power $p^*_{s,d}$ is obtained by solving Pr.$(I_{s,d_{direct}} \leq r_s) \leq p_{out}$.

When cooperation can be beneficial, the probabilistic optimization problem considering CSI error can be written as

$$\begin{aligned} &\underset{\{p_s, p_{k,s}\}}{\text{minimize}} \quad \sum_{s=1}^{S} (p_s + p_{k,s}) \\ &\text{subject to}: \\ &\text{Pr.}\left[(\chi^2_{2_{s,d}} p_s + \chi^2_{2_{k,d}} p_{k,s}) \leq \gamma_s\right] \leq p_{out}, \ \forall s, \\ &\text{Pr.}\left[(\chi^2_{2_{s,k}} p_s) \leq \gamma_s\right] \leq p_{out}, \ k \in \mathcal{K}(s), \ \forall s, \\ &p_s, \, p_{k,s} \geq 0, \ k \in \mathcal{K}(s), \ \forall s, \end{aligned} \tag{5}$$

where $\chi^2_{2_{s,d}} = |\hat{h}_{s,d} + e_{s,d}|^2$, $\chi^2_{2_{k,d}} = |\hat{h}_{k,d} + e_{k,d}|^2$ and $\chi^2_{2_{s,k}} = |\hat{h}_{s,k} + e_{s,k}|^2$ are recognized as non-central Chi-square distributed random variables with non-centrality parameter, $\lambda^2_{s,d} = \frac{|\hat{h}_{s,d}|^2}{\sigma^2_{e_{s,d}}/2}$, $\lambda^2_{k,d} = \frac{|\hat{h}_{k,d}|^2}{\sigma^2_{e_{k,d}}/2}$ and $\lambda^2_{s,k} = \frac{|\hat{h}_{s,k}|^2}{\sigma^2_{e_{s,k}}/2}$, respectively with degrees of freedom $n = 2$, and $\gamma_s = 2^{2r_s} - 1$. The first constraint guarantees that the target data rate r_s of user s is satisfied with a probability of $1 - p_{out}$. The second constraint satisfies the guaranteed decoding for any selected relay $k \in \mathcal{K}(s)$ with a probability of $1 - p_{out}$. The third constraint is the non-negativity power constraint.

If the optimal solution of (5) satisfies ${p_s}^* + p^*_{k,s} \leq p^*_{s,d}$, cooperation is beneficial in terms of total power minimization, otherwise, direct transmission is optimal for user s. If the cost of source power is much higher than relays, we can use the objective that minimizes only the sum of source powers. In that case, cooperation is beneficial if ${p_s}^* \leq p^*_{s,d}$. We assume that the target rate, r_s, is achieved for the users with power which is below the maximum power budget of the source and the relay. Note that, the optimization problem in (5) can not be solved easily in its present form. Next, our goal is to convert the probabilistic constraints into deterministic ones.

III. Proposed Optimization Framework

To determine the power requirement without cooperation, the probabilistic constraint Pr. $(I_{s,d_{direct}} \leq r_s) \leq p_{out}$ can be re-written as

$$\text{Pr.}\left(\chi^2_{2_{s,d}} p_{s,d} \leq 2^{r_s} - 1\right) \leq p_{out}. \tag{6}$$

The left-hand side of (6) can be evaluated as [12]

$$F_{\chi^2_{2_{s,d}}}(x) = 1 - Q_1\left(\lambda_{s,d}, \frac{\sqrt{2^{r_s}-1}}{\sqrt{\sigma^2_{e_{s,d}}/2}}\right), \tag{7}$$

where Q_1 is the generalized Marcum's Q function. Various approximations are proposed in the literature to avoid the infinite sum in Q_1. We use the approximation in [13] to obtain a closed-form result, where the non-central Chi-square distribution is approximated by the central Chi-square as

$$\text{Pr.}\left(\chi^2_{2_{s,d}} p_{s,d} \leq 2^{r_s} - 1\right) \approx \text{Pr.}\left(\chi^2_{2_{s,d}}(0) \leq \frac{\left(2^{r_s}-1\right)/p_{s,d}}{1+\lambda^2_{s,d}/2}\right). \tag{8}$$

Since $\chi^2_{2_{s,d}}(0)$, the central Chi-square distribution with degrees of freedom $n = 2$, yields exponential distribution, (8) can be computed as

$$\text{Pr.}\left(\chi^2_{2_{s,d}}(0) \leq \frac{\left(2^{r_s}-1\right)/p_{s,d}}{1+\lambda^2_{s,d}/2}\right) = 1 - e^{-\frac{\left(2^{r_s}-1\right)/p_{s,d}}{2\left(1+\lambda^2_{s,d}/2\right)}}. \tag{9}$$

Using the expression of (9) in (6), the minimum power for no cooperation case can be obtained as

$$p_{s,d} \geq C_{s,d}, \tag{10}$$

where

$$C_{s,d} = \left\{\frac{1}{-\ln(1-p_{out})}\right\} \frac{\left(2^{r_s}-1\right)}{2\left(1+|\hat{h}_{s,d}|^2/\sigma^2_{e_{s,d}}\right)}. \tag{11}$$

Using (8)-(9), constraint two of (5) can be written as

$$p_s \geq C_s, \tag{12}$$

where

$$C_s = \left\{\frac{1}{-\ln(1-p_{out})}\right\} \frac{\gamma_s}{2\left(1+|\hat{h}_{s,k}|^2/\sigma^2_{e_{s,k}}\right)}. \tag{13}$$

Therefore, cooperation can be beneficial for a user s with a relay $k \in \mathcal{K}(s)$ if $C_s < C_{s,d}$. Next, we need to find out a deterministic representation for the first constraint of (5).

By exploiting the independence of the positive random variables $\chi^2_{2_{s,d}}$ and $\chi^2_{2_{k,d}}$, we can write the following inequality for the first constraint of (5) as

$$\begin{aligned} &\text{Pr.}\left[(\chi^2_{2_{s,d}} p_s + \chi^2_{2_{k,d}} p_{k,s}) \leq \gamma_s\right] \\ &\leq \text{Pr.}(\chi^2_{2_{s,d}} p_s \leq \gamma_s)\text{Pr.}(\chi^2_{2_{k,d}} p_{k,s} \leq \gamma_s). \end{aligned} \tag{14}$$

Using (8)-(9), the right-hand side of (14) can be written as

$$\text{Pr.}(\chi^2_{2_{s,d}} p_s \leq \gamma_s)\text{Pr.}(\chi^2_{2_{k,d}} p_{k,s} \leq \gamma_s) \leq p_{out} \approx AB \leq p_{out}, \tag{15}$$

where $A = 1 - e^{-\left\{\frac{\gamma_s}{2p_s}\left(1+|\hat{h}_{s,d}|^2/\sigma^2_{e_{s,d}}\right)^{-1}\right\}}$ and $B = 1 - e^{-\left\{\frac{\gamma_s}{2p_{k,s}}\left(1+|\hat{h}_{k,d}|^2/\sigma^2_{e_{k,d}}\right)^{-1}\right\}}$.

However, $AB \leq p_{out}$ is not convex. We use another inequality, given by $1 - e^{-x} \leq x$, and write the approximation in (15) as

$$\frac{\gamma_s}{2p_s}\left(1+|\hat{h}_{s,d}|^2/\sigma^2_{e_{s,d}}\right)^{-1} \frac{\gamma_s}{2p_{k,s}}\left(1+|\hat{h}_{k,d}|^2/\sigma^2_{e_{k,d}}\right)^{-1} \leq p_{out}. \tag{16}$$

Note that, the left-hand side of the constraint is a convex function for positive p_s and $p_{k,s}$, which can be proved using the Hessian of the function [14], and hence the constraint is convex. Using the deterministic constraints (13) and (16), the probabilistic optimization problem of (5) can be written as

$$\begin{aligned} \underset{\{p_s, p_{k,s}\}}{\text{minimize}} \quad & \sum_{s=1}^{S} (p_s + p_{k,s}) \\ \text{subject to}: \quad & p_s p_{k,s} \geq C_{k,s}, \ \ \forall s, \\ & p_s \geq C_s, \quad k \in \mathcal{K}(s), \quad \forall s, \\ & p_{k,s} \geq 0, \quad k \in \mathcal{K}(s), \quad \forall s, \end{aligned} \tag{17}$$

where

$$C_{k,s} = \frac{{\gamma_s}^2}{4p_{out}}\left(1+|\hat{h}_{s,d}|^2/\sigma^2_{e_{s,d}}\right)^{-1}\left(1+|\hat{h}_{k,d}|^2/\sigma^2_{e_{k,d}}\right)^{-1}. \tag{18}$$

Note that, the formulated problem (17) is convex, for which the global optimum solution can be obtained. The Lagrangian of the optimization problem in (17) can be written as

$$\begin{aligned} \mathcal{L}(\cdot) = & \sum_{s=1}^{S}(p_s + p_{k,s}) - \sum_{s=1}^{S}\lambda_{s,1}\left(C_{k,s} - p_s p_{k,s}\right) \\ & - \sum_{s=1}^{S}\lambda_{s,2}\left(C_s - p_s\right) - \sum_{s=1}^{S}\lambda_{k,s} p_{k,s}, \end{aligned} \tag{19}$$

where $\lambda_{s,1}$, $\lambda_{s,2}$ and $\lambda_{k,s}$ are the Lagrange multipliers associated with the first, second and third inequality constraints of (17), respectively. The KKT conditions for the Lagrangian function in (19) are given by

$$\lambda^*_{s,1}\left(C_{k,s} - p^*_s p^*_{k,s}\right) = 0, \ \ \forall s, \tag{20a}$$

$$\lambda^*_{s,2}\left(C_s - p^*_s\right) = 0, \ \ \forall s, \tag{20b}$$

$$\lambda^*_{k,s} p^*_{k,s} = 0, \ \ k \in \mathcal{K}(s), \ \ \forall s, \tag{20c}$$

$$p^*_s p^*_{k,s} \geq C_{k,s}, \quad p^*_s \geq C_s, \quad \forall s, \tag{20d}$$

$$p^*_{k,s} \geq 0, \ \ k \in \mathcal{K}(s), \ \ \forall s, \tag{20e}$$

$$\lambda^*_{s,1}, \lambda^*_{s,2}, \lambda^*_{k,s} \geq 0 \ \ k \in \mathcal{K}(s), \ \ \forall s, \tag{20f}$$

$$\frac{\partial \mathcal{L}}{\partial p^*_s} = 1 - \lambda^*_{s,1} p^*_{k,s} - \lambda^*_{s,2} = 0, \ \ \forall s, \tag{20g}$$

$$\frac{\partial \mathcal{L}}{\partial p^*_{k,s}} = 1 - \lambda^*_{s,1} p^*_s - \lambda^*_{k,s} = 0, \ \ k \in \mathcal{K}(s), \ \ \forall s. \tag{20h}$$

From (20c) and (20d), we can conclude that $\lambda^*_{k,s} = 0$, otherwise, condition (20d) is violated for any positive $C_{k,s}$. This also guarantees that $\lambda^*_{s,1} \neq 0$ in (20h) and hence the constraint $p_s^* p_{k,s}^* \geq C_{k,s}$ must be met with equality in (20a). Therefore, p_s^* can be expressed as

$$p_s^* = 1/\lambda_{s,1}^*. \tag{21}$$

Note that, the constraint $p_s^* \geq C_s$, may or may not be active at the optimal point, which indicates that there can be two cases with $\lambda_{s,2}^*$, as explained below:

Case 1: $\lambda_{s,2}^* = 0$

In this case, we can write the following expression from (20g) as

$$p_{k,s}^* = 1/\lambda_{s,1}^*. \tag{22}$$

Substituting the values of p_s^* and $p_{k,s}^*$ into (20d), we obtain

$$p_s^* = p_{k,s}^* = \sqrt{C_{k,s}}. \tag{23}$$

Case 2: $\lambda_{s,2}^* \neq 0$

This guarantees from (20b) that the constraint $p_s^* \geq C_s$ must be active at the optimal point. Therefore, the solution is given by

$$p_s^* = C_s \text{ and } p_{k,s}^* = \frac{C_{k,s}}{C_s}. \tag{24}$$

Note that, if $C_s \geq \sqrt{C_{k,s}}$, we can conclude that the constraint $p_s^* \geq C_s$ is active, otherwise, we conclude that the constraint $p_s^* \geq C_s$ is inactive and $\lambda_{s,2}^* = 0$.

Remark: In the case of minimizing only the sum of source powers, the constraint $p_s^* \geq C_s$ is active and the optimal power allocation can be obtained as $p_s^* = C_s$ and $p_{k,s}^* = \dfrac{C_{k,s}}{C_s}$.

IV. Numerical Results

We have conducted extensive simulations considering different system parameters to analyze the effect of imperfect CSI. We evaluate and compare the performance considering imperfect CSI for the following three system models:

(1) No cooperation: a cellular network, where the users communicate directly with the BS.

(2) Always cooperation: a cellular network, where the users always make use of the relays in addition to the direct path to communicate with the BS, even if cooperation is not beneficial.

(3) Selective cooperation: a cellular network, where the users communicate with the BS via the relays only if it is beneficial in terms of power minimization or source power savings.

We have considered a cell of radius r_{cell} with 8 relays, where the relays are placed on a ring of radius $0.1r_{cell}$, and 1000 users uniformly distributed all over the cell. Each of the estimated channel coefficients are i.i.d. circularly symmetric complex Gaussian random variables and distributed as [15] $\mathcal{CN}\left(0, \dfrac{1}{(1+d)^\alpha}\right)$, where d is the normalized distance of the users and relays from the BS and $\alpha = 4$ is the path loss coefficient. Unless stated elsewhere, same target data rate, $r_s = 1$ is assumed for all users, same channel estimation error variance, $\sigma_e^2 = 0.1$ is assumed for all channels and probability of outage p_{out} is assumed to be 0.1. The results are averaged over 1,000 independent channel realizations.

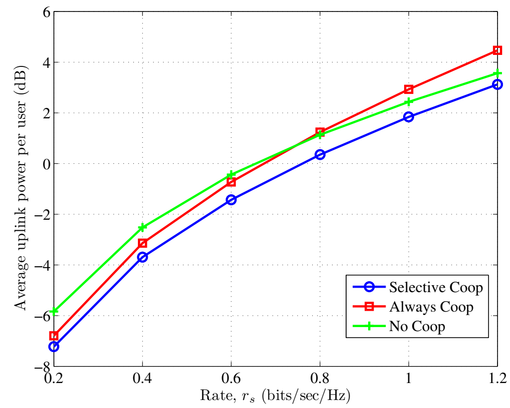

Fig. 1. Average uplink power per user versus rate (r_s).

In Fig. 1, average uplink power per user versus rate r_s is shown for the three system models. We can see that our proposed selective cooperation performs the best in terms of total uplink power minimization. Always cooperation requires less power than no cooperation when rate requirement is less than 0.75. At $r_s = 0.4$, using selective cooperation approximately 1.2 dB and 0.6 dB power can be saved than no cooperation and always cooperation schemes, respectively. At higher rate requirement, e.g., $r_s > 0.75$, no cooperation performs better than always cooperation and at $r_s = 1$, nearly 1.2 dB and 0.65 dB power can be saved using selective cooperation than always cooperation and no cooperation schemes, respectively. Note that, cooperation requires one more time slot than direct transmission and the power requirement for cooperation is proportional to $2^{2r_s} - 1$, which in turn, for no-cooperation is proportional to $2^{r_s} - 1$. Therefore, cooperation is beneficial in terms of power requirement at the lower rate region.

Fig. 2 shows the average source power per user versus error variance σ_e^2, when the objective is to minimize only the sum of source powers. As expected, the source power increases with the increase in σ_e^2 for all the three system models and the proposed selective cooperation scheme performs the best in terms of source power minimization for the entire range of error variance. For lower values of error variance, e.g., $\sigma_e^2 < 0.1$, always cooperation requires much less source power than no cooperation and at $\sigma_e^2 = 10^{-3}$, approximately 6 dB and 1.5 dB source power can be saved using selective cooperation than no cooperation and always cooperation schemes, respectively. However, at higher error, e.g., $\sigma_e^2 > 0.1$, no cooperation performs better than always cooperation.

In Fig. 3, average uplink power per user versus probability of outage p_{out} is shown for the three system models. We see that for very strict outage requirement, e.g., at $p_{out} = 0.025$, using selective cooperation, nearly 1.6 dB and 0.8 dB power can be saved than always cooperation and no cooperation schemes, respectively. Average uplink power decreases for more relaxed outage requirements and at $p_{out} = 0.25$, no cooperation performs very close to selective cooperation,

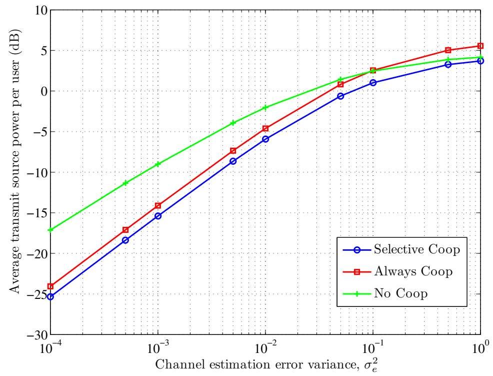

Fig. 2. Average source power per user versus error variance (σ_e^2).

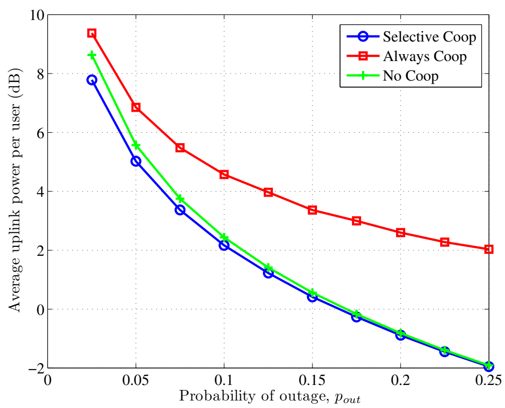

Fig. 3. Average uplink power per user versus probability of outage (p_{out}).

which is nearly 4 dB less than always cooperation scheme.

Fig. 4 shows the cooperation ratio versus error variance ratio, $\sigma_{e_{sr}}^2/\sigma_{e_{sd}}^2$, for the proposed selective cooperation scheme. Cooperation ratio is defined as the ratio of number of cooperating and non-cooperating users. When the ratio $\sigma_{e_{sr}}^2/\sigma_{e_{sd}}^2$ is low it indicates that the error variance is higher in the direct path and as a result, more users cooperate and vice-versa. As expected from (11) and (13), cooperation ratio increases with the decrease of the rate requirements.

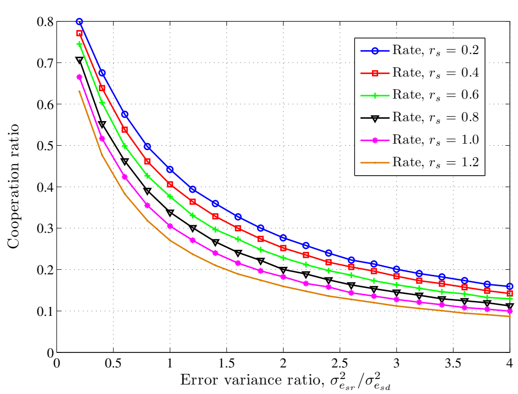

Fig. 4. Cooperation ratio versus error variance ratio ($\sigma_{e_{sr}}^2/\sigma_{e_{sd}}^2$).

V. Conclusion

In this paper, we have developed a power allocation scheme that works robustly under imperfect CSI for a DF cooperative cellular multi-user network with multiple fixed relays. We have proposed a method for selective relaying, where cooperation takes place only if it is beneficial for the network in terms of total transmit power minimization or source power savings. Our objective is to provide energy efficiency by minimizing the power consumption of the network while meeting the rate requirements of the users. We have considered the probabilistically constrained optimization approach, in which QoS constraint is satisfied for all users with certain probabilities. We have transformed the probabilistic optimization problem into a deterministic one and derived closed form analytical solutions. Simulation results have shown the effectiveness of our proposed algorithm.

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