Enhancing Achievable Sum-Rate by Making Strong and Weak Interference in an Ad-Hoc Network

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***Abstract*—In this study, we enhance achievable sum-rate in an *ad hoc* network consisting of two source-destination pairs and *k* half-duplex Decode-and-Forward (DF) relays. We assume that two receivers use strong interference cancellation technique and can cancel strong interference. Then, in order to enhance the achievable sum-rate, we propose a novel relay selection scheme that can make Strong and Weak Interference (SWI) at both receivers. Furthermore, in the proposed scheme, we aim to allocate resources fairly among two transmitters. Simulation results show that with the proposed relay selection scheme, SWI can be made with high probability (greater than 0.95 in crowded environments) at both receivers. Also simulations show that by using the proposed scheme, the transmitters achieve sufficient rates and their achievable rates increase linearly with power of relays.**

***Keywords*—Multi relay selection, sum-rate enhancing, two source-desination pairs, SWI scheme, decode-and-forward;**

I. INTRODUCTION

In the last few years, the demand for mobile communication services has increased drastically. Most of these services need fast and reliable communications [1-2]. In order to achieve these goals, the system should be able to provide reliable and high data rate communication with some constraints. Beside system resources limitations, such as power of nodes and available spectrum, interference and fading are two destructive effects that arise from other users and the natural features of environment [3]. On the other hand, spatial diversity is a key technique to combat the fading effects, consequently efficiently improving data rate and reliability of communication [4]. Cooperative communications is one of the promising techniques that uses single-antenna users to realize spatial diversity [5]. Opportunistic relay selection is one of the efficient techniques that has been proposed to realize cooperative communications and consequently spatial diversity on cooperative networks [6]. In cooperative networks with single transmitter-receiver, different relay selection strategies have been proposed for both Amplify-and-Forward (AF) and DF schemes [6-15]. In [7], a relay selection scheme based on forward (transmitter-relays) channel gains have proposed for DF networks. According to their scheme, relays that their forward channel gains be greater than a threshold, cooperate in communication. In [9-11], relay selection has done for maximizing the received Signal to Noise Ratio (SNR) at receivers. In [11] relay selection and relay ordering proposed for SNR maximization. In some works, maximizing the minimum channel gains of forward and backward (relays-receiver) channels are used for relay selection [6], [12]. Relay selection based on minimizing upper band of symbol error probability has been studied in [13]. Single and multiple relay selection based on MMSE criterion and best SNR have been investigated in [8]. When the nodes are multiple-antennas, the relay selection based on maximizing network capacity and minimizing the pairwise error probability is studied in [16] and [14] respectively.

In this study, we enhance the achievable sum-rate in an *ad-hoc* network consisting of two source-destination pairs and *k* half-duplex DF relays. To this aim, we propose a novel and practical scheme for relay selection in the aforementioned system model. In this paper, the proposed relay selection scheme is named SWI scheme. There is major difference between prior works and our work, all prior works studied relay selection for networks with single transmitter-receiver. In our system model, in each transmission two relays are selected for each transmitter by using the proposed scheme. Then, the transmitters use the selected relays and send signal to their corresponding receivers simultaneously. It is assumed that, the receivers are using Maximum Ratio Combining (MRC) technique and combine all received signals from the selected relays. We assumed that receivers exploit strong interference cancellation technique, therefore unlike other strategies, in some cases our proposed scheme intentionally selects relays that make strong interference at receivers. In fact, our proposed scheme, designed to make SWI at both receivers. As a result, in order to make strong interference at receivers, we select relays that make strong interference at receivers.

In SWI scheme we aimed to reach two main goals. Firstly, making SWI at both receivers, and secondly, fair resource allocation among two transmitters. We assumed that the power of relays are limited. After relay selection via SWI scheme, SWI is happen at both receivers and the receivers use strong interference cancellation technique and cancel strong interference. Also, in order to allocate resources fairly between

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the transmitters, relay selection in SWI scheme is performed with priority between the transmitters that will be described with more details in section III.

The rest of this paper is organized as follows: section II, describes transmission model. A novel multi relay selection scheme and its achievable rates are expressed in section III. Simulations and numerical results are reported in IV, and finally, conclusions are drawn in Section V.

Notation: We used normal letters (e.g., a) for scalars and boldface letters to represent vectors (e.g., $\boldsymbol{a}$). The letter $\mathbb{S}$ is used to represent sets. For nodes X and Y, $\mathcal{L}(X \rightarrow Y)$ denotes a signal link from X to Y, and $\mathcal{I}([X, Y])$ denotes the mutual information of the link $\mathcal{L}(X \rightarrow Y)$.

II. TRANSMISSION MODEL

We consider a two hop *ad hoc* network with two source-destination pairs and k half-duplex DF relays, as shown in Fig. 1. We assume that all nodes equipped with single antenna. Each transmitter wishes to transmit signal to its corresponding receiver. It is assumed that the distances between the sources and the destinations are very long and there is not direct link between the transmitters and the receivers. In each transmission, two relays are selecting for each transmitter using SWI scheme that will be described in section III. Selected relays for each transmitter have access to codebook of corresponding transmitter. After relay selection, the transmitters use the selected relays and send signals to intended receivers simultaneously. The transmission procedure consists of two stages. In the first stage, each transmitter sends its signal to the corresponding selected relays. In the second stage, selected relays forward the detected version of received signal to the destinations. The channel coefficient from first source S_1 to lth relay r_l is denoted by h_{S_1,r_l}, the channel coefficient from second source S_2 to lth relay r_l is denoted by $g_{\mathrm{S}_2,\mathrm{r}_l}$, the channel coefficient from lth relay r_l to first destination D_1 is denoted by $a_{\mathrm{r}_l,\mathrm{D}_1}$, and the channel coefficient from lth relay r_l to second destination D_2 is denoted by $b_{\mathrm{r}_l,\mathrm{D}_2}$for $l = 1,2, \dots, k$. Also, it is assumed that all channels coefficients are fixed over coherence time. All of noises are modeled as an Additive White Gaussian Noise (AWGN) with unit variance and zero mean.

We suppose $\mathcal{I}([\mathrm{S}_1, \mathrm{r}_m])$ and $\mathcal{I}([\mathrm{S}_2, \mathrm{r}_n])$ denote the mutual information of the links $\mathcal{L}(\mathrm{S}_1 \rightarrow \mathrm{r}_m)$ and $\mathcal{L}(\mathrm{S}_2 \rightarrow \mathrm{r}_n)$ respectively, also $\mathcal{I}([\mathrm{r}_l, \mathrm{D}_1])$ and $\mathcal{I}([\mathrm{r}_l, \mathrm{D}_2])$ denote the mutual information of the links $\mathcal{L}(\mathrm{r}_l \rightarrow \mathrm{D}_1)$ and $\mathcal{L}(\mathrm{r}_l \rightarrow \mathrm{D}_2)$ respectively, for $l = 1,2, \dots, k$. As well as, $\mathcal{I}([\mathrm{S}_1, \mathrm{D}_1])$ and $\mathcal{I}([\mathrm{S}_2, \mathrm{D}_2])$ denote the end-to-end mutual information $\mathrm{S}_1$and S_2 respectively. The values of $\mathcal{I}([\mathrm{S}_1, \mathrm{r}_m])$ and $\mathcal{I}([\mathrm{S}_2, \mathrm{r}_n])$ can be written as,

$$\mathcal{I}([\mathrm{S}_1, \mathrm{r}_m]) = \log_2\left(1 + P_{\mathrm{S}_1}\left|h_{\mathrm{S}_1,\mathrm{r}_m}\right|^2\right), \quad m = 1,2, \dots, k \tag{1}$$

$$\mathcal{I}([\mathrm{S}_2, \mathrm{r}_n]) = \log_2\left(1 + P_{\mathrm{S}_2}\left|g_{\mathrm{S}_2,\mathrm{r}_n}\right|^2\right), \quad n = 1,2, \dots, k \tag{2}$$

where P_{S_1} and P_{S_2} are the transmit power of S_1 and S_2

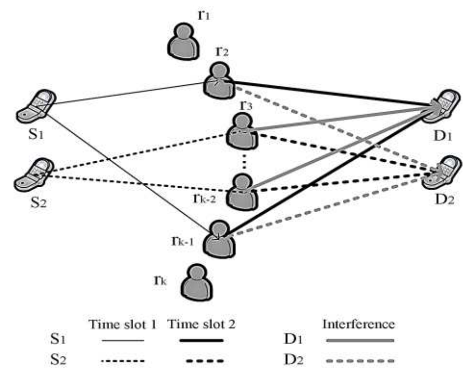

Fig. 1. A network of K relays and two source-destination pairs.

respectively. In this paper, in order to decrease the complexity of system, interference is ignored in the relay nodes. Without loss of generality, it is assumed that after relay selection, relays r_2 and r_{k-1} are selected for first source S_1, and relays r_3 and r_{k-2} are selected for second source S_2. In the next section, we will propose a novel relay selection scheme for this system model. Now, the values of $\mathcal{I}([\mathrm{S}_1, \mathrm{D}_1])$ and $\mathcal{I}([\mathrm{S}_2, \mathrm{D}_2])$ can be written as,

$$\mathcal{I}([\mathrm{S}_1, \mathrm{D}_1]) = \frac{1}{2}\log_2\left(1 + \frac{p_{r_2}|a_{2D_1}|^2 + p_{r_{k-1}}|a_{\mathrm{k}-1D_1}|^2}{1 + p_{r_3}|a_{3D_1}|^2 + p_{r_{k-2}}|a_{\mathrm{k}-2D_1}|^2}\right), \tag{3}$$

$$\mathcal{I}([\mathrm{S}_2, \mathrm{D}_2]) = \frac{1}{2}\log_2\left(1 + \frac{p_{r_3}|b_{3D_2}|^2 + p_{r_{k-2}}|b_{\mathrm{k}-2D_2}|^2}{1 + p_{r_2}|b_{2D_2}|^2 + p_{r_{k-1}}|b_{\mathrm{k}-1D_2}|^2}\right). \tag{4}$$

where p_{r_i} is the power of ith relay, a_{iD_1} and $b_{iD_2}$are the complex channel coefficient from ith relay to D_1 and D_2 respectively. Note that in (3) and (4) it is assumed that,

$$\mathcal{I}([\mathrm{S}_1, \mathrm{r}_i]) \geq \mathcal{I}([\mathrm{r}_i, \mathrm{D}_1]),\ \mathcal{I}([\mathrm{S}_1, \mathrm{r}_i]) \geq \mathcal{I}([\mathrm{r}_i, \mathrm{D}_2]), \tag{5}$$

$$\mathcal{I}([\mathrm{S}_2, \mathrm{r}_j]) \geq \mathcal{I}([\mathrm{r}_j, \mathrm{D}_1]),\ \mathcal{I}([\mathrm{S}_2, \mathrm{r}_j]) \geq \mathcal{I}([\mathrm{r}_j, \mathrm{D}_2]). \tag{6}$$

In other words, for selected relays i and j for S_1 and S_2 respectively, it is assumed that mutual information of the $\mathcal{L}(\mathrm{S}_1 \rightarrow \mathrm{r}_i)$ link is greater than both $\mathcal{I}([\mathrm{r}_i, \mathrm{D}_1])$ and $\mathcal{I}([\mathrm{r}_i, \mathrm{D}_2])$ and also mutual information of the $\mathcal{L}(\mathrm{S}_2 \rightarrow \mathrm{r}_j)$ link is greater than both $\mathcal{I}([\mathrm{r}_j, \mathrm{D}_1])$ and $\mathcal{I}([r_j, D_2])$. In order to satisfy this conditions, it can be supposed that there is no power constraint on the sources. But in some cases this is not reasonable assumption, and power of sources are limited. In our proposed scheme, there are some parameters that help to provide situation which the assumptions (5) and (6) will be held with high probability. Now, using (3) and (4), and assumptions (5) and (6) the end-to-end sum-rate for two transmitters can be written as follows,

$$R_{sum} = \mathcal{I}([\mathrm{S}_2, \mathrm{D}_2]) + \mathcal{I}([\mathrm{S}_2, \mathrm{D}_2]). \tag{7}$$

Using (3) and (4), the end-to-end sum-rate can be written as,

$$R_{sum} = \frac{1}{2}\left(\log_2\left(1 + \frac{p_{r_2}|a_{2D_1}|^2 + p_{r_{k-1}}|a_{\mathrm{k}-1D_1}|^2}{1 + p_{r_3}|a_{3D_1}|^2 + p_{r_{k-2}}|a_{\mathrm{k}-2D_1}|^2}\right) + \log_2\left(1 + \frac{p_{r_3}|b_{3D_2}|^2 + p_{r_{k-2}}|b_{\mathrm{k}-2D_2}|^2}{1 + p_{r_2}|b_{2D_2}|^2 + p_{r_{k-1}}|b_{\mathrm{k}-1D_2}|^2}\right)\right) \tag{8}$$

Note that we multiply the sum-rate by $\frac{1}{2}$, because communication from sources to destinations is done during two time slots.

III. SWI SCHEME AND ACHIEVABLE RATES

In session II, it is assumed that two relays were selected somehow for each transmitter. In this session, we propose a novel relay selection scheme for proposed system model in Fig.1. Our proposed scheme is different as other existing schemes [6-15]. We design this scheme for enhancing achievable sum-rate and fair resource allocation. In order to enhancing achievable sum-rate we aim to make SWI at both receivers. Then, since receivers use strong interference cancellation technique, they can cancel strong interference and achieve sufficient rate.

Depend on the values of interference power at destinations interference channels classified to different types. In [2] different types of two-user Gaussian interference channel (GIC) classifications are provided. According to the normalized channel gains that also named interference gain, two-user GIC is classified into strong, weak, mixed, one-sided, and degraded GIC. In two-user GIC, for particular case that power of sources be the same and also power of noises at destinations be the same, It has been shown that if the ratio $\sqrt{\frac{|h_{21}|^2}{|h_{11}|^2}}$ at first destination, and the ratio $\sqrt{\frac{|h_{12}|^2}{|h_{22}|^2}}$ at second destination, jointly be greater than 1, the interference classified as a strong interference. Where h_{ii} shows the complex channel coefficients between each pair source-destination and h_{ij} shows the interference complex channel coefficients between the nodes i and j [2]. In SWI scheme we aim to achieve strong interference at both receivers. Furthermore, we try to allocate network resources fairly between two transmitters. To this end, relay selection is performed with priority between two transmitters. In relay selection procedure it is assumed that all channel coefficients are available at processing center. The SWI scheme consists of four phases that can be expressed as follows,

Phase 1: Initially, we find suitable relays for each one of nodes S_1, S_2, D_1, and D_2 as follows,

$$\mathbb{S}_1: \left\{r_i \in \mathbb{S}_1 \quad \text{if} \quad |h_{\mathrm{S}1i}|^2 \geq \mathrm{H}_{\mathrm{th}_{\mathrm{S}1}}\right\}, \; i = 1,2,\ldots,k \tag{9}$$

$$\mathbb{S}_2: \left\{r_i \in \mathbb{S}_2 \quad \text{if} \quad |h_{\mathrm{S}2i}|^2 \geq \mathrm{H}_{\mathrm{th}_{\mathrm{S}2}}\right\}, \; i = 1,2,\ldots,k \tag{10}$$

$$\mathbb{S}_3: \left\{r_i \in \mathbb{S}_3 \quad \text{if} \quad |h_{i\mathrm{D}1}|^2 \geq \mathrm{H}_{\mathrm{th}_{\mathrm{D}1}}\right\}, \; i = 1,2,\ldots,k \tag{11}$$

$$\mathbb{S}_4: \left\{r_i \in \mathbb{S}_4 \quad \text{if} \quad |h_{i\mathrm{D}2}|^2 \geq \mathrm{H}_{\mathrm{th}_{\mathrm{D}2}}\right\}, \; i = 1,2,\ldots,k \tag{12}$$

where $\mathbb{S}_1$, $\mathbb{S}_2$, $\mathbb{S}_3$ and $\mathbb{S}_4$ are the sets of suitable relays for S_1, S_2, D_1 and D_2, respectively. And $\mathrm{H}_{\mathrm{th}_{\mathrm{S}1}}$, $\mathrm{H}_{\mathrm{th}_{\mathrm{S}2}}$, $\mathrm{H}_{\mathrm{th}_{\mathrm{D}1}}$ and $\mathrm{H}_{\mathrm{th}_{\mathrm{D}2}}$ are threshold for norm of channels coefficients for links $\mathcal{L}(\mathrm{S}_1 \to \mathrm{r}_i)$, $\mathcal{L}(\mathrm{S}_2 \to \mathrm{r}_i)$, $\mathcal{L}(\mathrm{r}_i \to \mathrm{D}_1)$ and $\mathcal{L}(\mathrm{r}_i \to \mathrm{D}_2)$ respectively, for $i = 1,2,\ldots,k$. Note that with choose suitable values for $\mathrm{H}_{\mathrm{th}_{\mathrm{S}1}}$, $\mathrm{H}_{\mathrm{th}_{\mathrm{S}2}}$, $\mathrm{H}_{\mathrm{th}_{\mathrm{D}1}}$ and $\mathrm{H}_{\mathrm{th}_{\mathrm{D}2}}$ we can control most parameters of the network. In section IV, we will describe that how these values can help to increase performance of SWI scheme.

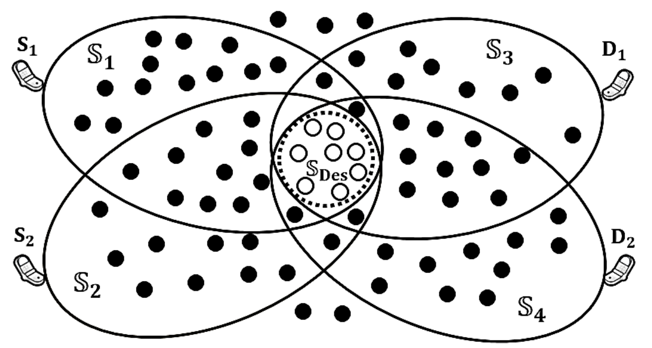

Fig. 2. Relay selection by SWI stratagy in our system model. $\mathbb{S}_1$: Set of suitable relays for S_1, $\mathbb{S}_2$: Set of suitable relays for S_2, $\mathbb{S}_3$: Set of suitable relays for D_1, $\mathbb{S}_4$: Set of suitable relays for D_2, $\mathbb{S}_{\mathrm{Des}}$: Suitable relays for all nodes.

Phase 2: Using (9) – (12), the intersection of sets $\mathbb{S}_1$, $\mathbb{S}_2$, $\mathbb{S}_3$, and $\mathbb{S}_4$ can be express as following

$$\begin{aligned} \mathbb{S}_{\mathrm{Des}} &= \cap_{i=1}^{4} \mathbb{S}_i \\ &= \mathbb{S}_1 \cap \mathbb{S}_2 \cap \mathbb{S}_3 \cap \mathbb{S}_4 \end{aligned} \tag{13}$$

where $\mathbb{S}_{\mathrm{Des}}$ is the set containing suitable relays for all S_1, S_2, D_1, and D_2. A graphical representation of $\mathbb{S}_{\mathrm{Des}}$ is illustrated in Fig. 2. Note that, the number of $\mathbb{S}_{\mathrm{Des}}$ elements is showed by n.

Phase 3: Then, using elements of $\mathbb{S}_{\mathrm{Des}}$, we define two gain sets $\mathbb{S}_{\mathrm{Gain1}}$ and $\mathbb{S}_{\mathrm{Gain2}}$ as follows,

$$\mathbb{S}_{\mathrm{Gain1}}: \left\{p_{r_m} \times \left|a_{mD_1}\right|^2, \; m = 1,2,\ldots,n\right\} \tag{14}$$

$$\mathbb{S}_{\mathrm{Gain2}}: \left\{p_{r_m} \times \left|b_{mD_2}\right|^2, \; m = 1,2,\ldots,n\right\} \tag{15}$$

where p_{r_m} is the power of mth relay of $\mathbb{S}_{\mathrm{Des}}$, a_{mD_1} is the channel coefficient from mth relay to first destination D_1, and b_{mD_2} is the channel coefficient from mth relay to second destination D_2, for $m = 1,2,\ldots,n$.

Phase 4: In this phase we aim to select two relays for each transmitter. In order to make SWI at both receivers, we intentionally select relays that make strong interference on unintended receiver, and to allocate resources fairly between the transmitters, relay selection is performed with priority between the transmitters. In order words, order of relay selection for transmitters is important. Relay selection procedure consists of four steps. These steps can be expressed as follows,

$$\text{if} \;\; \mathrm{P}_{\mathrm{S}1} \leq \mathrm{P}_{\mathrm{S}2} \tag{16}$$

$$r_1^{\{\mathrm{S}_1\}} = \underset{r_m}{\arg}\left(\max_m \left\{\mathbb{S}_{\mathrm{Gain2}}\right\}\right), \quad m \in \left\{\mathbb{S}_{\mathrm{Des}}\right\}$$

$$r_1^{\{S_2\}} = \arg_{r_q}\left(\min_q \left\{\mathbb{S}_{\text{Gain1}}\right\}\right), \quad q \in \left\{\left\{\mathbb{S}_{\text{Des}}\right\} - r_1^{\{S_1\}}\right\}$$

$$r_2^{\{S_2\}} = \arg_{r_i}\left(\max_i \left\{\mathbb{S}_{\text{Gain1}}\right\}\right), \quad i \in \left\{\left\{\mathbb{S}_{\text{Des}}\right\} - r_1^{\{S_1\}} - r_1^{\{S_2\}}\right\}$$

$$r_2^{\{S_1\}} = \arg_{r_j}\left(\min_j \left\{\mathbb{S}_{\text{Gain2}}\right\}\right), \quad j \in \left\{\left\{\mathbb{S}_{\text{Des}}\right\} - r_1^{\{S_1\}} - r_1^{\{S_2\}} - r_2^{\{S_2\}}\right\}$$

else $(P_{S2} \le P_{S1})$ (17)

$$r_1^{\{S_2\}} = \arg_{r_m}\left(\max_m \left\{\mathbb{S}_{\text{Gain1}}\right\}\right), \quad m \in \left\{\mathbb{S}_{\text{Des}}\right\}$$

$$r_1^{\{S_1\}} = \arg_{r_q}\left(\min_q \left\{\mathbb{S}_{\text{Gain2}}\right\}\right), \quad q \in \left\{\left\{\mathbb{S}_{\text{Des}}\right\} - r_1^{\{S_2\}}\right\}$$

$$r_2^{\{S_1\}} = \arg_{r_i}\left(\max_i \left\{\mathbb{S}_{\text{Gain2}}\right\}\right), \quad i \in \left\{\left\{\mathbb{S}_{\text{Des}}\right\} - r_1^{\{S_2\}} - r_1^{\{S_1\}}\right\}$$

$$r_2^{\{S_2\}} = \arg_{r_j}\left(\min_j \left\{\mathbb{S}_{\text{Gain1}}\right\}\right), \quad j \in \left\{\left\{\mathbb{S}_{\text{Des}}\right\} - r_1^{\{S_2\}} - r_1^{\{S_1\}} - r_2^{\{S_1\}}\right\}$$

where $r_1^{\{S_1\}}$ and $r_2^{\{S_1\}}$ are two selected relays for S_1, and $r_1^{\{S_2\}}$ and $r_2^{\{S_2\}}$ are two selected relays for S_2, and $\mathbb{S}_{\text{Gain1}}$ and $\mathbb{S}_{\text{Gain2}}$ are the gain sets that defined in the third phase. Note that m shows the index of selected relay in first step, q shows the index of selected relay in second step, i shows the index of selected relay in third step, and j shows the index of selected relay in fourth step.

Now, by assuming that relay selection is performed by SWI scheme, end-to-end achievable sum-rate in (8) and can be rewritten as follows,

$$R_{sum} = \frac{1}{2}\log_2\left(1 + \frac{\overbrace{p_{r_2}|a_{2D_1}|^2}^{Strong} + \overbrace{p_{r_{k-1}}|a_{k-1D_1}|^2}^{Weak}}{1 + \underbrace{p_{r_3}|a_{3D_1}|^2}_{Weak} + \underbrace{p_{r_{k-2}}|a_{k-2D_1}|^2}_{Strong}}\right)$$
$$+\frac{1}{2}\log_2\left(1 + \frac{\overbrace{p_{r_3}|b_{3D_2}|^2}^{Strong} + \overbrace{p_{r_{k-2}}|b_{k-2D_2}|^2}^{Weak}}{1 + \underbrace{p_{r_2}|b_{2D_2}|^2}_{Weak} + \underbrace{p_{r_{k-1}}|b_{k-1D_2}|^2}_{Strong}}\right). \quad (18)$$

Note that, without loss of generality, it is assumed that after relay selection, relays r_2 and r_{k-1} are selected for first source S_1, and relays r_3 and r_{k-2} are selected for second source S_2, that mean $r_1^{\{S_1\}} = r_2$, $r_1^{\{S_1\}} = r_{k-1}$, $r_1^{\{S_2\}} = r_3$, and $r_2^{\{S_2\}} = r_{k-2}$.

Then, since receivers use strong interference cancellation technique, they can cancel strong interference. As a result, end-to-end achievable sum-rate in (18) can be written as follows,

$$R_{sum-SWI} = \frac{1}{2}\log_2\left(1 + \frac{E_2|a_{2D_1}|^2 + E_{k-1}|a_{k-1D_1}|^2}{1 + E_3|a_{3D_1}|^2}\right) +$$
$$\frac{1}{2}\log_2\left(1 + \frac{E_2|a_{2D_1}|^2 + E_{k-1}|a_{k-1D_1}|^2}{1 + E_3|a_{3D_1}|^2}\right). \quad (19)$$

Note that, since the receivers are using strong interference cancellation technique, so terms of strong interferences have been omitted in denominator of frictions.

The SWI scheme is designed to select two relays for each transmitter. This is first scheme that proposed for relay selection for an ad hoc network with two source-destination pairs and k half-duplex relays. As we mentioned, we aimed to make SWI at both receivers, with selecting just one relay for each transmitter we could not reach our goal. On the other side, with selecting more than two relays for each transmitter the complexity of system increases significantly, and resource allocation could not performed fairly between two transmitters.

IV. SIMULATIONS AND NUMERICAL RESULTS

In this section, in order to evaluate the performance of SWI scheme some simulations and numerical results are provided. Simulations results reported for two scenarios. In the first scenario, we investigate the probability of strong interference at the receivers. In fact, we aim to show that with which probability strong interference will be happened at both receivers. In the second scenario, we evaluate end-to-end achievable sum-rate for case that relay selection is performed via SWI scheme. We assume that power of relays and all channel coefficients are known at a processing center and processing center selects two relay for each transmitter via SWI scheme. In all simulations, we take $H_{th_{S_1}} = H_{th_{S_2}} = H_{th_{D_1}} = H_{th_{D_2}} = 0.5$, and the power of noise at all nodes are assumed equal to 0 dBw. All channel coefficients are realized randomly with Rayleigh fading distributed and in each iteration of simulations, they are generated as i.i.d complex Gaussian random variables with variances 0 dB.

A. Probability of strong interference at the receivers

We now consider the probability of strong interference at the both receivers. In fact, the main result of this section is that relay selection via SWI scheme can make strong interference in the both receivers. In this scenario, power of each relay is random

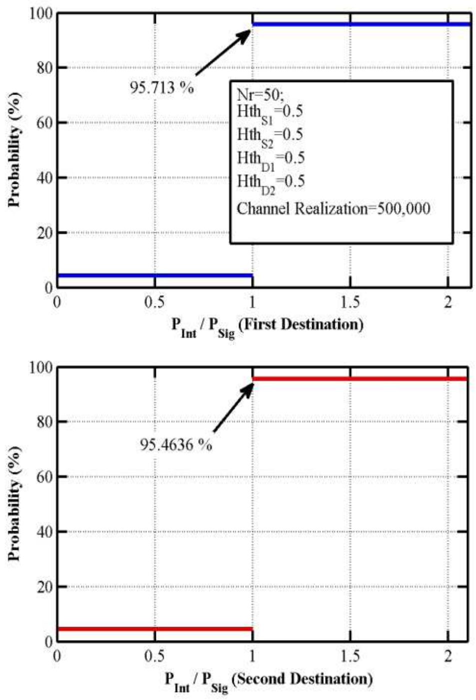

Fig. 3. The probability of strong interference at the both receivers for $N_r = 50$.

variable with uniform distribution from [0 10] dBw. All results reported for 500,000 channel realization.

Fig. 3 to Fig. 5 show the probability of strong interference at the both receivers for $N_r = 50, 100, 200$. In all figures, horizontal axis is the power of strong interference to power of weak and strong desire signals ratio $\frac{P_{Int}}{P_{Sig}} = \frac{\text{Power of strong interference}}{\text{Power of weak desire signal+Power of strong desire signal}}$, and vertical axis is the probability of strong interference at receivers (%). In Fig. 5, it is assumed that there are 50 relays in the network, it can be seen that if relay selection is done by SWI scheme, the strong interference will be happen with probability more than 95.4% at both receivers. In Fig. 6, there are 100 relays in the network, it can be seen that in this case, the strong interference will be happen with probability more than 96.7% at both receivers. In Fig. 6, number of relays has increased again and it is assumed that there are 200 relays in the network, it can be seen that in this case the strong interference will be happen with probability more than 98.4% at both receivers. According to the figures, when the number of relays increase, consequently, freedom of relay selection is increase, and in result the probability of the strong interference at both receivers are getting rise. It can be concluded, in environments with sufficient relay, freedom of relay selection is much and the strong interference will be happened with high probability at both receivers.

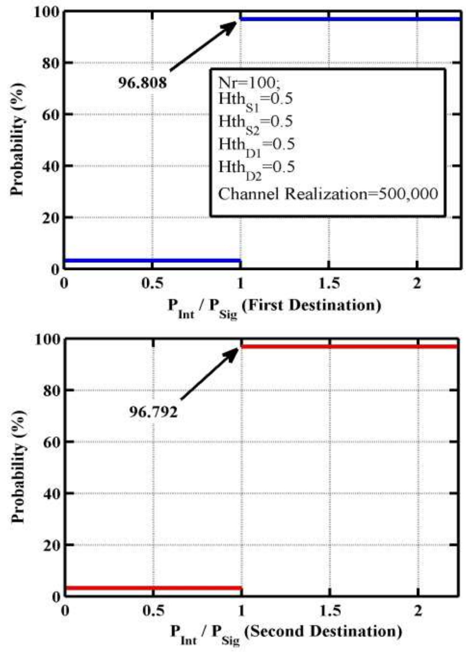

Fig. 4. The probability of strong interference at the both receivers for $N_r = 100$.

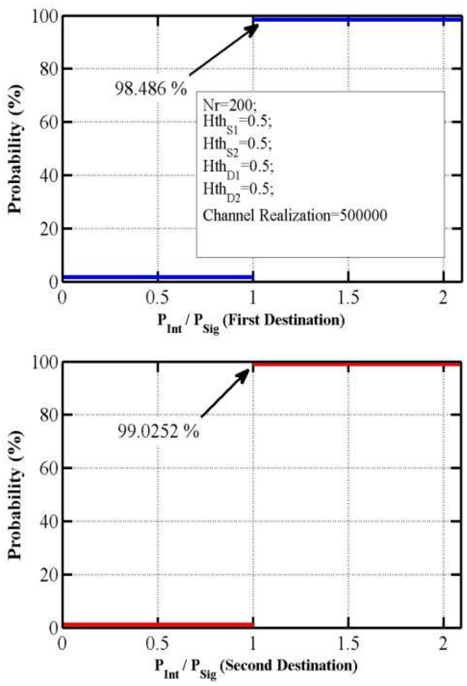

Fig. 5. The probability of strong interference at the both receivers for $N_r = 200$.

Note that in SWI scheme, using the values of $\mathrm{H}_{\mathrm{th}_{\mathrm{S}_1}}$, $\mathrm{H}_{\mathrm{th}_{\mathrm{S}_2}}$, $\mathrm{H}_{\mathrm{th}_{\mathrm{D}_1}}$ and $\mathrm{H}_{\mathrm{th}_{\mathrm{D}_2}}$ we have more control on network. In our simulation we take $\mathrm{H}_{\mathrm{th}_{\mathrm{S}_1}} = \mathrm{H}_{\mathrm{th}_{\mathrm{S}_2}} = \mathrm{H}_{\mathrm{th}_{\mathrm{D}_1}} = \mathrm{H}_{\mathrm{th}_{\mathrm{D}_2}} = 0.5$. That mean, we select relays that norm of their channel for both transmitters and receivers are greater than 0.7071 and are in the middle of the transmitters and the receivers approximately. In some environments that there is not enough relay for selection, maybe we cannot find 4 relays for selection, in other word, the number of $\mathbb{S}_{\mathrm{Des}}$ relays in (13) will be less than 4. In this case, we can decrease the values of thresholds and obtain more relays in $\mathbb{S}_{\mathrm{Des}}$. It is obvious that in this case achievable sum-rate will decrease also. Furthermore, by selecting suitable values for threshold we can increase the reasonability of assumption (5) and (6). For instance, if we take $\mathrm{H}_{\mathrm{th}_{\mathrm{S}_1}} = \mathrm{H}_{\mathrm{th}_{\mathrm{S}_2}} = 0.6$ and $\mathrm{H}_{\mathrm{th}_{\mathrm{D}_1}} = \mathrm{H}_{\mathrm{th}_{\mathrm{D}_2}} = 0.4$, as a result we will select relays that their channels with sources are better than their channels with destinations and our assumption in (5) and (6) will happen with high probability.

B. Achhivable sum-rate using SWI algorithm

In second scenario, we consider our system model with 100 relays. We investigate achievable sum-rate and individual rates for case that relay selected via SWI scheme. Also we aim to show that resources allocated fairly between two transmitters, and the balance is established in the network. In simulations, power of relays are random variable with uniform distribution. Our assumption for values of $\mathrm{H}_{\mathrm{th}_{\mathrm{S}_1}}$, $\mathrm{H}_{\mathrm{th}_{\mathrm{S}_2}}$, $\mathrm{H}_{\mathrm{th}_{\mathrm{D}_1}}$,$\mathrm{H}_{\mathrm{th}_{\mathrm{D}_2}}$ and channel coefficients are same as the first scenario, and simulation results reported for 100,000 channel realization.

In (19), achievable sum-rate for case that relays are selected via SWI scheme and receivers are using strong interference cancellation technique is given. In Fig. 6, we plot the achievable end-to-end individual and sum-rate of two transmitters versus the total consumed power at 4 selected relays. To the best of our knowledge, SWI scheme is the first scheme for relay selection between two transmitters simultaneously. Thus in order to evaluate SWI scheme, we compare with case that relay selection is performed randomly. In random relay selection, for each transmitter, two relays choose randomly. According to the

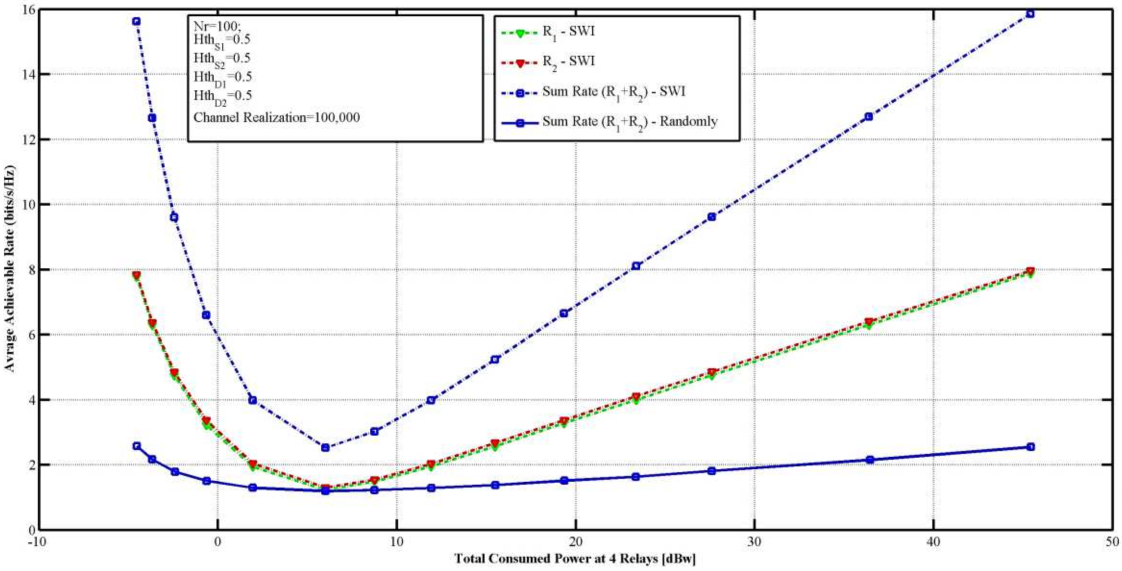

Fig. 4. Avrage achivable rates using SWI and random relay selection strategies versus consumed power at selected relays for $H_{th_{S1}} = H_{th_{S2}} = H_{th_{D1}} = H_{th_{D2}} = 0.5$ and $N_r = 100$.

figure, when the SWI scheme is used, transmitters achieve sufficient rate and their achievable rates increase linearly with power of relays. Also it can be seen that using the SWI scheme ensures that resources are allocated fairly between two transmitters, and individual rates almost are the same.

Note that, in Fig. 6, an interesting fact is achievable rates in lower powers. It can be seen that on the lower powers, achievable rates are more than middle powers. But in lower powers, signals strength are weak and non-sensible.

V. Conclusions

In order to enhance achievable sum-rate in an *ad-hoc* network consisting of two source-destination pairs and *k* half-duplex DF relays, a novel relay selection scheme has been proposed. We assumed that receivers use strong interference cancellation technique. In the proposed scheme, two issues were very important. First, making strong and weak interference at both receivers, second, allocate network resources fairly between two transmitters. Simulation and numerical results showed that with the proposed relay selection scheme, SWI can be made with probability greater than 0.95 in crowded environment. Also simulations showed that via SWI scheme, the transmitters achieve sufficient rates and their achievable rates increase linearly with power of relays.

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