Scheduling schemes for N-node cooperative networks

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Abstract— **In this paper, we consider an amplify-and-forward cooperative network composed of N nodes. Here we focus on the scheduling problem which consists in assigning the roles {source, relay} to the N nodes. Our target is to investigate and develop relay selection policies that can be used in amplify-and-forward cooperative systems. For fairness and simplicity issues, we assume that a node is chosen as a source in a Round Robin fashion. On the other hand, two relay selection schemes are proposed. In the first scheme, the relay selection problem is addressed under the knowledge of nodes positions and the relay is chosen to be the nearest neighbor of the source. This relay selection method combined with the RR source selection method will be called Network Topology based scheduling (NT-based scheduling). In the second scheme, the relay selection algorithm is based on the instantaneous channels qualities and the relay is the node with the best direct link in term of instantaneous signal-to-noise ratio (SNR). Since this second method requires much signaling which degrades the scheme performance, a channel feedback reduction method is proposed with the use of a threshold T. The relay selection method which use the proposed feedback reduction technique combined with the RR source selection method will be called semi Channels Qualities based scheduling (semi CQ-based scheduling). Simulation results will be provided in order to compare the performance of these scheduling schemes and to show the high performance provided by our proposed algorithms.**

I. Introduction

Cooperation in wireless communication is a new diversity technique beyond the point to point communication designed to mitigate fading without relying on multiple antennas. Its main idea is to exploit the nodes of the network that overhear the source transmission, thanks to the broadcast nature of the wireless system, to transmit the signal to the destination more than one time. The destination combines the direct signal received from the source with the relayed signals received from the relays so that a virtual array of antennas is formed.

The concept of cooperation in wireless channel was introduced by Van der Meulen in [1] and then developed by Cover and El Gamal in [2]. After that, the idea of introducing the concept of users cooperation in wireless networks was proposed in [3]-[4] as a new technique of spatial diversity and it has been proved that such cooperation improves the wireless system reliability and its robustness against channel fading.

In [3] and [5], two cooperative strategies were proposed, namely the decode-and-forward (DF) and the amplify-and-forward (AF) protocols. Specially, the AF protocol, where the relay simply scales the received signal and retransmits it to the destination is proved to be the best relaying protocol that allows a tradeoff between the efficiency and the simplicity [6]-[7].

A crucial challenge in cooperative network, is how to assign the pair of roles {source, relay} to the nodes so that we can obtain the best diversity gain. Therefore, a scheduling algorithm which wisely distributes these roles over the nodes is required.

Several works have been dealt with similar problems of scheduling. The performances of the possible solutions are evaluated according to three features : fairness, channel adaptation and implementation simplicity [14]. In [8], a channel adaptive scheduling for cooperative relay network was proposed. Nevertheless, it deals only with the source selection problem and doesn't take into account the fairness concept since it assumes that the channels are equivalent. In [9], a relay selection method based on the channels qualities was presented with the use of two control packets, Request-to-send/Clear-to-send. This scheduling method suffers from a high computational complexity and high signaling, besides, it is limited to the relay selection problem. In [10]-[11], the problem of scheduling is extended to both source and relay selection and the proposed solution exploits the concept of game theory. Nevertheless, it is indifferent to the channels qualities which leads to poor performance. In [12], the problem of scheduling is addressed under the assumption that only one node has data to transmit, and thus the source selection problem is not raised.

In [13]-[14], several scheduling algorithms were proposed for a three-node network. In spite of their utility in the networks composed of three nodes, these algorithms fall short when trying to apply them in a N-node network. In [14], a source selection algorithm is proposed that is completely based on the assumption that the channels remain constant during at least two source transmissions. However, for a N-node network, which requires more time slots than three-node networks to realize one source transmission, the assumption that the channels remain invariant during $N-1$ source transmissions cannot be supported. Moreover, the scheduling policies based on channels qualities require much signaling mainly when N becomes high, so they are not attractive for practical implementation. In addition, the work developed in [13]-[14], doesn't take into account the impact of the distances between the nodes on the links qualities.

In this paper, we propose two scheduling policies that can be used in any amplify-and-forward cooperative network. We suppose that all nodes have data to transmit and thus they

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can be a source. Moreover, we take into consideration the impact of the distances between the nodes on the channels qualities. The proposed scheduling solutions are designed to be independent of the number of nodes in the network and to satisfy, partially or perfectly, the three features : fairness, channel adaptation and implementation simplicity.

The remainder of this paper is organized as follows. In Section II, the considered system model, is presented together with the different assumptions. In section III, we present the proposed relay selection algorithms. Simulation results and their interpretations are provided in Section IV. Finally, in Section V, we give concluding remarks and future extensions.

II. System Model

We consider a cooperative network composed of N nodes using the AF relaying protocol and uniformly distributed within the unitary circle. Each node has data to send to the other $N-1$ nodes of the network. We assume that the nodes cannot transmit and receive data simultaneously. In addition, they have equivalent priorities. From a practical point of view, they are several applications that suits the adopted assumptions such as in ad hoc networks, wireless mesh network, ...

The time is divided into two slots : dedicated to the source and relay transmissions. During the source slot, the selected source broadcasts its data frame to the $N-1$ destinations. Each destination has interest in its own data but it can also "hear" the data of the other nodes. During the second slot (the relay one), the source keeps silent and one destination scales and forwards again a data frame containing the data of the other destinations. Since the source has $N-1$ destinations and the relay has $N-2$ destinations, the source slot is $\frac{N-1}{N-2}$ longer than the relay slot. Fig.1, illustrates this protocol and the slots structure. The destinations which receive a second copy of the source-transmitted signal from the relay use a Maximum Ratio Combiner (MRC) to combine the two signal copies. We consider a Rayleigh fading channel. Therefore, from a static point of view, the channel coefficients are zero-mean independent circularly symmetric complex Gaussian random variables. In addition, the additive noise is modeled as an additive white Gaussian noise. We take into consideration, the degradation of the transmitted signal power due to path loss. We use a Binary phase-shift keying (BPSK) modulation.

The system model described above can be formalized by

$$\begin{aligned} y_d^{(i_j)} &= h_{i_0,i_j}x^{(i_j)} + n_{i_0,i_j},\ i_j \in I\backslash\{i_0,i_1\} \\ y_d^{(i_1)} &= h_{i_0,i_1}x^{(i_1)} + n_{i_0,i_1} \\ y_r^{(i_j)} &= h_{i_1,i_j}\left[G(h_{i_0,i_1}x^{(i_j)} + n_{i_0,i_1})\right] + n_{i_1,i_j}, \quad (1) \end{aligned}$$

where i_0 and i_1 denotes the source and the relay, respectively, $I = \{1 \ldots N\}$ is the set of nodes, i_j denotes the j^{th} destination, $x = [x^{(i_1)} \ldots x^{(i_{N-1})}]$ is the vector of signals transmitted toward the $N-1$ destinations, $x^{(i_j)}$ is the data for the destination i_j, $y_d^{(i_j)}$ and $y_r^{(i_j)}$ are the direct and relayed received signals by the destination i_j, respectively, h_{i_0,i_j} is the coefficient of the channel between i_0 and i_j. G is the

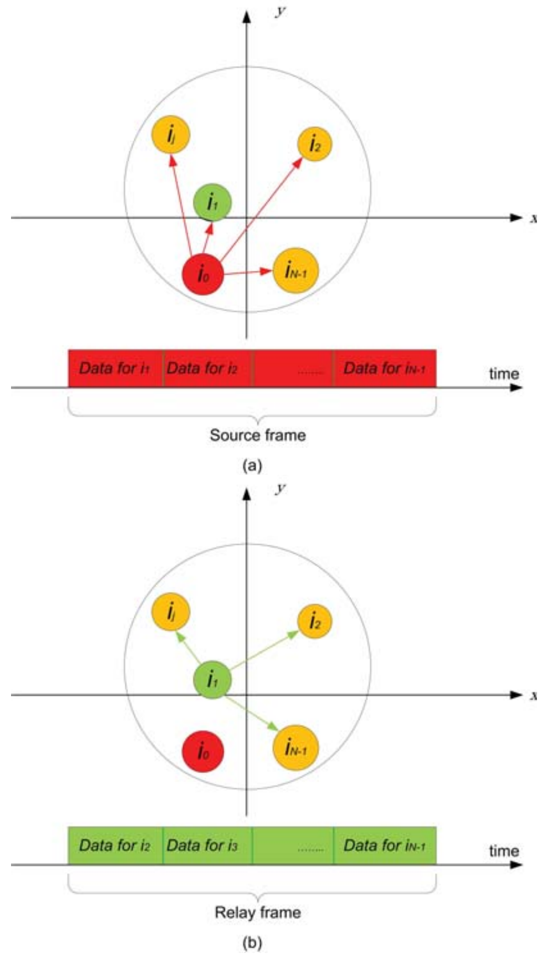

Fig. 1. Illustration of the proposed protocol. (a) the node i_0, used as source, broadcasts the data to the destinations, (b) the node i_1, used as relay, amplifies and retransmits the received signal to the destinations.

amplification factor used in the AF relaying protocol. It is given by

$$G = \frac{\sqrt{P_{signal}}}{\sqrt{P_{signal}|h_{i_0,i_1}|^2 + P_{noise}}}, \quad (2)$$

where P_{signal} and P_{noise} are the power of the transmitted signal and the noise, respectively.

Statistically, the system is characterized by the probability density function (pdf) of the SNR of the direct and relaying links. Based on the harmonic mean presented in [15], we can write

$$\begin{aligned} p_d^{(i_0,i_j)}(\gamma) &= \beta_{i_0,i_j}e^{-\beta_{i_0,i_j}\gamma} \\ p_r^{(i_0,i_1,i_j)}(\gamma) &= 2\beta_{i_0,i_1}\beta_{i_1,i_j}\gamma e^{-(\beta_{i_0,i_1}+\beta_{i_1,i_j})\gamma} \\ &\quad \times \Bigg(\frac{\beta_{i_0,i_1}+\beta_{i_1,i_j}}{\sqrt{\beta_{i_0,i_1}\beta_{i_1,i_j}}}K_1(2\gamma\sqrt{\beta_{i_0,i_1}\beta_{i_1,i_j}}) \\ &\quad +2K_0(2\gamma\sqrt{\beta_{i_0,i_1}\beta_{i_1,i_j}})\Bigg) \\ p_c^{(i_0,i_1,i_j)}(\gamma) &= p_d^{(i_0,i_j)}(\gamma) * p_r^{(i_0,i_1,i_j)}(\gamma) \quad (3) \end{aligned}$$

where $*$ denotes the convolution operation, $p_d^{(i_0,i_j)}(\gamma)$ is the pdf of the SNR of the direct link ($i_0 \rightarrow i_j$), $p_r^{(i_0,i_1,i_j)}(\gamma)$ is the pdf of the SNR of the relaying link ($i_0 \rightarrow i_1 \rightarrow i_j$),

$p_c^{(i_0,i_1,i_j)}(\gamma)$ is the pdf of the SNR of the MRC combination of the direct link and the relaying link ($i_0 \to i_j$, $i_0 \to i_1 \to i_j$), $\beta_{i_0,i_j} = \frac{1}{\overline{\gamma_{i_0,i_j}}}$, where $\overline{\gamma_{i_0,i_j}}$ is the average SNR for the link ($i_0 \to i_j$), and $K_n(.)$ is the n^{th}-order modified Bessel function of the second kind.

III. Scheduling algorithms for N-node network

A. Source selection

To select the source, we use the conventional Round Robin algorithm (RR) which chooses a node as a source periodically. The motivation behind the use of the RR is its simplicity and fairness. Although it has worse performance than the other algorithms which are channel adaptive, the RR seems a suitable source selection method for N-node cooperative network for many reasons. First, a source role assignment method based on the instantaneous channels qualities is not practical to implement since it requires too much signaling. Seeing that the channels vary within a transmission cycle ($N-1$ time slots for the source transmission + $N-2$ time slots for the relay transmission), the central supervisor unit cannot use the information about the channels acquired during a transmission cycle to select the source with the best $N-1$ links for the next transmission cycle because this information may change. Even if the channels qualities remain the same, the supervisor unit haven't enough instantaneous information about the $N(N-1)/2$ links of the network because several of these links weren't used to send data so the system has no information about their qualities. Hence, when the number of nodes becomes high, a source selection method based on the channels states becomes not feasible.

B. Relay selection based on partial channels states knowledge

This relay selection algorithm is partially based on the channels qualities (named Semi CQ-based relay selection). An algorithm completely based on channels qualities assigns the relaying role to the destination that has received the transmitted signal during the source slot with the best SNR. Nevertheless, this requires much signaling traffic, which constitute a shortcoming to the practical implementation. In this paper, the idea of the proposed algorithm is to reduce the channel feedback with the use of a threshold T. If the destination finds that its instantaneous SNR is higher than T, it will send it to the supervisor block to be compared with the other SNRs. In the contrary case, it only waits for a possible relaying. When the supervisor block doesn't receive any information about the SNRs of the different links (all the SNRs don't reach the threshold T), the scheduler randomly chooses one node among destinations with the same probability. The motivation behind this idea, is to avoid that the system remains silent for $N-2$ time slots which degrades the data rate without improving the BER by using the cooperative diversity. The threshold value depends on the percentage of channel feedback reduction. The probability that the SNR of the link ($i_0 \to i_j$), is less than the threshold T_{i_0,i_j} is calculated as

$$Pr(\gamma < T_{i_0,i_j}) = 1 - e^{-\beta_{i_0,i_j} T_{i_0,i_j}} \quad (4)$$

If we note λ the percentage of feedback reduction, T_{i_0,i_j} is given by

$$T_{i_0,i_j} = -\frac{1}{\beta_{i_0,i_j}} log(1-\lambda). \quad (5)$$

C. Relay selection based on the network topology

This algorithm is based on the topology of the network to take its decision. More specifically it assigns the role of relay to the nearest node to the source, supposing that it will often have higher average SNR than the other nodes, and hence it will often have the most reliable link toward the source. This algorithm requires some additional signaling between the "players" to discover the topology of the network and the distances between nodes but it has the advantage that it doesn't require a supervisor unit. This is a great benefit since it is suitable to Ad-hoc and sensors networks. Note that the discovery of the network topology and the distances between the nodes is out of the scope of this work.

IV. Simulation results

In this section, we present some simulation results carried out for many network topologies in order to evaluate the performance of the described algorithms.

The simulation environment is based on the system model described in the section II. The exponent of the path loss α is set to 3. We choose N=4 nodes.

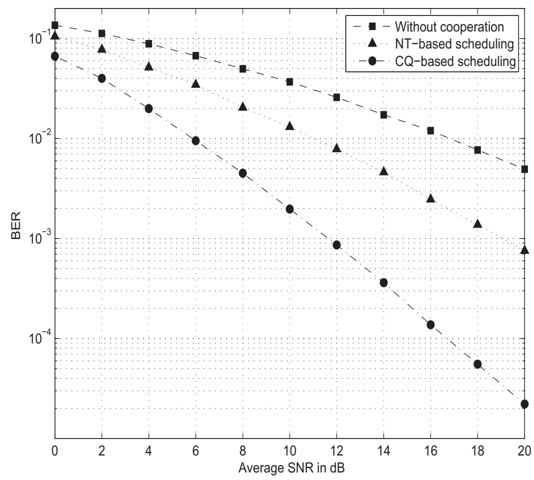

Fig. 2. BER performance comparison

Fig.2 presents the BER performance of the two scheduling schemes and the BER performance of the system if it doesn't use cooperation diversity. From this figure we can see that the use of the semi CQ-based relay selection algorithm and the network topology-based relay selection algorithm improve significantly the BER performance of the system. Moreover, we can see that the performance of the network topology-based scheduling scheme is approximately 5 dB worse than those of the CQ-based algorithm (T=0 and $BER = 10^{-2}$). However, it doesn't require a supervisor block compared to the CQ-based algorithm.

Fig.3 presents the BER performance of the semi CQ-based algorithm for different percentage of the channel feedback

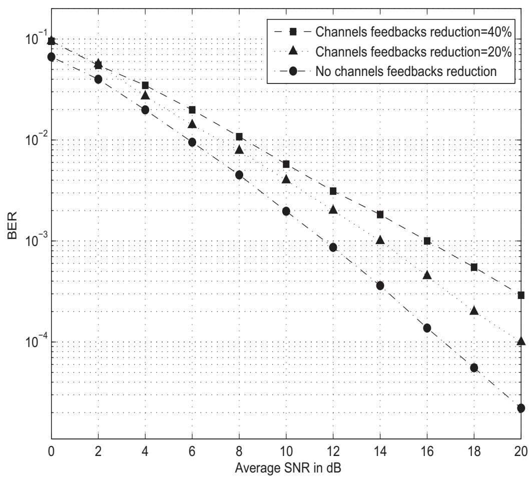

Fig. 3. Imapact of channel feedback reduction on the BER performance

reduction. Simulation curves show that the degradation in performance due to the reduction of the channel feedback is attenuated by an uniformly random choice of a relay node when all nodes fail to exceed the threshold T. So, we can reduce the channel feedback, and attenuate the great impact of neglecting some information about channels states on the BER performance of the system.

V. Conclusion

In this paper, we dealt with the scheduling problem for a N-node cooperative network where each node can be a source of traffic, a relay or a final destination. Our target was to find scheduling solutions to ensure an efficient assignment of the source and relay roles. We used the well known Round Robin algorithm to select the source for its simplicity and fairness and we proposed two methods to select the relay. The first is based on the network topology and the second one is based on channels qualities. For the last method, we proposed a channel feedback reduction method using a threshold T. The proposed algorithms are attractive for practical implementation. If the use of a supervisor unit is possible, we can use the semi CQ-based scheduling method. Otherwise, we can use the NT-based scheduling since it is a suitable solution for such networks for example Ad-hoc and sensors networks.

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