Resource Allocation and Sharing in Cooperative Networks

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***Abstract*—In this paper, we investigate the selection of cooperative relays in a cellular mobile network. We take into account the effect of the resource sharing of each relay by its served users on the relay selection strategy. At first, we propose a novel selection strategy of one cooperative relay considering both Amplify and Forward (AF) and Decode and Forwards (DF) protocols. Then, we extend our study to the case of selection of two cooperative relays in an attempt to improve the spatial diversity gain. The performances of the proposed selection algorithms are analyzed in terms of number of users assisted by cooperation and residual powers at the relays.**

Keywords—* *Cooperative Relaying, Relay selection, resource sharing, Amplify and Forward, Decode and Forward.

I. INTRODUCTION

Current wireless systems must guarantee high transmission speeds and good quality of services. Designers of radio transmission systems are faced with many problems such as the limited spectral resources available and the variations of the propagation environment (different types of fading and multi path). Cooperative communication has emerged as a promising way to exploit the spatial diversity without requiring multiple antennas at the terminals [1], [2], [3]. Indeed, the basic idea of cooperation is to involve one or more relay stations between the source and destination during transmission. Then, the destination combines various signals received thereby create some form of diversity. Indeed, there are usually multiple relay nodes in the region between the source and destination. The determination which one of these potential relays should be selected for the cooperative transmission is often difficult problem to solve and depends on several factors. For example, the channel between a relay node and the destination may be without fading, but this relay can have a power exhausted or insufficient to achieve the desired quality of service, after cooperating with other sources in their transmissions. In literature, the selection of the best relay has been studied in several SSD (single source-destination) [4-6] and in MSD (multiple source-destination) [7-11]. Many selection criteria have been proposed, such as the distance-based criterion where the relay nearest to the source was selected [12], utility-based criterion where ratio of throughput to the source power was considered [13], the outage probability based strategy where a relay giving rise to the minimum outage probability was selected [14], the power-aware strategy where a relay with the least power consumption is selected [15] or the mutual information based strategy provided at transmit powers of nodes were predetermined [16].

In a cooperative network, relay nodes can amplify and forward (AF) or decode and forward (DF) the received signal before retransmitting the message to the destination. In this paper, we develop new effective strategies for selection of one or two cooperative relays. We take into account not only the quality of links between terminals but also the sharing of relay resources by multiple users. The performances of these strategies are evaluated through simulation results.

The remainder of the paper is organized as follows: in section II, we propose novel strategies to select the best relay operating with AF and DF protocols, respectively. These strategies are based on maximizing the signal to noise ratio at the reception and on the residual power at the relay after helping other users. Then, we propose to extend this study in section III to the selection of the best two cooperative relays. We take into account the sharing of power relays for all users.

II. SELECTION OF ONE COOPERATIVE RELAY

A. System model

In our system, we consider M users ($\mathrm{S}_i, 1 \le i \le M$), N relays ($\mathrm{R}_j, 1 < j < N$) and one destination terminal (D). All terminals have each one transmitting and receiving antenna and work in half-duplex mode. This means that each terminal cannot transmit and receive simultaneously. Each user can use one relay to retransmit its information to D. Moreover, we assume, such as in a LTE context, that the destination (base station) assigns the resources to all nodes and this prevents collisions.

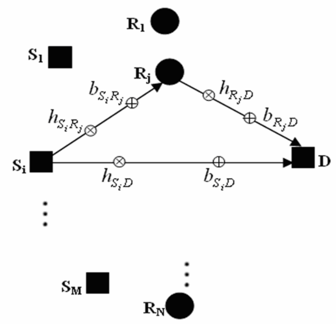

Fig. 1. Illustration of the system model with a single cooperative relay

Figure 1 represents the model of the system composed of one source, one relay and one destination. Each link between a sending node I (I = S_i, R_j) and a receiving node J (J = R_j, D) is modeled by a Rayleigh channel. Let's h_{IJ} be the channel gain between I-J. We assume that the gain takes into account the effects of the path-loss and the Rayleigh fading. Gains between any pair of terminals I and J are independent. We express the variances of the coefficients of the three channels as follow:

$$\sigma_{SR}^2 = \sigma_{SD}^2 \left(\frac{d_{SD}}{d_{SR}} \right)^{\alpha} \tag{1}$$

and

$$\sigma_{RD}^2 = \sigma_{SD}^2 \left(\frac{d_{SD}}{d_{RD}} \right)^{\alpha}, \tag{2}$$

where σ_{IJ}^2, (I = S, R; J = R, D), is the variance of the fading coefficient of the channel between I-J and d_{IJ}, (I = S, R; J = R, D), is the distance between I-J. α is the path-loss exponent, it is usually taken between 2 and 6. The signal emitted by the source is divided into blocks composed of K modulated symbols. For one symbol transmitted by the source, the received signals into baseband at the destination and at the relay are expressed respectively by:

$$y_{SD} = \sqrt{E_S}\, a h_{SD} + b_{SD} \tag{3}$$

and

$$y_{SR} = \sqrt{E_S}\, a h_{SR} + b_{SR}, \tag{4}$$

where E_S is the energy of the symbol a transmitted by the source. The noise b_{IJ} between the transmitter I and receiver J is the additive white Gaussian noise with variance N_0.

Our selection strategy is based on the potential received SNR at the destination. So, the later needs to know all relevant channel coefficients to do calculations. For this, we assume an LTE-like context, such that reporting of Channel Quality Information (CQI) is available at the base station. Like in LTE, the proposed system plans periodic ascents of sources and relays CQIs towards the destination. For the reporting of S-R gains to the destination, we assume that each relay R_i can overhear the sounding signals of the sources, for instance during the first source transmission phase. Then each relay aggregates all the CQI messages of the sources it is able to distinguish (all S_i-R_i in question) in one message that is sent to the destination. This seems to be more effective from a point of view of signalization, rather than sending different CQI messages for each S_i-R_j couple.

B. *Proposed selection strategy for the case of AF relaying*

In this case, the relay amplifies the received signal (4) by a factor μ before forwarding to the destination. The received signal at D sent by R is given by:

$$y_{RD}^{AF} = \mu y_{SR} h_{RD} + b_{RD}. \tag{5}$$

We can determine the amplification factor from the equation:

$$E_R = E\left(\left| \mu y_{SR} \right|^2 \right), \tag{6}$$

where E_R is the energy of the symbol emitted by R and *E( )* is the mathematical expectation. From equation (6), we can conclude that the amplification factor is given by the following term:

$$\mu = \sqrt{\frac{E_R}{\left(E_S \left| h_{SR} \right|^2 + N_0 \right)}}. \tag{7}$$

Substituting equation (4) in equation (5), we obtain:

$$Y_{RD}^{AF} = \mu \sqrt{E_S}\, h_{SR} h_{RD} a + \mu b_{SR} h_{RD} + b_{RD}. \tag{8}$$

At the destination, we propose to combine the two copies y_{SD} and y_{RD}^{AF} by using a Maximum Ratio Combining (MRC). The decision variable at the output of MRC combiner is given by:

$$\Delta = \alpha y_{RD}^{AF} + \beta y_{SD}, \tag{9}$$

where β is the weight for the direct link and α is the weight for the indirect link given by:

$$\beta = \frac{\sqrt{E_S}}{N_0} h_{SD}^{*} \tag{10}$$

and

$$\alpha = \frac{\mu \sqrt{E_R}\, h_{SR}^{*} h_{RD}^{*}}{\mu^2 N_0 \left| h_{RD} \right|^2 + N_0}. \tag{11}$$

The operator (.)* denotes the conjugation operator.

We easily show that the total SNR at the reception is expressed by

$$SNR_T^{AF} = \frac{E_S}{N_0} \left(\left| h_{SD} \right|^2 + \frac{E_R \left| h_{S_i R_j} \right|^2 \left| h_{R_j D} \right|^2}{E_{S_i} \left| h_{S_i R_j} \right|^2 + E_R \left| h_{R_j D} \right|^2 + N_0} \right). \tag{12}$$

Our idea is to choose from all available relays the one which maximizes equation (12). We assume that the coefficients of the three channels are constant during the transmission of a large number of packets. The step of selecting the best relay for each source precedes the transmission of these packets. Given that system resources are limited in terms of number of relays and power available at the relay, the best use of the system corresponds to the case where it is able to help the maximum users with AF relaying while ensuring a good quality of service. For this reason and with deleting the term $\left| h_{SD} \right|^2$ in equation (12) which does not depend on the S-R link, we propose to choose the relay that maximizes the following criterion:

$$RC(S_i) = \operatorname{argmax}_{R_j \in D(S_i)} \left\{ \frac{E_{R_j}^{res} \left| h_{S_i R_j} \right|^2 \left| h_{R_j D} \right|^2}{E_{S_i} \left| h_{S_i R_j} \right|^2 + E_{R_j}^{res} \left| h_{R_j D} \right|^2 + N_0} \right\}, \quad (13)$$

where $E_{R_j}^{res}$ is the residual energy in the relay before the selection for the source S$_i$. Here, D(S$_i$) denotes the set of relays that have enough residual energy to transmit information from the source S$_i$ with a very low error rate. We assume that the target rate for the transmission of the source is set to a value denoted R^{target}. According to the results of information theory, we can guarantee the transmission with such rate with minimal errors if the following condition is satisfied:

$$R^{target} \leq \log_2(1 + SNR_T^{AF}). \quad (14)$$

So, by setting the value of R^{target}, we can deduce the following value of the necessary transmit energy at the j^{th} relay, denoted with $E_{R_j}^{nec}$.

$$E_{R_j}^{nec} = \frac{\left(\frac{N0}{E_{S_i}} \left(2^{R^{target}} - 1 \right) - \left| h_{S_i D} \right|^2 \right) \left(E_{S_i} \left| h_{S_i R_j} \right|^2 + N0 \right)}{\left| h_{S_i R_j} \right|^2 \left| h_{S_i D} \right|^2 - \left| h_{R_j D}{}^2 \right| \left(\frac{N0}{E_{S_i}} \left(2^{R^{target}} - 1 \right) - \left| h_{S_i D} \right|^2 \right)}. \quad (15)$$

Thus, to determine D(S$_i$), we propose to compare $E_{R_j}^{nec}$ with $E_{R_j}^{res}$. If $E_{R_j}^{res} \geq E_{R_j}^{nec}$, we deduce that the relay is capable to efficiently retransmit source information at the target rate.

This implies that R$_j$∈ D(S$_i$). However, if $E_{R_j}^{res} < E_{R_j}^{nec}$, we deduce that the relay cannot meet the needs of the source flow and therefore R$_j$∉ D(S$_i$). Once the relaying is performed by the selected relay, this later will update its residual power as follows:

$$E_{R_j}^{res} = E_{R_j} - E_{R_j}^{cons}, \quad (16)$$

where $E_{R_j}^{cons}$ is the energy consumed by the selected relay.

C. Proposed selection strategy for the case of DF relaying

With this type of relaying, the relay decodes the symbol from the source before encoding and forwarding it to the destination. In this paper, we assume that the relaying take place only if the relay perfectly decodes the received signal from the source. Moreover, when the relay forwards the encoded signal, the source keeps silent. To enable the detection of errors at the relay, we assume that CRC (Cyclic Redundancy Check) bits are inserted into source information blocks. In this case, the received signal at D sent by R is given by:

$$y_{RD}^{DF} = \sqrt{E_R}\, h_{RD}\, a + b_{RD}. \quad (17)$$

Using the MRC combining at the destination, we get the decision variable as follows:

$$\Delta^{DF} = \left[\frac{E_S |h_{SD}|^2 + E_R |h_{RD}|^2}{N_0} \right] a + \frac{\sqrt{E_S}\, h_{SD}^*}{N_0} b_{SD} + \frac{\sqrt{E_R}\, h_{RD}^*}{N_0} b_{RD}. \quad (18)$$

In what follows, we will determine the total received SNR after MRC combining. Equation (18) can be written as follows:

$$\Delta^{DF} = \lambda^{DF} a + b_T^{DF}, \quad (19)$$

where

$$\lambda^{DF} = \frac{E_S |h_{SD}|^2 + E_R |h_{RD}|^2}{N_0}, \quad (20)$$

$$b_T^{DF} = \frac{\sqrt{E_S}\, h_{SD}^*}{N_0} b_{SD} + \frac{\sqrt{E_R}\, h_{RD}^*}{N0} b_{RD}. \quad (21)$$

Thus, the SNR is given by:

$$SNR_T^{DF} = \frac{(\lambda^{DF})^2}{E\left(|b_T|^2 \right)}. \quad (22)$$

By developing the expression (22) of SNR and taking into account that the noise terms b_{SD}, b_{SR} and b_{RD} are additive white Gaussian noise with variance N_0, we show that:

$$SNR_T^{DF} = \frac{E_S |h_{SD}|^2 + E_R |h_{RD}|^2}{N0}. \quad (23)$$

Our idea is to choose among all the relays that have correctly decoded the signal of S the one that maximizes equation (23). Given that the relays can cooperate with several sources, we propose to maximize the total SNR expressed in (23) by replacing E_R with $E_{R_j}^{res}$, i.e. the residual energy at the relay. We note that the term which depends only on the S-D link in the expression of total SNR is not considered in the maximization. Moreover, unlike the AF scheme where the relay systematically forwards the source information, in DF scheme the relay intervene in the cooperation procedure only if the packed is received without error. However, we assume in our work that for each source there is at least one relay that correctly decode its information. Consequently, our selection criterion is the following:

$$RC(S_i) = \operatorname{argmax}_{R_j \in D(S_i)} \left\{ E_{R_j}^{res} \left| h_{R_j D} \right|^2 \right\}, \quad (24)$$

where D(S$_i$) corresponds to the set of relays which have correctly decoded source information and which have a residual energy allowing to the source to transmit with a target rate R^{target}. According to the results of information theory, we have:

$$R^{target} \leq \log_2(1 + SNR_T^{DF}). \quad (25)$$

So, by setting the value of R^{target}, we can deduce the value of the required energy for transmission by the relay. This value is denoted by $E_{R_j}^{nec}$ and is given by:

$$E_{R_j}^{nec} = \frac{\left(2^{R^{target}} - 1\right)N_0 - P_{S_i}\left|h_{S_iD}\right|^2}{\left|h_{R_jD}\right|^2}. \tag{26}$$

Thus, to determine D(S$_i$), we compare $E_{R_j}^{nec}$ with $E_{R_j}^{res}$ exactly as we have proposed for the case of AF relaying (at the end of sub-section II.B).

D. Simulation results

To illustrate the performance of our proposed strategy for selecting one cooperative relay, we consider a cell radius 600 m centered on the destination. Five Rs are concentrically placed within the sector at the distance of 2/3 the radius to the D, with equal spacing between each other. We assume 100 users randomly distributed in the area between 400 m and 600 m, as shown in Figure 2. Five relays are placed in the circle of radius The path loss factors for links connecting the five relays with D are chosen as follows: α = 3.5, 3, 3.5, 3.5, 4. We choose different attenuation coefficients for studying the effect of path loss in results. Each relay has a power of 1W and each user has a power of 0.1 W. The value of R^{target} is set to 1bps/Hz.

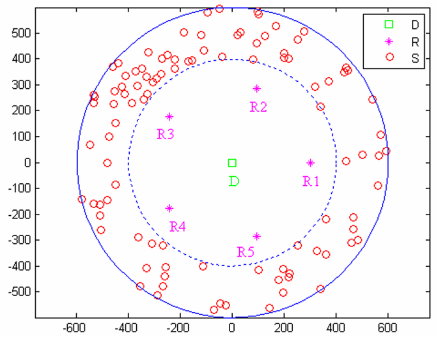

Fig. 2. Positions of source and relay terminals for simulations.

Firstly, in order to illustrate the importance of the relay selection in a cooperative system, we present in Figure 3 the throughput of one-relay cooperative system and the non-cooperative system (Direct transmission) as a function of E_s / N_0. We consider in this figure the three relays R$_1$, R$_2$ and R$_3$ (see Fig.2) and a source S such that the relay R$_1$ is located at the center of the line connecting S to D. The relays operate with AF mode. For this simulation we use a channel bandwidth of B= 5 MHz in the direct transmission system and 2.5 MHz in the cooperative one. Figure 3 shows that the throughput of the cooperative diversity network is higher than that of the classical direct transmission for the E_s / N_0 <17dB, if the relay position is selected with a great care.

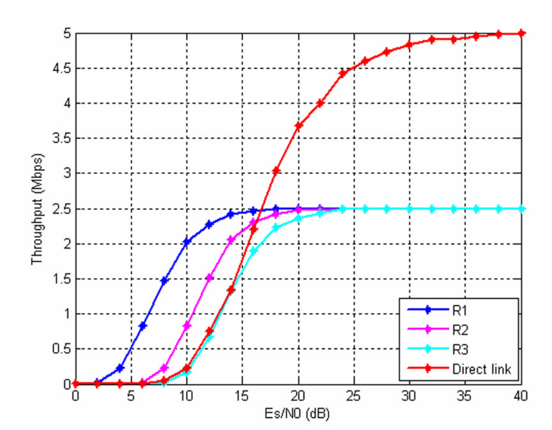

Fig. 3. Throughput of one-relay cooperative system and the non-cooperative system

Figures 4 and 5 show the average number of sources served by each relay operating with AF, with and without shadowing, respectively. We consider a standard deviation of Shadowing equal to 8 dB.

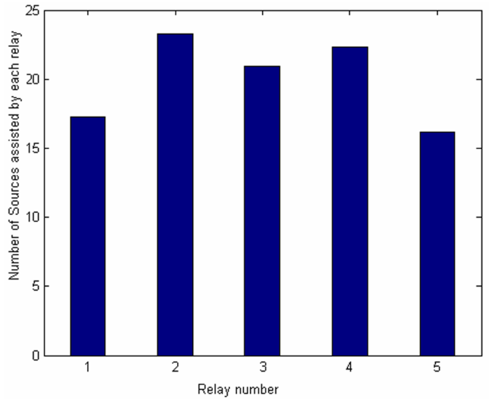

Fig. 4. Number of users assisted by each relay operating with AF, when shadowing is not considered.

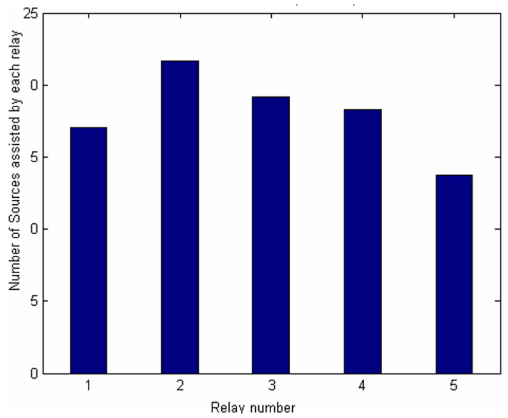

Fig. 5. Number of users assisted by each relay operating with AF when we consider shadowing.

We note that the total number of users assisted with AF relaying decreased in Figure 5 compared to Figure 4. In fact, by counting the total number of assisted sources, we note that it is less than 100 in figure 5. This is due to the effect of shadowing. We also note from figures 4 and 5, that the second relay that has the lowest value of the path loss can serve a number of users larger than the other relays. The fifth relay cannot help many sources to transmit their information because it has the highest value of path loss.

Figure 6 shows the percentage of the residual power of each relay after helping all users in retransmission. We consider two values of the power of each user: 0.1 W and 0.5 W. We note that the second relay has the lowest value of residual power.

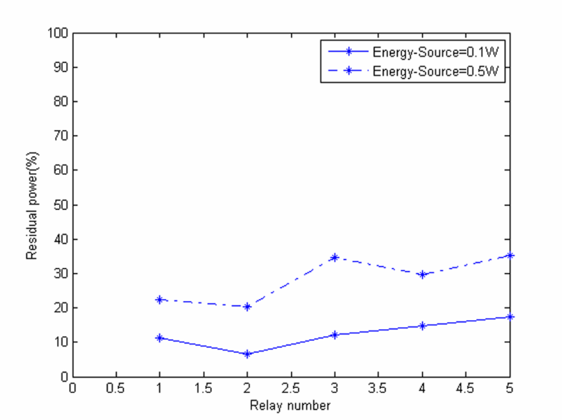

Fig. 6. Residual power at each relay operating with AF, after cooperating with 100 sources

Figures 7 and 8 show the average number of sources assisted each relay operating with DF, with and without shadowing respectively. We consider a standard deviation of shadowing equal to 8 dB. We note that the total number of users decreased assisted in Figure 8 compared to Figure 7.

Indeed, because of shadowing the energy at each relay to help the source to reach the target rate increases. Thus, the initial energy level of the five relay is not enough to ensure cooperation for each source. Therefore, some sources are not assisted by relays.

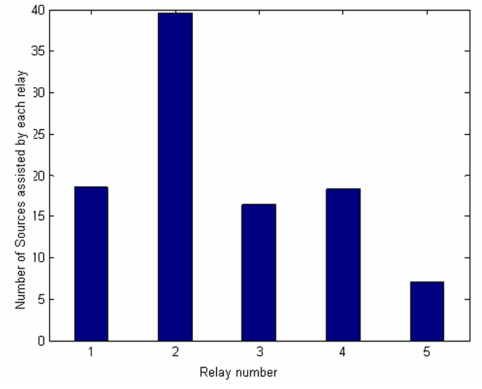

Fig. 7. Number of users assisted by each relay operating with DF, without shadowing

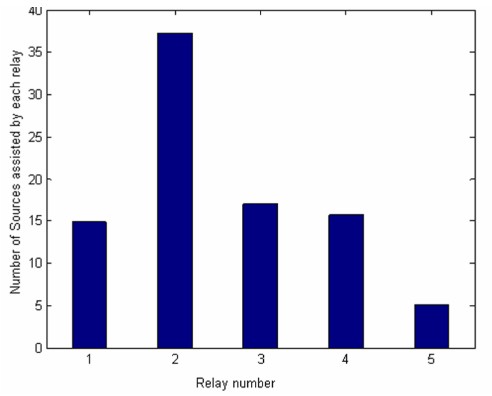

Fig. 8. Number of users assisted by each relay operating with DF. Shadowing effect is considered.

Figure 9 shows the percentage of the residual power of each relay after helping all users in retransmission. We note that the second relay has the lowest value of residual power since served more sources compared to other relays. However, the fifth relay has the highest residual power due to the small number of supported users.

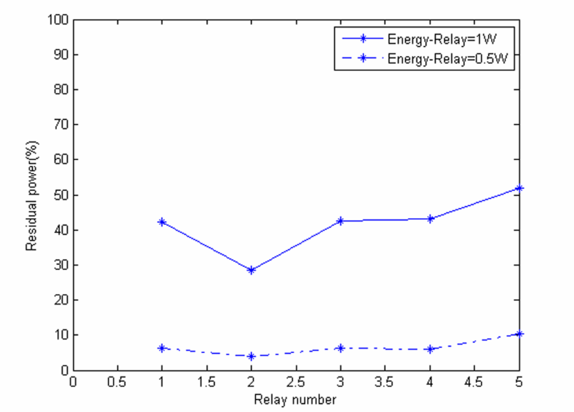

Fig. 9. Residual power at each relay operating with DF, after cooperating with 100 sources

III. SELECTION OF TWO COOPERATIVE RELAYS

In order to enhance the cooperative diversity, we consider, in this section, a cooperative wireless network where two parallel relays cooperate to send information received from the source to the destination using the DF approach. In fact, by comparing the results obtained with two relays to those obtained in the case of a single relay, we note that in the AF mode, increasing the number of relays does not improve performance because of the division of the total energy of all relays. Then, we don't consider next the selection of two relays using the AF mode.

A. System model

Here, we consider that each source terminal uses two relays (R_1 and R_2) to transmit its information to the destination D. All terminals have one transmitting and receiving antenna and work in half-duplex mode. Different links between the four terminals are independent. Each link is modeled by a Rayleigh channel quasi-static, which keeps constant the value of the coefficient of the channel during the transmission of one packet to another, and additive white Gaussian noise with variance N_0.

Let h_{SD}, h_{SR_1}, h_{SR_2}, h_{R_1D} and h_{R_2D} the complex gains of the five respective channels source-destination (S-D), source-relay1 (S-R$_1$), source-relay2 (S-R$_2$), relay1-destination (R$_1$-D) and destination-relay2 (R$_2$-D).

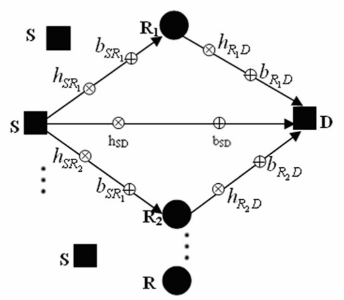

Fig. 10. Illustration model system with two cooperative relays

To take into account the effect of shadowing, we express the variance of the coefficients of the channels as follows:

$$\sigma_{IJ}^2 = \sigma_{SD}^2 \left(\frac{d_{SD}}{d_{IJ}} \right)^{\alpha}, \tag{27}$$

where σ_{IJ}^2, (I = S, R$_1$, R$_2$, J = R$_1$, R$_2$, D) is the variance of the coefficient of the channel between I and J, and d_{IJ},(I = S, R$_1$, R$_2$, J = R$_1$, R$_2$, D) is the distance between I and J. Let's α be the path-loss exponent. It is taken between 2 and 6. The signal emitted by the source is divided into blocks composed of K modulated symbols. For a symbol a emitted by the source with an energy E_S, the baseband signals received by the destination and two relays are expressed by:

$$y_{SD} = \sqrt{E_S} a h_{SD} + b_{SD}, \tag{28}$$

$$y_{SR_1} = \sqrt{E_S} a h_{SR_1} + b_{SR_1} \tag{29}$$

and

$$y_{SR_2} = \sqrt{E_S} a h_{SR_2} + b_{SR_2}. \tag{30}$$

The noise b_{IJ} between the transmitter I and receiver J is the additive white Gaussian noise with variance N_0.

In this section, we consider the case where the relays R$_1$ and R$_2$ decode the symbols from the source before forwarding them to the destination. When the two relays transmit the encoded signals, the source keeps silent. To enable the detection of errors at the relay, we assume that bit CRC (Cyclic Redundancy Check) are inserted into blocks of information emitted by the source. Using the combination MRC at the destination, we get the following decision variable:

$$\Delta^{DF} = \left[\frac{E_S \left| h_{SD} \right|^2 + E_{R_1D} \left| h_{R_1D} \right|^2 + {}_{R2} \left| h_{R_2D} \right|^2}{N_0} \right] a + \frac{\sqrt{E_S}\, h_{SD}^*}{N_0} b_{SD} + \frac{\sqrt{E_{R1}}\, h_{R_1D}^*}{N_0} b_{R1D} + \frac{\sqrt{E_{R_2}}\, h_{R_2D}^*}{N_0} b_{R_2D} . \tag{31}$$

In our strategy, we propose to choose the best two relays that can lead to total maximum SNR at the reception and have enough energy for retransmission.

In what follows, we will determine the total received SNR after MRC combiner. Equation (31) is written as follows:

$$\Delta^{DF} = \lambda^{DF} a + b_T^{DF}, \tag{32}$$

where

$$\lambda^{DF} = \frac{E_S \left| h_{SD} \right|^2 + E_{R_1} \left| h_{R_1D} \right|^2 + E_{R_2} \left| h_{R_2D} \right|^2}{N_0}, \tag{33}$$

$$b_T^{DF} = \frac{\sqrt{E_S}\, h_{SD}^*}{N_0} b_{SD} + \frac{\sqrt{E_{R_1}}\, h_{R_1D}^*}{N0} b_{R_1D} + \frac{\sqrt{E_{R_2}}\, h_{R_2D}^*}{N0} b_{R_2D}. \tag{34}$$

By developing the SNR expression (22) and taking into account that noise b_{SD}, b_{SR1}, b_{SR2}, b_{R1D} and b_{R2D} are additive white Gaussian noise, we show that:

$$SNR_T^{DF} = \frac{E_{S_i} \left| h_{S_iD} \right|^2 + E_{R_j} \left| h_{R_jD} \right|^2 + E_{R_k} \left| h_{R_kD} \right|^2}{N_0}. \; . \tag{35}$$

B. Proposed selection strategy of two relays

Our idea is to choose among the available relays those that maximize equation (35). With deleting the term $\left| h_{SD} \right|^2$ in equation (35) which does not depend on the SR link, we propose to choose the relay that maximizes the following report:

$$RC\{R_j, R_k\}(S_i) = \operatorname{argmax}_{R_j, R_k \in D(S_i)} \left\{ E_{R_j}^{res} \left| h_{R_jD} \right|^2 + E_{R_k}^{res} \left| h_{R_kD} \right|^2 \right\}, \tag{36}$$

where $E_{R_j}^{res}$ and $E_{R_k}^{res}$ are respectively the residual energies at the two relays R$_j$ and R$_k$ respectively prior the selection for the source. For each source S$_i$, we must determine all relays that guarantee a second phase of cooperation. In the sense that a target rate (R^{target}) can be achieved with a very low error rate. However, according to the results of information theory, we can write:

$$R^{target} \leq \log_2(1 + SNR_T^{DF}). \tag{37}$$

By developing the equation (37), we deduce that the minimum energy needed at both relays R$_j$ and R$_k$, denoted respectively $E^{nec}_{R_j}$ and $E^{nec}_{R_k}$, satisfy the following equation:

$$E^{nec}_{R_j}\left|h_{R_jD}\right|^2 + E^{nec}_{R_k}\left|h_{R_kD}\right|^2 \ge \left(2^{R^{target}} - 1\right)N_0 - E_{S_i}\left|h_{S_iD}\right|^2, \quad (38)$$

where $E^{nec}_{R_j} \le E^{res}_{R_j}$ and $E^{nec}_{R_k} \le E^{res}_{R_k}$.

From equation (38) and setting the value of R^{target}, we show that $E^{nec}_{R_k}$ verifies the following linear equation as a function of $E^{nec}_{R_j}$:

$$E^{nec}_{R_k} \ge \frac{\left[\left(2^{R^{target}} - 1\right)P_{S_i}\left|h_{S_iD}\right|^2\right]N_0 - E^{nec}_{R_j}\left|h_{R_jD}\right|^2}{\left|h_{R_kD}\right|^2}, \quad (39)$$

which can be rewritten as follows:

$$E^{nec}_{R_k} \ge b - aE^{nec}_{R_j}, \quad (40)$$

where

$$b = \frac{\left(2^{R^{target}} - 1\right)N0}{\left|h_{R_kD}\right|^2} \quad (41)$$

and

$$a = \frac{\left|h_{R_jD}\right|^2}{\left|h_{R_kD}\right|^2}. \quad (42)$$

Representing the equation $E^{nec}_{R_k} = b - aE^{nec}_{R_j}$, we deduce that the solutions of the equation (40) are points of the dashed line segment shown in Figure 11. The question that now arises: how are we going to choose the necessary energies of the two relays on the dashed segment?

For this aim, we propose the following strategy:

- If $\frac{b}{a} \le E^{res}_{R_j}$ et $b \le E^{res}_{R_k}$:

In this case we choose any point which connects the points $E^{nec}_{R_j} = \frac{b}{a}$ and $E^{nec}_{R_k} = b$. We avoid the bounds to allow more residual energy at the two relays in order to cooperate with other sources.

- If $\frac{b}{a} \le E^{res}_{R_j}$ et $b > E^{res}_{R_k}$:

We choose the value of $E^{nec}_{R_k}$ in the interval $]0, E^{res}_{R_k}[$. If we set the value of $E^{nec}_{R_k}$, we can deduce the value of $E^{nec}_{R_j}$ from equation (39).

- If $\frac{b}{a} > E^{res}_{R_j}$ et $b \le E^{res}_{R_k}$:

We choose the value of $E^{nec}_{R_j}$ in the interval $]0, E^{res}_{R_j}[$. Then we deduce the value of $E^{nec}_{R_k}$ from equation (39).

- If $\frac{b}{a} > E^{res}_{R_j}$ et $b > E^{res}_{R_k}$:

In this case we choose $E^{nec}_{R_j}$ any point on the segment that connects the points $\frac{(b - E^{res}_{R_k})}{a}$ and $E^{res}_{R_j}$. Then, we deduce the value of $E^{nec}_{R_k}$ from equation (39).

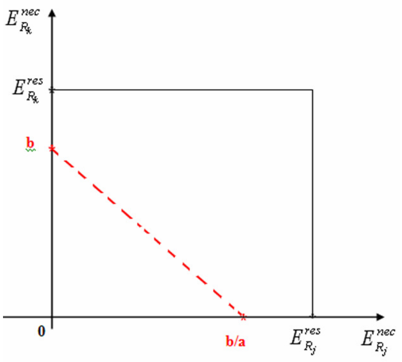

Fig. 11. Solutions of the equation (40)

Once the necessary energies $E^{nec}_{R_k}$ and $E^{res}_{R_j}$ are determined and the relaying is performed by the selected relays, those relays will update their residual powers as follows:

$$E^{res}_{R_j} = E_{R_j} - E^{cons}_{R_j} \quad (43)$$

and

$$E^{res}_{R_k} = E_{R_k} - E^{cons}_{R_k}, \quad (44)$$

where $E^{cons}_{R_j}$ and $E^{cons}_{R_k}$ are the energies consumed by relays R$_j$ and R$_k$ respectively for all performed cooperation.

C. Simulation results

To illustrate the performance of our proposed strategy of selecting two relays, we also consider the terminals positions depicted in Figure 2. Figure 12 shows the number of sources assisted by each relay. By counting the total number of sources assisted by five relays, we can conclude that each source is served by two relays. We also note that the number of sources assisted by the second relay is greater than the number of sources assisted by the other relays, yet these all relays have the same initial power.

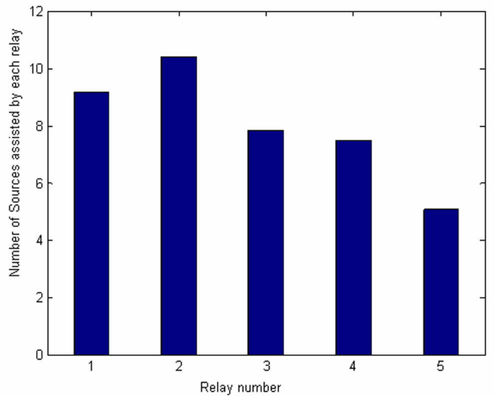

Fig. 12. Number of users assisted by each relay when the number of sources is equal to 100

Figure 13 shows the residual power at each relay after cooperating with the 100 users.

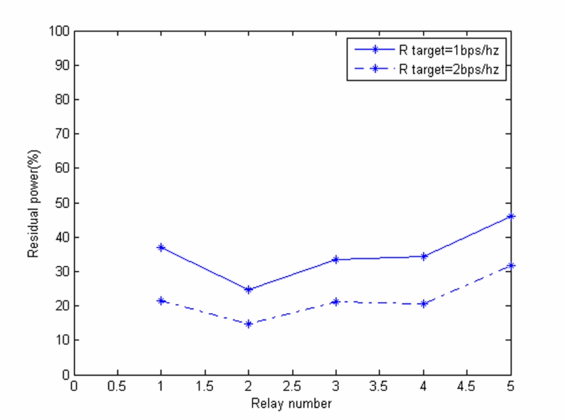

Fig. 13. Residual power at each relay having cooperated with 100 sources

IV. CONCLUSION

The objective of this paper was to propose new strategies for selecting one or two cooperative relay taking into account the sharing of relay resources by multiple users. We proposed a strategy of selection of the best relay for each of the two modes of AF and DF relaying. Our strategy is based on maximizing the total SNR at the reception after a MRC combination. We considered the sharing of resources relay by multiple users in our strategies. We evaluated the performance of the two proposed algorithms in terms of number of users assisted by the relays and in terms of residual powers at all relays. The effect of path loss and of shadowing on performances has been studied. We note that the terms of path-loss and shadowing has an enormous influence on the number of sources assisted by relays. The lower the value of path loss of a relay is, the more efficient the cooperation procedure. The total number of users supported by the relay decreases due to the shadowing effect. In an attempt to improve the spatial diversity gain, we subsequently proposed to extend our study to the case of the selection of two cooperative relays using DF mode. We show that, in DF mode, the performance improves by increasing the number of relays. Moreover, the performance evaluation of the proposed strategy for the selection of two relay shows that all sources are assisted by two relays.

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