Adaptive Transmission in Cooperative Wireless Communications

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Abstract—In this paper, we propose and investigate a decentralized adaptive transmission technique for cooperative wireless communications. A number of relays adaptively switch between two transmission modes: Alamouti diversity and spatial multiplexing. The relays may exploit Amplify-and-Forward (AF) or Decode-and-Forward (DF) transmission technique. The performances of the decentralized adaptive transmission technique based on channel quality estimations are evaluated and compared to the centralized adaptive transmission technique based on error probability minimization with limited feedback from the destination. Even though the simulations show that the Bit-Error-Rate (BER) performances of the decentralized adaptive approach are close to that of the centralized adaptive technique, our proposed technique provides less communications between the nodes and hence improves the communication in terms of delay and power consumption.

I. INTRODUCTION

In a cooperative communication, relaying nodes process received signals from a source node and retransmit it to the destination node. The destination combines the received signals for detection and thus exploits spatial diversity [1]. Many protocols had been developed for cooperative communications achieving spatial diversity. Authors of [2] proposed low-complexity cooperative protocols for a network with two relays. They studied the outage behavior of these protocols taking into account the power and bandwidth consumptions. Work was also conducted in exploiting Multiple-Input-Multiple-Output (MIMO) characteristics for cooperative communications [3]. Several studies investigated diversity and spatial multiplexing in cooperative communications. The authors of [4] implemented the rate-1/2 orthogonal Space-Time-Block-Code (STBC) Alamouti scheme in wireless relay networks. Their simulation showed that achieved diversity is around $R/2$ when $R$, the transmission rate, is very large. In [5], the authors proposed new designs of distributed STBC implemented on Amplify-and-Forward (AF) relays. They showed that these designs achieve higher diversity than “selection Decode-and-Forward (DF)” with multiple relays. The theoretical analysis for the distributed STBC had been conducted in [6]. The authors of [7] provided an outage probability analysis for cooperative communications with DF-relays exploiting diversity. In [8], the authors proposed a new cooperative communication approach based on the spatial multiplexing design (Cooperative-SM). They investigated the BER and spectral efficiency performances as a function of parameters such as constellation size of the source and the relays as well as the number of relays and their locations. It has been shown that Cooperative-SM is attractive for high data-rates transmissions.

Ideas of protocols that combine the benefits of diversity and spatial multiplexing have been introduced first in MIMO systems. The authors of [9] derived a switching criteria between diversity and spatial multiplexing in point-to-point MIMO systems with limited-rate feedback. This transmission technique guarantees the lowest BER for any channel realization. An application to MIMO-OFDM 802.11 IEEE standard has been developed in [10]. The authors introduced the “Mixed Mode” and evaluated the BER performances for two switching criterions: the Euclidian distance and SNR (Signal-to-Noise) threshold. They showed that both transmission techniques outperform any fixed mode (diversity mode or “Mixed mode”, or spatial multiplexing). However, the Euclidian distance switching achieves better BERs than the SNR threshold switching. Authors of [11] proposed a new antenna selection and link adaptive space-time modulation algorithms to support cooperative wireless networks. They showed by analysis that the adaptive design based on switching between diversity and spatial multiplexing at a fixed rate $R$ achieves equivalent performance to MIMO systems.

In this paper, we investigate the performance of a cooperative communication system with multiple relays. All relays are single-antenna nodes and exploit diversity or spatial multiplexing with AF or DF relaying. We introduce a switching mode based on the estimated SNR. Then, we evaluate its BER performance and compare it to the error probability minimization switching mode presented in [11] (introduced as minimum Euclidean distance in [11]). The proposed approach has the advantage to minimize the communications between the nodes and even omit it completely when the relay nodes are AF. As a consequence, smaller delay and power consumption is guaranteed in the system.

The rest of this paper is organized as follows. The next section details the system model. In section III, we present the transmission modes in the wireless communication with AF and DF relaying. Section IV details the switching mode adopted. In section V, we present and discuss the simulation
results and a conclusion is presented in section VI.

II. SYSTEM MODEL

A. Network Model

We assume a network composed of a single-antenna source node, $K$ relay nodes and one destination node with $L_d$ antennas. All relays have only one antenna. We assume $L_d \geq K$. The relays do not provide additional traffic and the nodes are assumed to be “half-duplex”. A cooperative communication is performed during two transmission phases.

During the first phase, called “broadcast phase”, the source sends $T_1$ unprotected symbols over $T_1$ time periods. The relays modulate and amplify or decode (depending on the transmission technique) the received symbols and enter into the second phase.

In the “relay phase”, the relays transmit simultaneously the received symbols using one of the distributed transmission modes (diversity or spatial multiplexing mode) during time periods $T_2$. We assume perfect synchronization between the relays (the issue of asynchronous relay nodes has been well investigated in [12, 13] and [14]). In our model, the network requires at least one relay as we assume that the direct link source-destination is always corrupted and hence not used.

In this paper, we investigate only the network configuration having two relays and a destination node with 2 antennas. Extending the study to multiple-relay with multiple-antenna will be interesting for further research.

B. Channel Model

We assume stationary terminals and quasi-static channel conditions for the entire transmission period $(T_1 + T_2)$. We assume flat fading Rayleigh wireless channels with independent identically distributed (i.i.d.) zero mean complex Gaussian distributed random variables, circularly symmetric with unit variance. We assume the channel is unknown at the transmitters. In AF, the destination has Channel State Information (CSI) of all the channels. Whereas, in DF, the destination has CSI of the relays-destination channels only and each relay has the CSI of its source-relay channel. The transmit power should be the same over the two phases in order to maximize the expected received SNR [6]. We assume also that the transmit power is equally distributed between the relays. We note $P_1$ the transmit power of the “broadcast phase” and $P_2$ the transmit power of the $k^{th}$ relay on the “relay phase”. Thus, we have $P_1 \times T_1 = K \times P_2 \times T_2$.

During the “broadcast phase”, the vector of signals received at the $k^{th}$ relay, $\mathbf{r}_k$ (whose size is $1 \times T$), can be expressed by:

$$\mathbf{r}_k = \sqrt{P_1 T} \mathbf{h}^{s,k} \mathbf{s}_k + \mathbf{n}^{s,k}, \quad k = 1, \ldots, K$$

(1)

where $\mathbf{h}^{s,k}$ is the source-$k^{th}$ relay channel coefficient, $\mathbf{s}_k$ is a $1 \times T$ vector of the transmitted symbols ($T = T_1$ in the diversity mode and $T = T_1/K$ in the spatial multiplexing mode) received at the $k^{th}$ relay and $\mathbf{n}^{s,k}$ is the $1 \times T$ vector of an additive white gaussian noise (AWGN) with zero mean and covariance matrix $E\{\mathbf{n}^{s,k}\mathbf{n}^{s,k}\} = N_0 \mathbf{I}_T$ (the notation $E\{\cdot\}$ denotes the expectation and $\mathbf{I}_T$ denotes the $T \times T$ identity matrix). We denote $\mathbf{A}'$, $\mathbf{A}''$, $\mathbf{A}$ and $\|\mathbf{A}\|_F$ the transpose, the conjugate transpose, the conjugate and the Frobenius norm of a complex matrix $\mathbf{A}$, respectively.

The next section details the transmission modes of the “relay phase” for AF and DF relaying nodes.

III. TRANSMISSION MODES IN COOPERATIVE WIRELESS COMMUNICATIONS

The considered network has two relays, thus $T_1 = 4$ and $T_2 = 2$. We assume that the source uses always the same modulation scheme (BPSK), and the signals received at the relays may be transformed to adapt to a different constellation at the destination node (BPSK for the spatial multiplexing receiver and QPSK for the Alamouti receiver). This operation allows to get the same system data rate $R$ (bits/time period) for Alamouti and spatial multiplexing modes and thus allow to make a fair comparison between the two transmission techniques.

A. Spatial Multiplexing mode

For spatial multiplexing, on the “broadcast phase” each relay detects a fraction $T_1/2$ of the transmitted symbols and stays inactive for $T_1/2$ time periods. In our model, a simple proposed way to do so is to let the $1^{st}$ ($2^{nd}$) relay detect the symbols transmitted on the odd (even) time periods and stay inactive on the even (odd) time periods. Consequently, $T = T_1/2 = 2$. Fig.1 describes the distributed spatial multiplexing transmission mode.

1) Amplify-and-Forward Relaying: Before entering the “relay phase”, each relay amplifies its signal by a gain factor $g_k$. The $1 \times T_2$ transmitted vector of signals of the $k^{th}$ relay is:

$$\mathbf{x}_k = g_k^r \mathbf{r}_k,$$

(2)

where $E\{\|\mathbf{x}_k\|_F^2\} = P_2 T_2$. The received $L_d \times T_2$ matrix of signals at the destination is:

$$\mathbf{D} = \sum_{k=1}^{2} \mathbf{h}^{k,d} \mathbf{x}_k + \mathbf{N}^d,$$

(3)

where $\mathbf{h}^{k,d}$ is the $L_d \times 1$ vector of the $k^{th}$ relay-destination channel coefficients and $\mathbf{N}^d$ is the $L_d \times T_2$ matrix containing the AWGN of the relays-destination channel.
zero mean elements and a covariance matrix $E\left\{ \mathbf{N}^{d} \mathbf{N}^{d^T} \right\} = N_{I} \mathbf{I}_{d}$. Substituting (1) and (2) in (3), $\mathbf{D}$ becomes,

$$\mathbf{D} = \sqrt{P_1 \mathbf{T}} \sum_{k=1}^{2} \mathbf{h}^{k,d} g^k \mathbf{h}^{s,k} \mathbf{s}^k + \hat{\mathbf{N}}^d. \quad (4)$$

Finally,

$$\mathbf{D} = \sqrt{P_1 \mathbf{T}} \mathbf{H}_{eq} \mathbf{S}_{eq} + \hat{\mathbf{N}}^d, \quad (5)$$

where $\mathbf{H}_{eq} = \begin{bmatrix} \mathbf{h}^{1,d} g^1 \mathbf{h}^{s,1} & \mathbf{h}^{2,d} g^2 \mathbf{h}^{s,2} \end{bmatrix}$, $\mathbf{S}_{eq} = \begin{bmatrix} \mathbf{s}^{1} \\ \mathbf{s}^{2} \end{bmatrix}$ and $\hat{\mathbf{N}}^d = \sum_{k=1}^{2} \mathbf{h}^{k,d} g^k \mathbf{n}^{s,k} + \mathbf{N}^d$.

At the destination, we assume a maximum likelihood detection delivering $\tilde{\mathbf{S}}_{eq}$ (the $K \times T$ matrix of estimated symbols):

$$\tilde{\mathbf{S}}_{eq} = \arg \min_{\mathbf{S}_{eq} \in \mathcal{S}} \left\| \mathbf{D} - \sqrt{P_1 \mathbf{T}} \mathbf{H}_{eq} \mathbf{S}_{eq} \right\|_F, \quad (6)$$

where $\mathcal{S}$ is the set of all possible $K \times T$ matrices of transmitted symbols (from the BPSK constellation in our model) in the “broadcast phase”.

2) Decode-and-Forward Relaying: Since each relay has knowledge of the CSI of the source-relay channel, it decodes the transmitted symbols by performing maximum likelihood, delivering a $1 \times T$ vector $\mathbf{s}^{k,DF}$, $\forall k = 1, 2$, as follows:

$$\mathbf{s}^{k,DF} = \arg \min_{\mathbf{s} \in \mathcal{S}} \left\| \mathbf{r}^k - \sqrt{P_1 \mathbf{T}} \mathbf{h}^{s,k} \mathbf{s}^k \right\|_F. \quad (7)$$

Entering the “relay phase”, each relay sends the estimated symbols with a gain factor $g^{k,DF}$ to respect the energy distribution among the two transmission phases and the relays. The $1 \times T$ matrix of signals sent by the $k^{th}$ relay, $\mathbf{x}^{k,DF}$, is given by:

$$\mathbf{x}^{k,DF} = g^{k,DF} \mathbf{s}^{k,DF}. \quad (8)$$

The received $L_d \times T_2$ matrix of signals $\mathbf{D}^{DF}$ at the destination is defined by (similar to (5)):

$$\mathbf{D} = \mathbf{H}_{eq}^{DF} \mathbf{S}_{eq}^{DF} + \hat{\mathbf{N}}^d, \quad (9)$$

where $\mathbf{H}_{eq}^{DF} = \begin{bmatrix} \mathbf{h}^{1,d} g^{1,DF} \mathbf{h}^{2,d} g^{2,DF} \end{bmatrix}$ and $\mathbf{S}_{eq}^{DF} = \begin{bmatrix} \mathbf{s}^{1,DF} \\ \mathbf{s}^{2,DF} \end{bmatrix}$. The destination performs maximum likelihood detection and the estimated symbols at the destination $\tilde{\mathbf{S}}_{eq}^{DF}$ are:

$$\tilde{\mathbf{S}}_{eq}^{DF} = \arg \min_{\mathbf{S}_{eq}^{DF} \in \mathcal{S}} \left\| \mathbf{D}^{DF} - \sqrt{P_1 \mathbf{T}} \mathbf{H}_{eq}^{DF} \mathbf{S}_{eq}^{DF} \right\|_F, \quad (10)$$

where $\mathcal{S}$ is the set of all possible $K \times T$ matrices of transmitted symbols in the “broadcast phase”.

B. Alamouti diversity transmission mode

On the “broadcast phase”, each relay detects all the transmitted symbols. Then, in equation (1), $\mathbf{s}^k = \mathbf{s}^{k'}$, $\forall k \neq k'$. In our model, $T_1 = 4$ and $T_2 = 2$. Fig. 2 shows the Alamouti transmission executed during $T_1 + T_2$ time periods.

1) Amplify-and-Forward Relaying: Since fixed transmission rate is considered, a transformation has to be made to the received signals to be detected as QPSK symbols at the destination. For Amplify-and-Forward and BPSK transmitted symbols by the source node, we propose the following procedure: The relay node $k$ combines the received signals to get a new received vector of signals $\mathbf{y}^k$:

$$\mathbf{y}^k = [r^k \mathbf{1} + jr^k \mathbf{2} r^k \mathbf{3} + jr^k \mathbf{4}], \quad (11)$$

where $r^k[i]$ is the received signal at the $i^{th}$ time period at relay $k$, $i = 1, …, T$. By denoting $s_1 = s_1 + js_2, s_2 = s_3 + js_4$, $\mathbf{s} = \begin{bmatrix} s_1 \\ s_2 \end{bmatrix}$ and $\mathbf{n}^{s,k} = \begin{bmatrix} n^{s,k} \mathbf{1} + jn^{s,k} \mathbf{2} n^{s,k} \mathbf{3} + jn^{s,k} \mathbf{4} \end{bmatrix}$, $\mathbf{y}^k$ is expressed by:

$$\mathbf{y}^k = \sqrt{P_1 \mathbf{T}} \mathbf{h}^{s,k} \mathbf{s}^k + \mathbf{n}^{s,k}. \quad (12)$$

The $1 \times T_2$ vector of signals sent by the $k^{th}$ relay is given by:

$$\mathbf{x}^k = \mathbf{y}^k \mathbf{A}^k g^k, \quad (13)$$

where

$$1^{st} \text{case } : \mathbf{A}^k = \mathbf{B}^k (\mathbf{A}^k = \mathbf{0}_{T_2}), \mathbf{y}^k = \mathbf{y}^k,$$

$$\mathbf{h}^{s,k} = \mathbf{h}^{s,k}, \mathbf{n}^{s,k} = \mathbf{n}^{s,k}, \mathbf{s}^k = \mathbf{s}^k,'$$

$$2^{nd} \text{case } : \mathbf{A}^k = \mathbf{B}^k (\mathbf{A}^k = \mathbf{0}_{T_2}), \mathbf{y}^k = \mathbf{y}^k,$$

$$\mathbf{h}^{s,k} = \mathbf{h}^{s,k}, \mathbf{n}^{s,k} = \mathbf{n}^{s,k}, \mathbf{s}^k = \mathbf{s}^k,'$$

with $\mathbf{A}^k$ and $\mathbf{B}^k$, of dimensions $T_2 \times T_2$, the Alamouti STBC matrices associated to the $k^{th}$ relay [5] and $\mathbf{0}_{T_2}$ denotes the matrix of zeros whose size is $T_2 \times T_2$. The received signal at the destination is expressed by:

$$\mathbf{D} = \sqrt{P_1 \mathbf{T}} \mathbf{H} \mathbf{S} + \hat{\mathbf{N}}^d, \quad (15)$$

where $\mathbf{H} = \begin{bmatrix} \mathbf{h}^{1,d} g^1 \mathbf{h}^{s,1} & \mathbf{h}^{2,d} g^2 \mathbf{h}^{s,2} \end{bmatrix}$, $\mathbf{S} = \begin{bmatrix} \mathbf{s}^{(1)} \mathbf{A}^{(1)} \\ \mathbf{s}^{(2)} \mathbf{A}^{(2)} \end{bmatrix}$ and $\hat{\mathbf{N}}^d = \sum_{k=1}^{2} \mathbf{h}^{k,d} g^k \mathbf{n}^{s,k} \mathbf{A}^k + \mathbf{N}^d$. Since Alamouti coding is used, then $\mathbf{A}^1 = \mathbf{A}^1 = \begin{bmatrix} 1 & 0 \\ 0 & 1 \end{bmatrix}$ and $\mathbf{A}^2 = \mathbf{B}^2 = \begin{bmatrix} 0 & 1 \\ -1 & 0 \end{bmatrix}$. Let $\mathbf{d}_{eq}$ be the vector $\mathbf{d}_{eq} = \begin{bmatrix} D_{1} \mathbf{1} d_{2} \mathbf{1} D_{2} \mathbf{1} D_{2} \mathbf{2} D_{2} \mathbf{2} \end{bmatrix}$, where $D_{i,j}$ is the $(i,j)^{th}$ element of matrix $\mathbf{D}$, $\forall i = 1, 2$ and $\forall j = 1, 2$. $\mathbf{d}_{eq}$ is written:

$$\mathbf{d}_{eq} = \sqrt{P_1 \mathbf{T}} \mathbf{H}_{eq} \mathbf{S}_{eq} + \hat{\mathbf{N}}^d_{eq}, \quad (16)$$
symbols' estimation as in (17),

\[ s'_1, s'_2 \]

and \( \hat{\mathbf{n}}^d_e = \begin{bmatrix} \hat{N}^d_{1,1} & \hat{N}^d_{2,1} & \hat{N}^d_{1,2} & \hat{N}^d_{2,2} \end{bmatrix} \). The equivalent channel matrix \( \mathbf{H}_{eq} \) is orthogonal (i.e. \( \mathbf{H}_{eq} \mathbf{H}_{eq}^H = \mathbf{I}_2 \), with

\[ \mathbf{h} = \begin{bmatrix} h^1, d, g^1 \hat{h}^1, s, 1 & h^2, d, g^2 \hat{h}^2, s, 2 \end{bmatrix}^t \). If \( z = \mathbf{H}_{eq}^\dagger \hat{\mathbf{n}}^d_e \), we get

\[ z = \sqrt{P_T} \| \mathbf{h} \|_2^2 \mathbf{s}_{eq} + \mathbf{H}_{eq}^\dagger \hat{\mathbf{n}}^d_e. \]  

Where, \( \mathbf{H}_{eq} = \begin{bmatrix} h^1, d, g^1 \hat{h}^1, s, 1 & -h^2, d, g^2 \hat{h}^2, s, 2 \\ h^2, d, g^2 \hat{h}^2, s, 2 & h^1, d, g^1 \hat{h}^1, s, 1 \end{bmatrix} \), \( \mathbf{s}_{eq} = \begin{bmatrix} s'_1 \\ s'_2 \end{bmatrix} \)

Hence, the symbols \( s'_1 \) and \( s'_2 \) are detected separately at the destination (using QPSK constellation).

2) Decode-and-Forward Relaying: The detected vector of symbols at each relay is issued from equation (7). We propose to modulate the BPSK symbols into QPSK symbols to satisfy the fixed rate constraint and a new vector of symbols \( \mathbf{y}_{k,DF} \) is generated:

\[ \mathbf{y}_{k,DF} = \begin{bmatrix} y_{1,DF}^k & y_{2,DF}^k \end{bmatrix}, \]  

where \( y_{1,DF}^k = s_{1}^{k,DF}[1] + j s_{2}^{k,DF}[1] \) and \( y_{2,DF}^k = s_{1}^{k,DF}[3] + j s_{2}^{k,DF}[4] \). Here, \( s_{i}^{k,DF}[i] \) is the \( i \)th estimated symbol at relay node \( k \), \( \forall k = 1, \ldots, T \). The transmitted vector of signals by the \( k \)th relay \( \mathbf{x}_{k,DF} \) is similar to that in equation (13). The received \( L_d \times T_2 \) matrix of signals \( \mathbf{D}_{DF} \) at the destination is defined by:

\[ \mathbf{D}_{DF} = \mathbf{H}_{DF} \mathbf{S}_{DF} + \mathbf{N}_d, \]  

where \( \mathbf{H}_{DF} = \begin{bmatrix} \mathbf{h}^1, d, g^1 \mathbf{1,DF} & \mathbf{h}^2, d, g^2 \mathbf{2,DF} \end{bmatrix} \) and \( \mathbf{S}_{DF} = \begin{bmatrix} \mathbf{y}_{1,DF}^1 & \mathbf{y}_{2,DF}^1 \\ \mathbf{y}_{1,DF}^2 & \mathbf{y}_{2,DF}^2 \end{bmatrix} \). Assuming that \( \mathbf{y}_{1,DF}^k = \mathbf{y}_{2,DF}^k = \mathbf{y}_{DF}^k \), then the vector \( \mathbf{d}_{eq}^D \) can be defined as in equation (16) and is expressed by:

\[ \mathbf{d}_{eq} = \mathbf{H}_{eq}^DF \mathbf{s}_{eq} + \hat{\mathbf{n}}^d_{eq}, \]  

where \( \mathbf{H}_{eq}^DF = \begin{bmatrix} \mathbf{h}^1, d, g^1 \mathbf{1,DF} & -\mathbf{h}^2, d, g^2 \mathbf{2,DF} \\ \mathbf{h}^2, d, g^2 \mathbf{2,DF} & \mathbf{h}^1, d, g^1 \mathbf{1,DF} \end{bmatrix} \), \( \mathbf{s}_{eq} = \begin{bmatrix} \mathbf{S}_{DF}^1 \\ \mathbf{S}_{DF}^2 \end{bmatrix} \) and \( \hat{\mathbf{n}}^d_{eq} \) is identical to that in (16). Performing symbols' estimation as in (17), \( \mathbf{z}_{DF} = \mathbf{H}_{eq}^{DF\dagger} \mathbf{d}_{eq}^D \) is given by

\[ \mathbf{z}_{DF} = \mathbf{H}_{eq}^{DF\dagger} \mathbf{d}_{eq}^D = \| \mathbf{H}_{eq}^{DF\dagger} \|_{2}^{2} \mathbf{s}_{eq} + \mathbf{H}_{eq}^{DF\dagger} \hat{\mathbf{n}}^d_{eq}, \]  

where \( \mathbf{H}_{eq}^{DF} = \begin{bmatrix} \mathbf{h}^1, d, g^1 \mathbf{1,DF} & \mathbf{h}^2, d, g^2 \mathbf{2,DF} \end{bmatrix}^t \).

IV. DECENTRALIZED SWITCHING MODE BASED ON ESTIMATED SNR

In AF relaying, the \( k \)th relay has statistics of the channel source-\( k \)th relay. Based on this information, it estimates the SNR and compares it to SNR Threshold (\( \gamma_{AF} \)) to decide which transmission mode to use for the next transmission.

In DF relaying, we adopt the same switching mode as in [10]. Relay \( k \) knows the statistics of the \( k \)th relay-destination channel by listening to the reports feedback from the destination node (ACK or NACK). A decision is then made by each relay by comparing the estimated SNR to threshold \( \gamma_{DF} \).

Optimizing \( \gamma_{AF} \) (or \( \gamma_{DF} \)) is an open problem since it depends on many factors such as Doppler frequency, the multi-path environment, etc. However, in this paper we assume fixed nodes during a cooperative transmission and we choose a fixed transmission rate \( \bar{R} \), thus \( \gamma_{AF} \) and \( \gamma_{DF} \) are constants.

Note that the AF-relays choose the transmission mode based only on the estimated SNR of the “broadcast phase”. It is a sub-optimal selection since it does not take into account the \( k \)th relay-destination channel statistics.

The centralized switching mode based on symbol error probability minimization is well detailed in [9] and [11]. At each channel realization, the destination evaluates the symbol error probability \( P_e \) of the system channel (source-relays channel + relays-destination channel in AF and relays-destination channel in DF) and sends a feedback information (1bit) to the source node (and the relays) about the modulation (the transmission technique) to be adopted.

The decentralized switching mode presents less communication between the nodes in the network than the centralized switching mode and thus saves more energy and time delay. With AF relaying, the savings are more important than DF relaying. Moreover, no different source modulation is required for each transmission mode since the relays process the received signals to be adapted to the adequate constellation at the destination node.

V. SIMULATION RESULTS

In this section, we present the Bit Error Rate (BER) performance using Monte-Carlo simulations of all the transmission modes using AF or DF relays. As it has been introduced previously, the system has 2 relays and offers a system transmission rate \( R = \frac{1}{2} \) bits/time period. Figures 3 and 4 present the BERs of AF and DF relaying techniques for different transmission modes, respectively. We call by “SNR Decentralized Approach” and “\( P_e \) Centralized Approach” the adaptive transmission techniques based on the estimated SNR criterion and the minimal symbol error probability \( P_e \) criterion, respectively.

Fig.3 shows the BERs of Alamouti, spatial multiplexing and the decentralized and centralized modes for AF relays. The achieved diversity for spatial multiplexing and Alamouti are 1 and 2 respectively. Alamouti achieves the maximal diversity order and this result agrees with the theoretical result in [6] where diversity in relay networks is defined by \( d = \min(L_s, L_d)L \), with \( L_s \), \( L_d \) and \( L \) are the number of antennas at the source, the destination and the sum of antennas of all relays, respectively. For low SNR values (< 0dB), spatial multiplexing performs better than Alamouti and performs worse at high SNR. Consequently, the SNR decentralized approach performs as good as spatial multiplexing at low SNR and as good as Alamouti at high SNR. This result is valid since we assume the same noise conditions for the two transmission phases \( (N_0 = N_1) \). Otherwise, the performance will be degraded since the estimation is based only on the source-relay channel. \( \gamma_{AF} \) value that defines the transmission technique to be used is set at the intersection of
BER very small. At however, its gain compared to the decentralized approach is very small. At $BER = 10^{-2}$, the SNR gain is less than 1dB.

Fig. 4 presents the BERs of all the transmission modes when the relays are DF nodes. In this case, Alamouti and spatial multiplexing achieve the same diversity 1. In fact, the system diversity follows the minimal achieved diversity over the two transmission phases [5]. The decentralized approach chooses spatial multiplexing for $\gamma_{DF} = -1.34dB$ and Alamouti for $SNR \leq \gamma_{DF}$. As for AF relaying, the centralized approach shows better BER than the decentralized approach, At $BER = 10^{-2}$, the SNR gain is about 1dB.

VI. CONCLUSION

In this paper, we have analyzed adaptive transmission techniques in cooperative wireless communications with AF or DF relays. We proposed a simple decentralized switching mode based on the estimated SNR value at the relays and compare its performance to the switching technique based on symbol error probability minimization. We evaluated the BER performances of systems with two relays deployed. We showed that the adaptive transmissions give interesting gains compared to fixed transmission modes (using only distributed Alamouti or only distributed spatial multiplexing). We found also that decentralized switching BER performance approaches the centralized switching performance for AF and DF relaying. This result is attractive since the decentralized switching provides better energy and time delay savings. This paper has also proposed a simple scheme for signal processing at the relay nodes. Future research will be interested in determining a type of modulation flexible enough to allow easy transformation of signals at the relay nodes and to be applicable for larger transmission rates.

REFERENCES