Static Hybrid Multihop Relaying

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Abstract—In this work, we propose a new static hybrid multihop relaying protocol where some relays amplify the received signal whereas the remaining ones use Decode and Forward (DF) relaying. The relaying mode in each relay is set using the distance between the different nodes or the average SNR. The exact and asymptotic bit error probabilities are derived. Simulation results are provided in different contexts to compare the performance of hybrid relaying to conventional AF and DF relaying.

Keywords: Cooperative diversity, Decode and Forward relaying, Amplify and Forward Relaying, Rayleigh fading channels.

I. INTRODUCTION

Multihop relaying can be used in wireless networks in order to increase the coverage and reduce the outage probability. By increasing the number of hops, the average Signal to Noise Ratio (SNR) at the destination increases for the same power spent by the source and all relays. Amplify and Forward (AF) and Decode and Forward (DF) relaying are the most widely used protocols. In AF relaying, each relay amplifies the received signal using an adaptive gain. DF relays demodulate the signal and regenerate it. To avoid error propagation, they transmit only if they correctly decoded. Therefore, AF protocol is less complex than DF but it may offer worse performance than DF since the noise is amplified with the useful signal.

The Bit Error Probabilities (BEP) of dual-hop and multihop relaying using AF have been derived in [1]-[3]. Multihop multibranch relaying using DF has been studied in [4]. Some adaptive AF and DF relaying protocols were proposed in the literature for dual-hop relaying [5]-[9]. In [5]-[7], the relay first tries to decode the received signal. If the decoding succeeds, it transmits the decoded signal as in DF protocol. If the decoding fails, the relay simply amplifies the received signal. In [8], the relay estimates the BEP using log-likelihood ratios. If the estimated BEP is above a given threshold, DF relaying is used. Otherwise, the relay amplifies the received signal since it contains no or only few errors. In [9], a Decode-Amplify Forward protocol is proposed where a relay amplifies the soft output of the channel decoder output. In [10], an adaptive relaying protocol has been proposed called Threshold based adaptive Decode-Amplify and Forward relaying. In this protocol, AF is used only when the instantaneous SNR is larger than the average one. Otherwise, DF is used. Static hybrid dual hop relaying has been proposed in [11]-[12] where some relays use AF and faraway relays decode the received signal. In this static dual hop hybrid relaying protocol, the relaying mode is fixed as long as the relay node position remains unchanged. The relaying mode of each relay is based on relays position or the average SNR. To the best of the authors’ knowledge, static multihop hybrid relaying, where some relays use AF and other relays use DF relaying, hasn’t been previously proposed or studied. The paper scope is to set the relaying mode (AF or DF) for each relay to have a good compromise between complexity and performance. For example, for 3 hops network, we will compare the performance of AF-DF, DF-AF, DF-DF and AF-DF. AF-DF means that the first relays amplifies the received signal whereas the next one use decode and forward relaying.

The paper is organized as follows. The next section deals with hybrid three hops relaying whereas section III is dedicated to four hops relaying. Section IV generalizes the previous results to multihop relaying. Section V provides some simulation results. Section VI draws some conclusions and perspectives.

II. HYBRID THREE HOPS RELAYING

A. Performance analysis of DF-DF relaying

We consider a cooperative network composed of a source $S$, two relays $R_1$ and $R_2$, and a destination $D$. Each symbol $x$ is transmitted from $S$ to $R_1$, then $R_1$ detects it and forwards it to $R_2$. Finally, $R_2$ detects the symbol and forwards it to $D$. Both relays transmit only they have correctly detected. Otherwise, $R_1$ and/or $R_2$ are idle and the symbol will not be received at $D$. We assume that each relay perfectly judges if it has correctly decoded.

The Bit Error Probability (BEP) at $D$ is given by

$$P_{e,D}^{DF,DF} = 1 - (1 - P_e,S,R_1)(1 - P_e,R_1,R_2)(1 - P_e,R_2,D),$$

(1)

where $P_e,X,Y$ is the BEP between nodes $X$ and $Y$, $(X,Y) \in \{(S,R_1); (R_1,R_2); (R_2,D)\}$. For $M-QAM$ modulation and Rayleigh fading channels, it is given by

$$P_{e,X,Y} = A \left( 1 - \frac{\Gamma_{XY}}{\Gamma_{XY} + \frac{B}{\pi}} \right),$$

(2)

$A$ and $B$ depend on the considered modulation (for example, $A = 1$, $B = 2$ for BPSK), $\Gamma_{XY}$ is the average SNR of $X$-$Y$ link

$$\Gamma_{XY} = E(\Gamma_{XY}) = \frac{E_X}{N_0}E(|h_{XY}|^2),$$

(3)

$E(\cdot)$ is the expectation operator, $E_X$ is the transmitted energy per symbol by $X$ and $E(|h_{XY}|^2)$ is the power of the Rayleigh fading channel $h_{XY}$.

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The asymptotic BEP at D can be written as
\[
\tilde{P}_{e,D}^{DFDF} = \frac{A}{2B} \left[ \frac{1}{\Gamma_{SR_1}} + \frac{1}{\Gamma_{R_1R_2}} + \frac{1}{\Gamma_{R_2D}} \right] - \left( \frac{A}{2B} \right)^2 \frac{1}{\Gamma_{SR_1}} \left[ \frac{1}{\Gamma_{R_1R_2}} + \frac{1}{\Gamma_{R_2D}} \right]
\]

\[B. \ Performance \ analysis \ of \ AF-AF \ relaying\]

For AF relaying, the SNR at the destination can be written as [2]
\[
\Gamma_D = \frac{\Gamma_{SR_1R_2} \Gamma_{D}}{1 + \Gamma_{SR_1R_2} + \Gamma_{D}} < \Gamma_{up}^D = \min(\Gamma_{SR_1}, \Gamma_{R_1R_2}, \Gamma_{D}),
\]
where \( \Gamma_{SR_1R_2} \) is the SNR of \( SR_1R_2 \) AF link.

For Rayleigh fading channels, \( \Gamma_{up}^D \) follows an exponential distribution with mean
\[
\Gamma_{up}^D = \frac{1}{\Gamma_{SR_1} + \frac{1}{\Gamma_{R_1R_2}} + \frac{1}{\Gamma_{R_2D}}}.
\]

We deduce a lower bound of the BEP at the destination for M-QAM modulations:
\[
P_{e,D}^{AF} > \int A(Q(\sqrt{B\gamma}))p_{\Gamma_{up}^D}(\gamma)d\gamma = \frac{A}{2} \left( 1 - \sqrt{\Gamma_{up}^D + \frac{2}{\gamma}} \right)
\]

Using (7), the asymptotic BEP of AF-AF relaying is given by
\[
\tilde{P}_{e,D}^{AF} = \frac{A}{2B} \left[ \frac{1}{\Gamma_{SR_1}} + \frac{1}{\Gamma_{R_1R_2}} + \frac{1}{\Gamma_{R_2D}} \right] - \left( \frac{A}{2B} \right)^2 \frac{1}{\Gamma_{SR_1}} \left[ \frac{1}{\Gamma_{R_1R_2}} + \frac{1}{\Gamma_{R_2D}} \right]
\]

\[C. \ Performance \ analysis \ of \ the \ proposed \ DF-AF \ relaying\]

In DF-AF relaying, the first relay detects the transmitted symbol whereas \( R_2 \) amplifies the received signal. The BEP at the destination is given by
\[
P_{e,D}^{DF} = 1 - (1 - P_{e,SR_1})(1 - P_{e,R_1R_2D}),
\]

We can derive the exact expression of the BEP of \( R_1R_2D \) link [3]. However, we prefer to use min upper bound to obtain closed form expressions
\[
\Gamma_{R_1R_2D} < \Gamma_{up}^{R_1R_2D} = \min(\Gamma_{R_1R_2}, \Gamma_{R_2D})
\]

This upper bound gives
\[
P_{e,R_1R_2D} > \frac{A}{2} \left( 1 - \sqrt{\Gamma_{up}^{R_1R_2D} + \frac{2}{\gamma}} \right)
\]

where
\[
\Gamma_{up}^{R_1R_2D} = \frac{\Gamma_{R_1R_2} \Gamma_{R_2D}}{\Gamma_{R_1R_2} + \Gamma_{R_2D}}
\]

Combining (9) and (11), we obtain a lower bound on the BEP at the destination for hybrid DF-AF relaying.

The asymptotic BEP of hybrid DFAF relaying is given by
\[
\tilde{P}_{e,D}^{DFAF} = \frac{A}{2B} \left[ \frac{1}{\Gamma_{SR_1}} + \frac{1}{\Gamma_{R_1R_2}} + \frac{1}{\Gamma_{R_2D}} \right] - \left( \frac{A}{2B} \right)^2 \frac{1}{\Gamma_{SR_1}} \left[ \frac{1}{\Gamma_{R_1R_2}} + \frac{1}{\Gamma_{R_2D}} \right]
\]

\[D. \ Performance \ analysis \ of \ the \ proposed \ DF-AF \ relaying\]

For AF-AF relaying, the BEP at D is given by
\[
P_{e,D} = 1 - (1 - P_{e,SR_1})(1 - P_{e,R_2D}),
\]

\[
P_{e,SR_1R_2} > \frac{A}{2} \left( 1 - \sqrt{\Gamma_{up}^{SR_1R_2} + \frac{2}{\gamma}} \right),
\]

\[
\Gamma_{up}^{SR_1R_2} = \frac{\Gamma_{SR_1} \Gamma_{R_2D}}{\Gamma_{SR_1} + \Gamma_{R_2D}}.
\]

The asymptotic BEP of hybrid AFDF relaying is given by
\[
\tilde{P}_{e,D}^{AFDF} = \frac{A}{2B} \left[ \frac{1}{\Gamma_{SR_1}} + \frac{1}{\Gamma_{R_1R_2}} + \frac{1}{\Gamma_{R_2D}} \right] - \left( \frac{A}{2B} \right)^2 \frac{1}{\Gamma_{SR_1}} \left[ \frac{1}{\Gamma_{R_1R_2}} + \frac{1}{\Gamma_{R_2D}} \right]
\]

\[E. \ Performance \ comparison \ of \ the \ different \ protocols\]

By comparing the asymptotic BEP, we first notice that AFAF relaying offers worse performance than the other protocols. Also, DFDF offers always better performance than DAF and AFDF. The difference between the asymptotic performance of DAF and AFDF is given by
\[
\tilde{P}_{e,D}^{AFDF} - \tilde{P}_{e,D}^{DFDF} = \left( \frac{A}{2B} \right)^2 \left[ \frac{1}{\Gamma_{R_1R_2}} \left( \frac{1}{\Gamma_{SR_1}} + \frac{1}{\Gamma_{R_2D}} \right) - \frac{1}{\Gamma_{SR_1}} \right]
\]

\[III. \ HYBRID \ FOUR \ HOPS \ RELAYING\]

\[A. \ DFDFDF \ relaying\]

For DFDFDF relaying, the BEP at the destination is given by
\[
P_{e,D}^{DFDFDF} = 1 - (1 - P_{e,SR_1})(1 - P_{e,R_2D}) \times (1 - P_{e,R_3R_2D})
\]

Therefore, the asymptotic BEP is given by
\[
\tilde{P}_{e,D}^{DFDFDF} = \frac{A}{2B} \left[ \frac{1}{\Gamma_{SR_1}} + \frac{1}{\Gamma_{R_1R_2}} + \frac{1}{\Gamma_{R_2D}} \right] - \left( \frac{A}{2B} \right)^2 \frac{1}{\Gamma_{SR_1}} \left[ \frac{1}{\Gamma_{R_1R_2}} + \frac{1}{\Gamma_{R_2D}} \right]
\]

\[
+ \frac{1}{\Gamma_{R_1R_2}} \left( \frac{1}{\Gamma_{R_2D}} + \frac{1}{\Gamma_{R_3D}} \right)
\]
B. AFAF relaying

Similarly to section II.B, a lower bound of the BEP at the destination for AFAF relaying is given by

$$P_{e,D}^{AFAF} > \frac{A}{2} \left( 1 - \sqrt{\frac{2}{B} + \frac{2}{B^2}} \right),$$

(21)

where

$$\frac{1}{\Gamma^a D} = \frac{1}{\Gamma_{SR_1}} + \frac{1}{\Gamma_{R_1 R_2}} + \frac{1}{\Gamma_{R_2 R_3}} + \frac{1}{\Gamma_{R_3 D}}.$$ 

(22)

The asymptotic BEP is expressed as follows

$$\tilde{P}_{e,D}^{AFAF} = \frac{A}{2B} \left( \frac{1}{\Gamma_{SR_1}} + \frac{1}{\Gamma_{R_1 R_2}} + \frac{1}{\Gamma_{R_2 R_3}} + \frac{1}{\Gamma_{R_3 D}} \right).$$

(23)

C. AFDFAF relaying

For 4-hops AFDFAF relaying, the BEP at D is given by

$$P_{e,D}^{AFDFAD} = 1 - (1 - P_{e,SR_1, R_2}) (1 - P_{e,R_2 R_3}) (1 - P_{e,R_3 D}).$$

(24)

The asymptotic BEP is given by

$$\tilde{P}_{e,D}^{AFDFAD} = \frac{A}{2B} \left[ \frac{1}{\Gamma_{SR_1}} + \frac{1}{\Gamma_{R_1 R_2}} + \frac{1}{\Gamma_{R_2 R_3}} + \frac{1}{\Gamma_{R_3 D}} \right],$$

(25)

$$ - \left( \frac{A}{2B} \right)^2 \left[ \frac{1}{\Gamma_{SR_1}} \left( \frac{1}{\Gamma_{R_1 R_2}} + \frac{1}{\Gamma_{R_2 R_3}} \right) + \frac{1}{\Gamma_{R_3 D}} \right] \right].$$

Therefore, the difference between the asymptotic BEP of AFDFAF and DFDFDF relaying is

$$\tilde{P}_{e,D}^{AFDFAD} - \tilde{P}_{e,D}^{DFDFDF} = \left( \frac{A}{2B} \right)^2 \frac{1}{\Gamma_{SR_1} \Gamma_{R_1 R_2}}.$$ 

(26)

AFDFDF relaying offers close performance to DFDFDF relaying if $R_1$ is close to $S$ or $R_2$. We also notice that the difference between the asymptotic BEP of AFDFAF and DFDFDF is proportional to the product of the inverse SNRs of the AF relaying link (i.e. $\frac{1}{\Gamma_{SR_1} \Gamma_{R_1 R_2}}$).

D. DFAFDF relaying

For DFAFDF relaying, the BEP at D is given by

$$P_{e,D}^{DFADFD} = 1 - (1 - P_{e,SR_1, R_2}) (1 - P_{e,R_1 R_2 R_3}) (1 - P_{e,R_3 D}).$$

(27)

The asymptotic BEP is given by

$$\tilde{P}_{e,D}^{DFADFD} = \frac{A}{2B} \left[ \frac{1}{\Gamma_{SR_1}} + \frac{1}{\Gamma_{R_1 R_2}} + \frac{1}{\Gamma_{R_2 R_3}} + \frac{1}{\Gamma_{R_3 D}} \right],$$

(28)

$$ - \left( \frac{A}{2B} \right)^2 \left[ \frac{1}{\Gamma_{SR_1}} \left( \frac{1}{\Gamma_{R_1 R_2}} + \frac{1}{\Gamma_{R_2 R_3}} + \frac{1}{\Gamma_{R_3 D}} \right) \right] \right].$$

Therefore, the difference between the asymptotic BEP of DFAFDF and DFDFDF relaying is given by

$$\tilde{P}_{e,D}^{DFADFD} - \tilde{P}_{e,D}^{DFDFDF} = \left( \frac{A}{2B} \right)^2 \frac{1}{\Gamma_{SR_1} \Gamma_{R_1 R_2} \Gamma_{R_2 R_3}}.$$ 

(29)

DFAFDF relaying offers close performance to DFDFDF relaying if $R_2$ is close to $R_1$ or $R_3$. We also notice that (29) is proportional to the product of the inverse SNRs of the AF relaying link (i.e. $\frac{1}{\Gamma_{SR_1} \Gamma_{R_1 R_2} \Gamma_{R_2 R_3}}$).

E. DFDF relaying

For DFDF relaying, the BEP at D is given by

$$P_{e,D}^{DFDF} = 1 - (1 - P_{e,SR_1}) (1 - P_{e,R_1 R_2}) (1 - P_{e,R_2 R_3}).$$

(30)

The asymptotic BEP is given by

$$\tilde{P}_{e,D}^{DFDF} = \frac{A}{2B} \left[ \frac{1}{\Gamma_{SR_1}} + \frac{1}{\Gamma_{R_1 R_2}} + \frac{1}{\Gamma_{R_2 R_3}} + \frac{1}{\Gamma_{R_3 D}} \right],$$

(31)

$$ - \left( \frac{A}{2B} \right)^2 \left[ \frac{1}{\Gamma_{SR_1}} \left( \frac{1}{\Gamma_{R_1 R_2}} + \frac{1}{\Gamma_{R_2 R_3}} \right) \right] \right].$$

Therefore, the difference between the asymptotic BEP of DFDFAF and DFDFDF relaying is given by

$$\tilde{P}_{e,D}^{DFDF} - \tilde{P}_{e,D}^{DFDFDF} = \left( \frac{A}{2B} \right)^2 \frac{1}{\Gamma_{SR_1} \Gamma_{R_1 R_2} \Gamma_{R_2 R_3}}.$$ 

(32)

DFDFAF relaying offers close performance to DFDFDF relaying if $R_3$ is close to $R_2$ or $D$. We also notice that (32) is proportional to the product of the inverse SNRs of the AF relaying link (i.e. $\frac{1}{\Gamma_{SR_1} \Gamma_{R_1 R_2} \Gamma_{R_2 R_3}}$).

F. AFDAF relaying

For AFDAF relaying, the BEP at D is given by

$$P_{e,D}^{AFDAF} = 1 - (1 - P_{e,SR_1, R_2}) (1 - P_{e,R_1 R_2 R_3}).$$

(33)

The asymptotic BEP is given by

$$\tilde{P}_{e,D}^{AFDAF} = \frac{A}{2B} \left[ \frac{1}{\Gamma_{SR_1}} + \frac{1}{\Gamma_{R_1 R_2}} + \frac{1}{\Gamma_{R_2 R_3}} + \frac{1}{\Gamma_{R_3 D}} \right],$$

(34)

$$ - \left( \frac{A}{2B} \right)^2 \left[ \frac{1}{\Gamma_{SR_1}} \left( \frac{1}{\Gamma_{R_1 R_2}} + \frac{1}{\Gamma_{R_2 R_3}} \right) \right] \right].$$

Therefore, the difference between the asymptotic BEP of AFDFAF and DFDFDF relaying is given by

$$\tilde{P}_{e,D}^{AFDAF} - \tilde{P}_{e,D}^{DFDFDF} = \left( \frac{A}{2B} \right)^2 \frac{1}{\Gamma_{SR_1} \Gamma_{R_1 R_2} \Gamma_{R_2 R_3} \Gamma_{R_3 D}}.$$ 

(35)

AFDFAF relaying offers close performance to DFDFDF relaying if $R_3$ is close to $S$ or $R_2$ and $R_3$ is close to $R_2$ or $D$. We also notice that (35) is proportional to the sum of the product of the inverse SNRs of the two AF relaying link (i.e. $\frac{1}{\Gamma_{SR_1} \Gamma_{R_1 R_2}}$ and $\frac{1}{\Gamma_{SR_2} \Gamma_{R_2 R_3}}$). The last equation, (26) and (29) shows that AFDFAF relaying offers worse performance than AFDFAF and DFAFDF relaying.
G. AFAFDF relaying

For AFAFDF relaying, the BEP at $D$ is given by

$$P_{e,D}^{AFAFDF} = 1 - (1 - P_{e,SR_1R_2R_3}) (1 - P_{e,R_3D}) \tag{36}$$

The asymptotic BEP is given by

$$\tilde{P}_{e,D}^{AFAFDF} = \frac{A}{2B} \left[ \frac{1}{\Gamma_{SR_1}} + \frac{1}{\Gamma_{R_1R_2}} + \frac{1}{\Gamma_{R_2R_3}} + \frac{1}{\Gamma_{R_3D}} \right]$$

$$- \left( \frac{A}{2B} \right)^2 \frac{1}{\Gamma_{SR_1}} \left[ \frac{1}{\Gamma_{R_1R_2}} + \frac{1}{\Gamma_{R_2R_3}} + \frac{1}{\Gamma_{R_3D}} \right] \tag{37}$$

Therefore, the difference between the asymptotic BEP of AFAFDF and DFDFDF relaying is given by

$$\tilde{P}_{e,D}^{AFAFDF} - \tilde{P}_{e,D}^{DFDFDF} = \left( \frac{A}{2B} \right)^2 \left[ \frac{1}{\Gamma_{SR_1}} \frac{1}{\Gamma_{R_1R_2}} + \frac{1}{\Gamma_{R_2R_3}} + \frac{1}{\Gamma_{R_3D}} \right]$$

$$+ \frac{1}{\Gamma_{R_1R_2}} \left( \frac{1}{\Gamma_{SR_1}} + \frac{1}{\Gamma_{R_2R_3}} + \frac{1}{\Gamma_{R_3D}} \right) \tag{38}$$

AFAFDF relaying offers close performance to DFDFDF if $R_1$ is close to $S$ or $R_2$ and $R_2$ is close to $R_3$. The last equation, (26) and (29) shows that AFAFDF relaying offers worse performance than AFDFF and DFFAF relaying.

H. DFAFDF relaying

For DFAFDF relaying, the BEP at $D$ is given by

$$P_{e,D}^{DFAFDF} = 1 - (1 - P_{e,SR_1}) (1 - P_{e,R_1R_2R_3D}) \tag{39}$$

The asymptotic BEP is given by

$$\tilde{P}_{e,D}^{DFAFDF} = \frac{A}{2B} \left[ \frac{1}{\Gamma_{SR_1}} + \frac{1}{\Gamma_{R_1R_2}} + \frac{1}{\Gamma_{R_2R_3}} + \frac{1}{\Gamma_{R_3D}} \right]$$

$$- \left( \frac{A}{2B} \right)^2 \frac{1}{\Gamma_{SR_1}} \left( \frac{1}{\Gamma_{R_1R_2}} + \frac{1}{\Gamma_{R_2R_3}} + \frac{1}{\Gamma_{R_3D}} \right) \tag{40}$$

Therefore, the difference between the asymptotic BEP of DFAFDF and DFDFDF relaying is given by

$$\tilde{P}_{e,D}^{DFAFDF} - \tilde{P}_{e,D}^{DFDFDF} = \left( \frac{A}{2B} \right)^2 \left[ \frac{1}{\Gamma_{SR_1}} \frac{1}{\Gamma_{R_1R_2}} + \frac{1}{\Gamma_{R_2R_3}} + \frac{1}{\Gamma_{R_3D}} \right]$$

$$+ \frac{1}{\Gamma_{R_1R_2}} \left( \frac{1}{\Gamma_{SR_1}} + \frac{1}{\Gamma_{R_2R_3}} + \frac{1}{\Gamma_{R_3D}} \right) \tag{41}$$

DFAFDF relaying offers close performance to DFDFDF if $R_2$ is close to $R_1$ or $R_3$ and $R_3$ is close to $D$. The last equation, (29) and (32) shows that DFAFDF relaying offers worse performance than AFDFF and DFFAF relaying.

IV. HYBRID MULTIHOP RELAYING

The previous results can be extended to hybrid multihop relaying. The difference between the asymptotic BEP of multihop hybrid relaying and DF is given by

$$\tilde{P}_{e,D}^{hybrid} - \tilde{P}_{e,D}^{DF} = \sum_{i=1}^{nAF} \sum_{j=1}^{n_i} \sum_{k=1}^{n_i} \frac{1}{\Gamma_{ij}} \Gamma_{ik} \tag{42}$$

where $nAF$ is the number of AF links, $\{\Gamma_{ij}\}_{j=1}^{n_i}$ are the average SNRs characterizing the $i$-th AF link composed of $n_i$ hops. For example, for AFDFDF relaying, we have $nAF = 2$ AF links ($SR_1R_2$ and $R_2R_3D$), $\Gamma_{11} = \Gamma_{SR_1}$, $\Gamma_{12} = \Gamma_{R_1R_2}$, $\Gamma_{21} = \Gamma_{R_2R_3}$ and $\Gamma_{22} = \Gamma_{R_3D}$. Using (42), we verify that we obtain the result of the previous section (35). Equation (42) shows that hybrid relaying offers close performance to DF relaying if:

- In each AF link, all SNRs $\{\Gamma_{ij}\}_{j=1}^{n_i}$ are high (ten times higher than the lowest SNR of the different links)
- Or, in each AF link, all $\{\Gamma_{ij}\}_{j=1}^{n_i}$ are high except one value.

This will be our policy to set the relaying mode (i.e. AF or DF) for each relay node.

V. SIMULATION RESULTS

In this section, we provide some simulation results for BPSK modulation. The same power is allocated to the different nodes. The average power of the channel coefficient of the link between nodes $X$ and $Y$ is modeled as follows

$$E(|h_{XY}|^2) = \frac{\beta}{d_{XY}} \tag{43}$$

where $\alpha$ is the path loss exponent, $d_{XY} = d_{XY}^0/d_0$ is the normalized distance between $X$ and $Y$, $d_{XY}^0$ is the effective distance in meters, $d_0$ is an arbitrary reference distance and $\beta$ is the path loss at the reference distance. In the simulation results, the following parameters were used: $\alpha = 3$, and $\beta = 1$.

Fig. 1 shows the BER at $D$ for three hops relaying for $d_{SR_1} = 0.3$, $d_{R_1R_2} = 1$ and $d_{R_2D} = 1$. We notice that the AFDF relaying offers better performance than DF which was expected since $\Gamma_{SR_1} > \Gamma_{R_2D}$ (see equation (18)). Since $R_1$ is close to $S$, the proposed protocol AFDF offers the same performance as DFDF (see equations (4) and (17)) and 1.1 dB gain with respect to AFAF for BER=0.05.

Fig. 2 shows the BER at $D$ for three hops relaying when $d_{SR_1} = d_{R_1R_2} = 1$ and $d_{R_2D} = 0.4$. We notice that DFFAF relaying outperforms AFDFF which was expected since $\Gamma_{SR_1} < \Gamma_{R_2D}$. DFFAF offers the same performance as DFDF relaying and 1.1 dB gain with respect to AFDFF for BER=0.05.

Fig. 3 shows the BER at $D$ for four hops relaying when $d_{SR_1} = 1$, $d_{R_1R_2} = d_{R_2R_3} = 2$ and $d_{R_3D} = 0.2$. Since $R_3$ is close to $D$, DFDFDF offers close performance to DFDFDF (see equation (32)). DFDFDF offers 1 dB gain with respect to AFDFF and 3 dB gain with respect to noncooperative communications ($d_{SD} = d_{SR_1} + d_{R_1R_2} + d_{R_2R_3} + d_{R_3D}$). The order in performance of the different hybrid protocols is in accordance with the analysis provided in section III. Besides, AFDFF offers the same performance as AFDFF with is confirmed by the theoretical analysis (see (25) and (34)). AFDFF offers the same performance as AFAFDF (see (28) and (40)). AFDFF offers the same performance as AFAFDF (see (23) and (37)).

VI. CONCLUSIONS

In this paper, we have proposed and analyzed the performance of hybrid multihop relaying where some relays amplify the received signal and the remaining ones use DF relaying. We have shown that hybrid relaying offers better performance than AF relaying and close performance to DF relaying. The proposed protocol is less complex than DF and reduces power consumption and transmission delays since decoding is not performed at all nodes.
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Fig. 1. BEP of 3-hops relaying with respect average SNR : \( d_{SR_1} = 0.3 \), \( d_{R_1R_2} = 1 \) and \( d_{R_2D} = 1 \).

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