Inter-Sector Cooperative Relaying for Network Power Minimization

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***Abstract*—In this paper, we propose to minimize the downlink transmission power through inter-sector cooperative relaying. One common resource block (RB) is shared by two users near the boundary between two neighbouring sectors, and a half-duplex shared relay node (SRN) is introduced along the sector boundary to assist the transmission. The SRN and the two basestation (BS) sectors cooperate to transmit information to the two users. The time sharing factor and frequency sharing factor are jointly optimized to minimize the total network power while satisfying the transmission rate constraint. We also consider rate splitting technique to optimize the cooperation between SRN and BS in order to further reduce the power consumption. Joint optimization is then performed on the message splitting, time and frequency sharing factors. Numerical results show that our proposed scheme can save total network power as high as 10 dB over the system without SRN.**

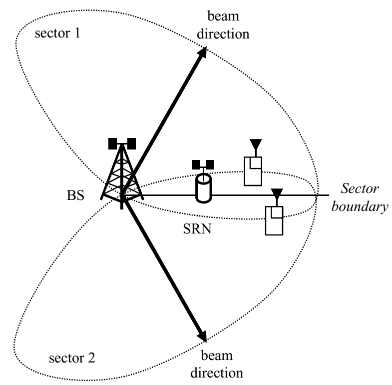

Fig. 1. Deployment of shared relay node (SRN) at sector boundary.

I. Introduction

A lot of research works have been dedicated to improve the cell edge user throughput, through, e.g., mitigating the neighbouring cells' interference by using interference alignment (or coordination) [1], coordinated beamforming [2], cooperative multipoint (CoMP) transmission [3], and so on. By jointly scheduling the transmission or processing the transmit/receive signals among the neighboring cells, significant throughput enhancement can be achieved. However, to enable joint transmission/reception among the cells, huge amount of data such as channel state information (CSI) and/or the message itself needs to be shared among the cooperating cells [4].

In a cellular system, sector antennas, co-located at the basestation (BS) with directional beam patterns, are deployed to cover the whole cell. Sector antennas with non-overlapping beam patterns enable frequency re-use among different sectors in each cell, hence increase the system capacity. However, due to non-ideal beam pattern, a user close to the sector boundary will experience higher signal attenuation than that at the sector centre. The non-ideal beam pattern also leads to inter-sector interference which further degrades the performance of sector-edge users. Nevertheless, signal leakage to the neighbouring cells has also enabled cooperative processing [5]. In this paper, we propose to use the non-ideal beam pattern characteristics and improve the sector-edge users' performance through inter-sector cooperation.

Inter-sector cooperation avoids CSI and data message sharing across backhaul links, hence is a lot easier to implement in practice than the aforementioned CoMP [6], [7]. To compensate for the power loss from the antenna beam patterns at the sector edge, we propose to use *a half-duplex shared relay node* (*SRN*) between the two sectors with a directional receive antenna and an omni-directional transmit antenna (Fig. 1). A common resource block (RB) is shared by the two sector-edge users from two neighbouring sectors. The whole transmission period needs to be divided into two phases due to the half-duplex SRN. The time sharing factor between the two phases and the frequency sharing factor between the two users are jointly optimized such that the total network power is minimized. To further reduce the total network power consumption, *rate splitting* technique [8] is applied to the messages in such a way that SRN optimally cooperates with BS. By optimally splitting the messages, the total network power is further reduced significantly. Computer simulations show that the proposed technique leads to as high as 10 dB power saving by the proposed technique.

Notations: The following notations are used throughout the paper. $C(x) = \log_2(1+x)$ and $C^{-1}(x) = 2^x - 1$ for $x \geq 0$. For $0 < a < 1$ and $\bar{a} = 1 - a$. The length n codeword of input message $\mathcal{W}$ generated at BS (SRN) is denoted by $\mathbf{x}^n_{\mathrm{B(S)}}(\mathcal{W}) = \{x_{\mathrm{B(S)},1}(\mathcal{W}), \cdots, x_{\mathrm{B(S)},i}(\mathcal{W}), \cdots, x_{\mathrm{B(S)},n}(\mathcal{W})\}$.

II. System Model

The frequency response of each channel is assumed to be constant within one RB. Each user is equipped with one receive antenna. If no orthogonalization of users is considered, the achievable rate of the uth user becomes [9]

$$R_u = C\left(\frac{p_i \gamma_{i,u}}{p_j \gamma_{j,u} + 1}\right) \text{ (bps/Hz)} \tag{1}$$

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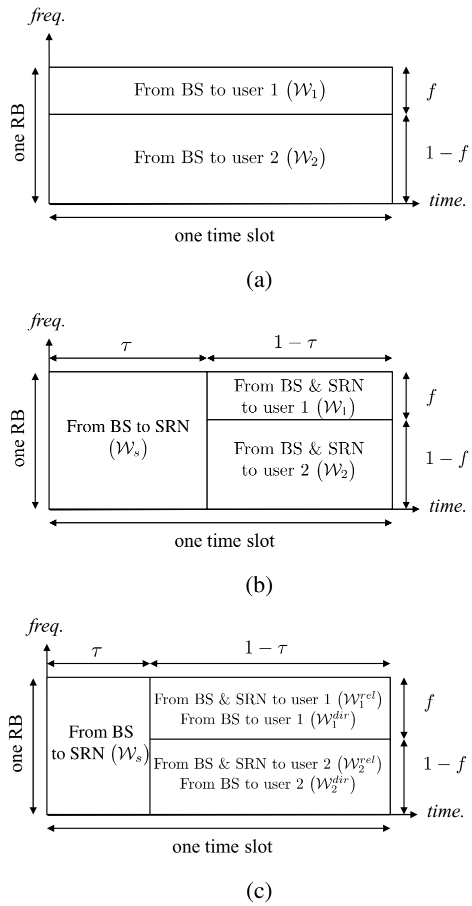

Fig. 2. Time&Frequency allocation: (a) w/o SRN, (b) w/ SRN, (c) w/ SRN&rate splitting.

by assuming Gaussian codebook is used for transmission with $j \neq i$. p_i denotes the transmission power of the ith sector antenna and $\gamma_{i,u}$ is the instantaneous channel gain between the ith sector antenna and the uth user, which is given by

$$\gamma_{i,u} \triangleq |h_{i,u}|^2 = \Gamma_{i,u} \times |g_{i,u}|^2, \tag{2}$$

where $\Gamma_{i,u} \triangleq A(\phi_{i,u}) \times d_u^{-\alpha}$ and $g_{i,u}$ is the complex channel coefficient between the ith sector antenna and the uth user. $A(\phi_{i,u})$ is the antenna gain calculated from the relative angle of the uth user from the ith sector antenna boresight, d_u is the distance of the uth user from BS, α is the pathloss exponent. To increase the signal-to-interference plus noise ratio (SINR) of the uth user, it is necessary to increase p_i or decrease p_j. This reduces the other user's SINR.

III. Orthogonal Frequency Allocation

The two users are sharing the common RB as shown in Fig. 2 (a). The RB is divided into two orthogonal sub-RBs to create orthogonal links, corresponding to adaptive frequency reuse factor (FRF) [10].

Since the sector antennas are co-located at the same BS, the message for each user can be shared among the antennas. Each user is assigned to the orthogonal sub-RB, so user may receive the signal from both sector antennas. The achievable rate of the uth user ($u \in \{1, 2\}$) is given as

$$R_u = f_u C\left(\sum_{i=1}^{2} p_{i,u}\gamma_{i,u}\right), \tag{3}$$

where the frequency sharing factor f_u indicates the fraction of RB allocated to the uth user with $\sum_{u=1}^{2} f_u = 1$ and $p_{i,u}$ is the transmission power of the ith sector antenna allocated to the uth user. Let us define the total network power as

$$\mathcal{P}_{\mathrm{OFA}} \triangleq \sum_{u=1}^{2}\left(f_u \sum_{i=1}^{2} p_{i,u}\right). \tag{4}$$

To minimize the total network power while satisfying the transmission rate constraint, the optimization problem is formulated as

$$\min_{\{f_u \geq 0, p_{i,u} \geq 0\}} \mathcal{P}_{\mathrm{OFA}} \tag{5a}$$

$$\text{s.t}: \quad R_u^{tar} \leq f_u C\left(\sum_{i=1}^{2} p_{i,u}\gamma_{i,u}\right) \quad \forall u, \tag{5b}$$

$$\sum_{u=1}^{2} f_u = 1, \tag{5c}$$

where R_u^{tar} is the target rate of the uth user. It is necessary to find the optimum set of f_u and $p_{i,u}$ such that $\mathcal{P}_{\mathrm{OFA}}$ is minimized. To simplify the optimization problem, we have the following lemma.

Lemma 1: To minimize the total network power with fixed target rate and f_u, the optimum transmission power of the ith sector antenna for the uth user is given by

$$p_{i,u\star} = \begin{cases} \frac{1}{\gamma_{i,u}} C^{-1}\left(\frac{R_u^{tar}}{f_u}\right) & \text{if } i = i_u^\star \\ 0 & \text{if } i \neq i_u^\star \end{cases} \tag{6}$$

with $i_u^\star = \arg\max_i \gamma_{i,u}$.

Proof: Let us fix f_u such that constraint (5c) is satisfied. Then, we can rewrite (5) as

$$\min_{p_{i,u} \geq 0} \sum_{i=1}^{2}\sum_{u=1}^{2} p_{i,u} \quad \text{s.t}: \sum_{i=1}^{2} p_{i,u}\gamma_{i,u} \geq \underbrace{C^{-1}\left(\frac{R_u^{tar}}{f_u}\right)}_{\text{constant}} \ \forall u. \tag{7}$$

It is clear that the solution is given by (6). ■

Although the selected sector antenna index $i_u^\star$ for the uth user's transmission is a function of the user index u, i.e., there is direct mapping from u to $i_u^\star$, we simply denote it by $i^\star$ in the rest of the paper. Lemma 1 indicates *selection of sector antenna* minimizes the required power. Then, we can simplify the problem (5) as

$$\min_{f_u \geq 0} \mathcal{P}_{\mathrm{OFA}}, \tag{8a}$$

$$\text{s.t}: p_{i^\star,u} = \frac{1}{\gamma_{i^\star,u}} C^{-1}\left(\frac{R_u^{tar}}{f_u}\right) \quad \forall u, \tag{8b}$$

$$\sum_{u=1}^{2} f_u = 1, \tag{8c}$$

where $i^\star = \arg\max_i \gamma_{i,u}$.

Since $\sum_{u=1}^{2} f_u = 1$, we set $f_1 = f$ and $f_2 = \bar{f}$. The total network power for *given* f becomes

$$\mathcal{P}^\star_{\text{OFA}}(f) = \frac{f}{\gamma_{i^\star,1}} C^{-1}\left(\frac{R_1^{tar}}{f}\right) + \frac{\bar{f}}{\gamma_{i^\star,2}} C^{-1}\left(\frac{R_2^{tar}}{\bar{f}}\right), \quad (9)$$

$\mathcal{P}^\star_{\text{OFA}}(f)$ is a convex function over f. The optimum $f^\star$ which minimizes $\mathcal{P}^\star_{\text{OFA}}(f)$ can be obtained by standard optimization approach [11]. Then the optimum transmission power at each sector antenna is calculated from (6).

IV. Shared Relay Node and Resource Allocation

In this section, *a shared relay node* (*SRN*) for two neighboring sectors is introduced and the optimization problem of the resource allocation is provided.

A. Optimization of Time/Frequency Sharing Factor

The SRN operates in a half-duplex mode. Hence, it is necessary to divide the whole transmission period into two phases as shown in Fig. 2 (b). Before the transmission, the two messages are aggregated into one *super message*. The super message is transmitted from BS to SRN in the *first phase*. After decoding the super message, BS and SRN cooperatively transmit the messages to users using orthogonal sub-RBs in the *second phase*. The first (second) phase consists of n_1 $(1-n_1)$ channel uses and the time sharing factor is defined as $\tau \triangleq \frac{n_1}{n}$.

The BS aggregates the two messages $\mathcal{W}_1$ and $\mathcal{W}_2$ into a super message $\mathcal{W}_s$ whose code rate is $R_s = \sum_{u=1}^{2} \mu_u R_u^{tar}$ where $\mu_u \in \{0,1\}$ is a variable indicating whether the message $\mathcal{W}_u$ is forwarded to SRN or not. Then the super message $\mathcal{W}_s$ is encoded into a codeword $\mathbf{w}_{\text{B}}^{n_1}(\mathcal{W}_s)$. Based on Lemma 1, $\mathbf{w}_{\text{BS}}^{n_1}(\mathcal{W}_s)$ is transmitted from the $i^\star$th sector antenna with $i^\star = \arg\max_i \gamma_{i,r}$, where $\gamma_{i,r}$ is the instantaneous channel gain between the ith sector antenna and the SRN.

The signal received by SRN at $t \in \{1,\ldots,n_1\}$ is given as

$$y_{\text{SRN},t} = h_{i^\star,r}\sqrt{p_{i^\star,r}}\, w_{\text{B},t}(\mathcal{W}_s) + n_{\text{SRN},t}, \quad (10)$$

where $p_{i^\star,r}$ is the transmission power of the $i^\star$th antenna and $n_{\text{SRN},t} \sim \mathcal{CN}(0,\sigma^2_{\text{SRN}})$ is additive white Gaussian noise (AWGN) at SRN.

The accumulated mutual information at SRN from $t=1$ to $t=n_1$ becomes

$$I\big(\mathbf{w}_{\text{B}}^{n_1}(\mathcal{W}_s); \mathbf{y}_{\text{SRN}}^{n_1}\big) = n_1 \times C\big(p_{i^\star,r}\gamma_{i^\star,r}\big), \quad (11)$$

by assuming Gaussian codebook [9]. For successful decoding of $\mathcal{W}_s$ at SRN, we need to set $R_s \le \tau C(p_{i^\star,r}\gamma_{i^\star,r})$.

Suppose the super message $\mathcal{W}_s$ is correctly decoded by SRN. SRN first dissolves the super message into two independent messages, then encodes the message $\mathcal{W}_u$ into a codeword $\mathbf{w}_{\text{S}}^{n_2}(\mathcal{W}_u)$. At the same time, BS encodes the message $\mathcal{W}_u$ into a codeword $\tilde{\mathbf{w}}_{\text{B}}^{n_2}(\mathcal{W}_u)$. All codebooks are independently generated. Then, the signals are transmitted by using the orthogonal sub-RBs.

The received signal at $t \in \{(n_1+1),\ldots,n\}$ at the uth user is expressed as

$$y_{u,t} = h_{i^\star,u}\sqrt{p_{i^\star,u}}\,\tilde{w}_{\text{B},t}(\mathcal{W}_u) + h_{r,u}\sqrt{q_u}\, w_{\text{S},t}(\mathcal{W}_u) + n_{u,t}, \quad (12)$$

where q_u is the transmission power of SRN allocated to the uth user, and $n_{u,t} \sim \mathcal{CN}(0,\sigma^2)$ is AWGN at each user.

The achievable rate of the uth user is calculated as

$$R^u = \underbrace{\bar{\tau} f_u C\big(p_{i^\star,u}\gamma_{i^\star,u} + q_u\gamma_{r,u}\big)}_{\triangleq \mathcal{R}_{\text{SRN},u}(\tau,f_u,p_{i^\star,u},q_u)}. \quad (13)$$

Let us define the total network power as

$$\mathcal{P}_{\text{SRN}} \triangleq \tau p_{i^\star,r} + \bar{\tau}\sum_{u=1}^{2} f_u\big(p_{i^\star,u} + q_u\big). \quad (14)$$

The optimization problem is formulated as

$$\begin{aligned}
&\min_{\{\tau,f_u,p_{i^\star,u}\ge 0,q_u\ge 0\}} \mathcal{P}_{\text{SRN}}, && (15a)\\
&\text{s.t}: \quad R_s \le \tau C\big(p_{i^\star,r}\gamma_{i^\star,r}\big), && (15b)\\
&\quad R_u^{tar} \le \mathcal{R}_{\text{SRN},u}(\tau,f_u,p_{i^\star,u},q_u)\ \forall u, && (15c)\\
&\quad \sum_{u=1}^{2} f_u = 1, && (15d)\\
&\quad 0 \le \tau < 1, && (15e)
\end{aligned}$$

where $R_s = \sum_{u=1}^{2}\mu_u R_u^{tar}$ and (15b) guarantees the correct decoding of the super message $\mathcal{W}_s$ at SRN in the first phase, (15c) guarantees the correct decoding of $\mathcal{W}_u$ at each user during the second phase.

Let us focus on the achievable rate of the uth user in the second phase which is given in (13). By applying the same argument as Lemma 1, we have the following power allocation strategy in the second phase.

Corollary 1: The optimum transmission power strategy in the second phase is given by

$$(p_{i^\star,u^\star}, q_{u^\star}) = \begin{cases} (0, q_{u^\star}) \text{ if } \gamma_{r,u} \ge \gamma_{i^\star,u} \\ (p_{i^\star,u^\star}, 0)\ \text{, otherwise} \end{cases} \quad (16)$$

Proof: Proof is the same as that of Lemma 1. ■

Corollary 2: The indicator variable μ_u is given as

$$\mu_u = \begin{cases} 1 \text{ if } \gamma_{r,u} \ge \gamma_{i^\star,u} \\ 0 \text{ otherwise} \end{cases} \quad (17)$$

Proof: The proof is based on Corollary 1. To minimize the total network power, the SRN should not transmit during the second phase if $\gamma_{r,u} < \gamma_{i^\star,u}$, hence the message $\mathcal{W}_u$ does not need to be forwarded to SRN during the first phase. ■

Since it is enough to allocate the power such that $\mathcal{W}_s$ $(\mathcal{W}_u)$ is correctly decoded at SRN (the uth user) in the first (second) phase, we can rewrite $\mathcal{P}_{\text{SRN}}$ as a function of τ and f as

$$\mathcal{P}^\star_{\text{SRN}}(\tau,f) = \frac{\tau}{\gamma_{i^\star,r}} C^{-1}\left(\frac{\sum_{u=1}^{2}\mu_u R_u^{tar}}{\tau}\right) + \bar{\tau}\sum_{u=1}^{2}\left\{\frac{f_u}{\gamma_u^{\max}} C^{-1}\left(\frac{R_u^{tar}}{\bar{\tau} f_u}\right)\right\} \quad (18)$$

$$\mathcal{P}^{\star}_{\mathrm{RS}}(\tau,f,R^{rel}_u)=\frac{\tau}{\gamma_{i^\star,r}}C^{-1}\left(\frac{\sum_{u=1}^{2}R^{rel}_u}{\tau}\right)+\bar{\tau}\sum_{u=1}^{2}f_u\left\{\frac{1}{\gamma^{\max}_u}C^{-1}\left(\frac{R^{tar}_u}{\bar{\tau}f_u}\right)+\left(\frac{1}{\gamma_{i^\star,u}}-\frac{1}{\gamma^{\max}_u}\right)C^{-1}\left(\frac{R^{tar}_u-R^{rel}_u}{\bar{\tau}f_u}\right)\right\}. \quad (25)$$

with $\gamma^{\max}_u=\max\{\gamma_{i^\star,u},\gamma_{r,u}\}$, $f_1=f$, and $f_2=\bar{f}$. Since the indicator variable μ_u is directly obtained from the channel condition as shown in (17), what to be optimized is τ and f only. Then the optimization problem becomes

$$\min_{0\le\tau<1,0<f<1}\mathcal{P}^{\star}_{\mathrm{SRN}}(\tau,f). \quad (19)$$

B. Introduction of Rate Splitting

To further reduce the power consumption, *rate splitting technique* is introduced. The message $\mathcal{W}_u$ is split into two sub-messages, which are denoted as $\mathcal{W}^{rel}_u$ and $\mathcal{W}^{dir}_u$ with the code rate of R^{rel}_u and R^{dir}_u. We refer to them as *relayed message* and *direct message*. The relayed message is transmitted to user *via* SRN and the direct message is transmitted to user *directly* as shown in Fig. 2 (c). The two relayed messages are aggregated into one *super relayed message* whose code rate is $R_s=\sum_{u=1}^{2}R^{rel}_u$.

In the first phase, same as in Section IV.A, it is necessary to satisfy $R_s\le\tau C\big(p_{i^\star,r}\gamma_{i^\star,r}\big)$ such that the super relayed message is correctly decoded at SRN.

Suppose the super relayed message $\mathcal{W}_s$ is correctly decoded by SRN. SRN encodes the relayed message $\mathcal{W}^{rel}_u$ into a codeword $\mathbf{v}^{n_2}_{\mathrm{S}}\big(\mathcal{W}^{rel}_u\big)$. BS encodes the direct message $\mathcal{W}^{dir}_u$ into a codeword $\mathbf{u}^{n_2}_{\mathrm{B}}\big(\mathcal{W}^{dir}_u\big)$ and encodes the relayed message $\mathcal{W}^{rel}_u$ into a codeword $\tilde{\mathbf{w}}^{n_2}_{\mathrm{B}}\big(\mathcal{W}^{rel}_u\big)$.

The received signal at $t\in\{(n_1+1),\dots,n\}$ at the uth user is expressed as

$$y_{u,t}=h_{i^\star,u}\Big\{\sqrt{p^{rel}_{i^\star,u}}\tilde{w}_{\mathrm{B},t}\big(\mathcal{W}^{rel}_u\big)+\sqrt{p^{dir}_{i^\star,u}}u_{\mathrm{B},t}\big(\mathcal{W}^{dir}_u\big)\Big\} + h_{r,u}\sqrt{q_u}v_{\mathrm{S},t}\big(\mathcal{W}^{rel}_u\big)+n_{u,t}. \quad (20)$$

where $p^{rel}_{i^\star,u}$ and $p^{dir}_{i^\star,u}$ are the transmission powers allocated to the relayed and direct messages at the $i^\star$th sector antenna.

Lemma 2: To minimize the total network power in the second phase, it is optimum to use successive decoding with the relayed message being first decoded.

Proof: Proof is based on multiple access channel (MAC) [12]. Due to the limited space, the detail is omitted here. ■

Then, the achievable rate of the relayed message and the direct message of the uth user with the fixed decoding order is respectively given as

$$\begin{cases}R^{rel}_u &=\bar{\tau}f_uC\left(\frac{q_u\gamma_{r,u}+p^{rel}_{i^\star,u}\gamma_{i^\star,u}}{p^{dir}_{i^\star,u}\gamma_{i^\star,u}+1}\right),\\ R^{dir}_u &=\bar{\tau}f_uC\big(p^{dir}_{i^\star,u}\gamma_{i^\star,u}\big).\end{cases} \quad (21)$$

Let us define the achievable rate region of the relayed message and the direct message of the uth user as

$$\mathcal{R}_{\mathrm{RS},u}(\tau,f_u,\mathbf{p}_{\mathrm{RS},u},q_u) =\left\{\begin{matrix}R^{rel}_u\le\bar{\tau}f_uC\left(\frac{q_u\gamma_{r,u}+p^{rel}_{i^\star,u}\gamma_{i^\star,u}}{p^{dir}_{i^\star,u}\gamma_{i^\star,u}+1}\right)\\ R^{dir}_u\le\bar{\tau}f_uC\big(p^{dir}_{i^\star,u}\gamma_{i^\star,u}\big)\end{matrix}\right\} \quad (22)$$

with $\mathbf{p}_{\mathrm{RS},u}=(p^{rel}_{i^\star,u},p^{dir}_{i^\star,u})$.

Then, the optimization problem is formulated as

$$\min_{\{\tau,f_u,R^{rel}_u,\mathbf{p}_{\mathrm{RS},u}\ge\mathbf{0},q_u\ge0\}}\mathcal{P}_{\mathrm{RS}} \quad (23a)$$

$$\text{s.t}:\quad R_s\le\tau C(p_{i^\star,r}\gamma_{i^\star,r}), \quad (23b)$$

$$(R^{rel}_u,R^{dir}_u)\in\mathcal{R}_{\mathrm{RS},u}(\tau,f_u,\mathbf{p}_{\mathrm{RS},u},q_u)\ \forall u, \quad (23c)$$

$$0\le R^{rel}_u\le R^{tar}_u, \quad (23d)$$

$$\sum_{u=1}^{2}f_u=1, \quad (23e)$$

where $R_s=\sum_{u=1}^{2}R^{rel}_u$ and

$$\mathcal{P}_{\mathrm{RS}}\triangleq\tau p_{i^\star,r}+\bar{\tau}\sum_{u=1}^{2}f_u\big(p^{rel}_{i^\star,u}+p^{dir}_{i^\star,u}+q_u\big). \quad (24)$$

Following the similar step in Section IV.A, the total network power can be rewritten as (25) (shown at the top of this page) where $\gamma^{\max}_u=\max\{\gamma_{i^\star,u},\gamma_{r,u}\}$, $f_1=f$, and $f_2=\bar{f}$. Finally we obtain the following optimization problem.

$$\min_{0\le\tau<1,0<f<1,0\le R^{rel}_u\le R^{tar}_u}\mathcal{P}^{\star}_{\mathrm{RS}}(\tau,f,R^{rel}_u). \quad (26)$$

From the view point of practical implementation, it is undesirable to change both the time sharing factor and the frequency sharing factor. We also consider the system with the fixed frequency sharing factor, i.e., $f=0.5$. Then the optimization problem becomes

$$\min_{0\le\tau<1,0\le R^{rel}_u\le R^{tar}_u}\mathcal{P}^{\star}_{\mathrm{RS}}(\tau,0.5,R^{rel}_u). \quad (27)$$

V. Simulation Results

In this section, the computer simulation results are provided. Two adjacent sectors are considered and the cell radius is 1 km. Each user is randomly located within each sector with the maximum angle spread from the sector boundary of $\theta_{\max}=10$ degrees. Same target rates are assumed for the two users. The SRN is located at the sector boundary and the distance from BS is parameterized and denoted by d_{SRN} m. The pathloss exponent is set to 3.5. The noise levels at users and SRN are set to -131.5 dBm/Hz and -134.5 dBm/Hz, respectively. The antenna pattern of the sector antenna at BS is characterized as

$$A(\phi)=-\min\big[12(\phi/\phi_{3\mathrm{dB}})^2,A_m\big]\ (\mathrm{dB}) \quad (28)$$

with $\phi_{3\mathrm{dB}}=70$ degrees and $A_m=25$ dB [13]. The transmit antenna of SRN is an omni antenna and the receive antenna of SRN is a directional antenna with 7 dBi gain [13].

In Fig. 3, the impact of d_{SRN} on the average total network power is presented. The target rate is set to $R^{tar}_u=1$ bps/Hz.

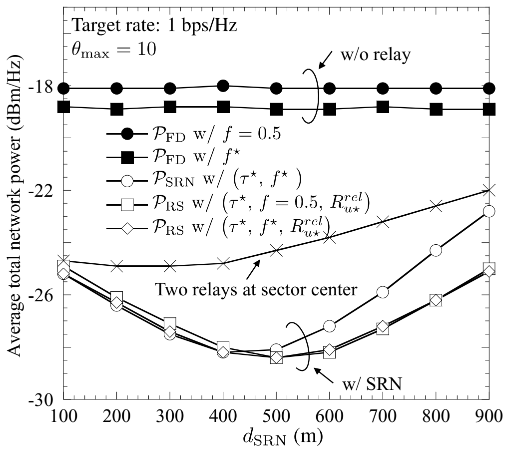

Fig. 3. Impact of the relay position on the average total network power.

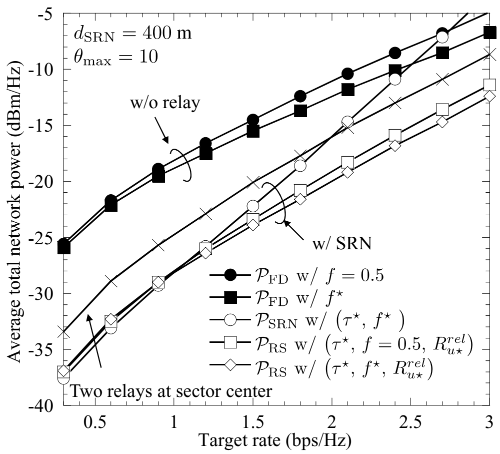

Fig. 4. Average total network power as a function of the target rate.

For comparison, the performance when one dedicated relay is deployed at each sector center is shown as a conventional approach. In this case, one half of RB is allocated to each sector, i.e., $f = 0.5$. The time sharing factor and message splitting are jointly optimized *within* each sector, i.e., *independent* from each other. From the figure, we can see that there is an optimum range of d_{SRN} which minimizes the total network power. If d_{SRN} is small, the transmission power at BS can be reduced in the first phase because of the small pathloss to the SRN, however, the distance between SRN and users may become longer and the transmission power at SRN needs to be higher. On the other hand, if d_{SRN} is large, the transmission power at SRN can be saved while the larger transmission power is necessary at BS.

The average total network power is shown in Fig. 4 as a function of the target rate. Based on the result in Fig. 3, d_{SRN} is set to 400 m. From the figure, we can see that by introducing SRN and optimizing τ and f, significant power saving is achieved for the whole range of the target rate. However, as the target rate increases, the power saving reduces and even becomes worse than the system without relay when rate splitting is not incorporated. This is because the super message whose code rate is higher than or equal to the original message needs to be reliably transmitted from BS to SRN and each message needs to be transmitted from SRN to each user. On the other hand, by introducing rate splitting, such performance degradation can be avoided. This is because the code rates of the relayed and the direct messages are adaptively changed based on the channel condition among the nodes.

The figure shows the power saving more than 7 dB and as high as 10 dB compared to the system w/o SRN is achieved by introducing SRN. Furthermore, by jointly optimizing τ and R_r^u, the significant power saving is achieved even when f is fixed to 0.5. From the figure, the proposed SRN approach provides larger power saving than the conventional approach, where one dedicated relay is deployed at the sector center.

VI. Conclusion

In this paper, inter-sector cooperative relaying was proposed to minimize the downlink power consumption. A half-duplex shared relay node (SRN) for the two neighboring sectors was introduced at the sector boundary to assist the transmission for two users. To optimize the cooperation between BS and SRN, rate splitting technique was introduced. Through joint optimization on the message splitting, time and frequency sharing factors, it was shown that the total network power can be saved as high as 10 dB over the system without SRN.

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