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A Cooperative Relaying Scheme Without The Need For Modulation With Increased Spectral Efficiency

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***Abstract*— Future infrastructure based wireless systems are likely to use *relaying* due to energy savings, simpler roll-out of cellular networks, simpler increase of coverage and so forth. To increase the performance of relaying based systems *cooperative relaying* has emerged as an additional option to exploit *spatial diversity*. In order to allow for a fair comparison between single-hop and multi-hop schemes, an N-fold more spectrally efficient use of each link needs to be assumed for the multi-hop case. We propose a novel protocol relying on two relaying nodes which does not require the need for an increase in spectral efficiency in comparison to direct transmission. However, we achieve a better performance in the *low SNR/high rate regime* (which is of interest in many cellular networks, e. g. UMTS) at the expense of a worse performance in the high SNR/low rate regime. The proposal is compared to direct transmission, conventional relaying, transmit diversity and a distinct cooperative relaying scheme considering their *outage probability*.**

I. Introduction

The demand for ubiquitous support of high data rates will increase in future infrastructure based wireless networks. These requirements cannot be fulfilled by only using conventional techniques and therefore more advanced methods are required, like relaying mechanisms. Relaying offers one solution for the tradeoff between coverage and supported data rate by using an intermediate node (the relay node) which receives the source message and retransmits it to the destination. Therefore, due to the reduced distances and non-linear pathlosses, less power is necessary to transmit the information. The concept of relaying was introduced by van der Meulen [1], and Cover and El Gamal were the first to deeply investigate capacity theorems for the one-relay case [2]. Among others [3], [4], [5] extended the one-relay case to a network of relays and proposed capacity theorems for it.

The probability of experiencing a deep fade and thus loosing a packet, rises with the number of serially concatenated links when conventinal relaying is used. Therefore, advanced techniques are necessary to increase the capacity and robustness, e. g. using multiple antennas [6] in combination with space-time coding like the well-known Alamouti scheme [7]. Another solution offering spatial diversity and therefore increased capacity, without employing physical antenna arrays, is cooperative relaying, which was originally proposed by Sendonaris *et al.* [8], [9].

There exists a variety of possible protocols which differ for instance in the degree of cooperation between relays and source. One example is the Simple Adaptive Decode-And-Forward (AdDF) proposed by Herhold *et al.* [10] which is the basis for the novel scheme presented in this paper. Advantages of the Simple AdDF are that it neither relies on channel state information at the transmitter nor on any feedback from the destination (as for instance ARQ (Automatic Repeat Request) based schemes do).

In [11], Laneman *et al.* applied the orthogonality constraint to cooperative relaying, i. e. a terminal cannot transmit and receive at the same time at the same frequency. This implies that relaying protocols introduce an additional delay and need to increase the instantaneous spectral efficiency. An additional delay has only consequences for the QoS but due to increased spectral efficiency relaying suffers from poor performance in the low SNR/high rate regime which is tackled in this paper.

We propose a novel protocol which has a significant performance improvement in this regime, at the cost of worse performance in the high SNR/low rate regime. The paper is structured as follows: section II defines the assumed system and channel model, section III shows an already proposed scheme which is profiled in a performance comparison and section IV introduces our novel protocol. Finally, section V analyzes the outage probability behaviour of our scheme and section VII gives some conclusions and outlines further work.

II. System and Channel Model

Our system consists of a single source s which tries to transmit its packet $x_s[k]$ during time interval $n = k$ (which is of length T) to the destination node d. In our analysis we assume that this message can be received and retransmitted by the two relays r_1 and r_2 with a) equal pathloss to the destination node and b) equal pathloss to the source. This symmetric pathloss is motivated by one or multi-tier relay networks where relay nodes are assumed to be grouped as a ring or rings around the base station. For fair comparison between direct transmission and the presented protocol, the overall spent power of all schemes is limited by P_sT which is the transmission energy of the source node in case of direct transmission. Furthermore, the maximum power at every single node is also limited by P_s (again for fairness reasons since most mobile terminals are power limited).

Moreover we assume that channel state information is only available at the receiver, no feedback from any node is supported, all nodes transmit synchronously and that for all nodes the orthogonality constraint holds. Since we concentrate on the analysis of scenarios where no other source of diversity can be exploited, the channels are assumed to be flat block fading channels, i. e. during one time interval of length T the fading statistics remain constant and the coherence interval of the channel is sufficiently long, so that time or frequency diversity cannot be exploited.

The recevied signal at node j, $y_j[n]$, is modeled as:

$$y_j[n] = h_{i,j}[n]x_i[n] + z_j[n] \tag{1}$$

with $h_{i,j}[n]$ denoting the fading coefficient, $z_j[n]$ denoting the receiver noise and $i \in \{s, r_1, r_2\}, j \in \{r_1, r_2, d\}$.

Both $h_{i,j}[n]$ and $z_j[n]$ are zero-mean, mutually indepedent, circularly symmetric, complex Gaussian random variables with variances $\sigma^2_{i,j}$ and N_0, respectively. Since the performance of all protocols is compared with the direct transmission case, all variances $\sigma^2_{i,j}$ are normalized to $\sigma^2_{s,d}$, i. e. $\sigma^2_{s,d} = 1$ and the SNR of the source-destination transmission $\Gamma = {}^{P_s}/_{N_0}$ is used as reference value. The effective, instantaneous SNR at the destination in case of direct transmission is therefore $\gamma[n] = |h_{s,d}[n]|^2 \Gamma$ where the time index n is omitted in the following since the random processes $h_{i,j}$ and z_j are assumed to be time invariant during one time interval and mutually independent. Furthermore, it is known that $|h_{i,j}|^2$ is exponentially distributed with mean $\sigma^2_{i,j} = {}^1/_{\lambda_{i,j}}$ ($\lambda_{i,j}$ is used as parameter for the probability density function of an exponential random variable).

Our novel protocol needs to rely on some kind of interference suppression in multiple-access channels. Therefore, we model the ability of the receiver to separate two messages by different transmitters with $\eta_{i,j}$, i. e. N nodes (defined as set $\mathcal{S}$) transmit on a multiple access channel and node j tries to separate these streams. If P_i denotes the transmit power of node i, the instantaneous power of the transmission originating from node i received by node j is given by $|h_{i,j}|^2 P_i$. Since the transmissions cannot be perfectly separated, we assume that every transmission originating from node i is interfered by an additional instantaneous power $\sum_{l \in \mathcal{S}, l \neq i} \eta_{l,j} |h_{l,j}|^2 P_i$. The parameter $\eta_{i,j}$ models the ability of node j to suppress other transmissions. Although $\eta_{i,j}$ can also be incorporated into $\sigma^2_{i,j}$, we treat it separately since it models a distinct phenomenon and eases the computation at certain points.

III. Simple Adaptive Decode-And-Forward

In [11], Laneman *et al.* proposed selection relaying which, based on the instantaneous SNR threshold, adaptively decides whether the relay retransmits the source message or the source itself repeats the transmission.

Simple AdDF proposed by Herhold *et al.* [10] also relies on a three-node scenario consisting of a source, a relay and a destination. The transmission is again divided in two phases:

1) In the first phase the source broadcasts its message $x_s[n]$ to relay and destination.
2) In the second phase the relay retransmits $x_s[n]$ if the SNR of the source-relay link in phase 1 was sufficiently high otherwise both relay and source remain silent.

In comparison to selection relaying Simple AdDF does not rely on any feedback from the destination which is necessary in

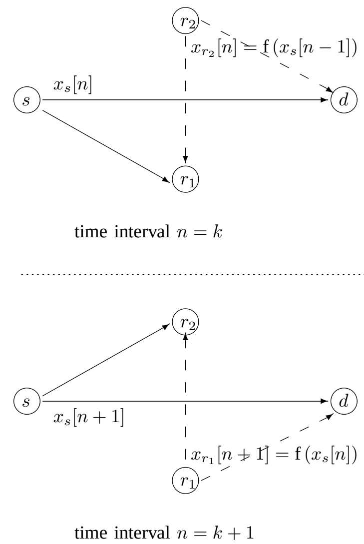

Fig. 1. Example situation for YARP at $n = k$ and $n = k+1$ if r_2 decoded at $n = k-1$ and r_1 decodes at $n = k$. The transmission of r_2 at $n = k$ and of r_1 at $n = k+1$ interferes the source transmission at the respective time intervals which complicates the decoding at the respectively other relay.

Laneman’s proposal to indicate whether the relay successfully decoded or not.

Like all other cooperative relaying protocols which do not rely on a ARQ scheme, Simple AdDF suffers from the increase of the instantaneous spectral efficiency since it needs to transmit the whole message in ${}^1/_k$-th the time of a direct transmission (assuming k hops). This results in a high outage probability in the low SNR and high rate regime [12].

IV. The Novel Protocol YARP

In our research we concentrate on the low SNR regime ($10 - 20dB$) since this region seems to have higher practical relevance than high SNR scenarios analyzed so far by most other publications. To overcome the problems in the low SNR regime, the increased spectral efficiency needs to be avoided. This is achieved by our novel YARP (**Y**ARP is an **A**dvanced **R**elaying **P**rotocol) which establishes two sub-streams each transmitting with single spectral efficiency R. Since two sub-streams are established also two relays are necessary and each relay only retransmits every second source message:

1) During time interval $n = k$ the source broadcasts the message $x_s[k]$ with spectral efficiency R to relay r_1 and destination d.
2) Relay r_1 tries to decode $x_s[k]$ and if the source-relay channel is reliable (i. e. sufficient instantaneous SNR) it sends the message $x_{r_1}[k+1] = \mathrm{f}(x_s[k])$ to the destination at time interval $n = k+1$.
3) While r_1 transmits $x_{r_1}[k+1]$, the source transmits the next message $x_s[k+1]$ to the destination and relay r_2.
4) At time interval $n = k+2$ relay r_2 now transmits $x_{r_2}[k+2] = \mathrm{f}(x_s[k+1])$ if the channel condition between source and relay r_2 was sufficiently good. This

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transmission again interferes with the source transmission $x_s[k+2]$.

In Fig. 1 it is illustrated that both the source-relay and the source-destination link are interfered by a relay transmission. If the destination successfully decoded the previous message it can (theoretically) perfectly cancel out the interference term. On the other hand, at both relays and if the previous message was not decoded also at the destination, no interference cancellation is possible. This calls for a sufficient separation of transmissions, which can be done in different ways, e. g. using beamforming/smart antennas or by utilizing code orthogonality. Another problem is the normalization issue: YARP uses in comparison to Simple AdDF one more relay. If Simple AdDF uses two instead of one relay the spectral efficiency is tripled which results in even worse performance in the low SNR regime. Therefore the two-relay scenario is not considered. Furthermore, although YARP uses an additional resource like code orthogonality which is not considered in Simple AdDF, it is still a fair comparison since code orthogonality won't give any benefit in a non-interference scenario as considered by Simple AdDF and comparable protocols.

V. Outage Probability Analysis

This section now analyzes the outage probability of the novel protocol in comparison to direct transmission, transmit diversity, conventional relaying and Simple AdDF with one relay. Due to the power normalization, the overall power P_s is partitioned into the two fractions p_s and p_r where $p_s + p_r = 1$ and p_s is the fraction of P_s assigned to the source and p_r the fraction of P_s assigned to the currently transmitting relay (i .e. the average SNR of the source-destination link is $p_s\gamma$ and of the relay-destination link $p_r\sigma_{r,d}^2\gamma$).

The outage probability analysis is split into two parts: in the first part the outage at the relay (decoding probability) and in the second part the outage at the destination is derived.

A. Outage Probability $\mathrm{p}_{\mathrm{D}}^{(o)}(\gamma)$ at relay

During the analysis we omit the indices of the currently transmitting or receiving relay due to the equal pathloss between both relays and the source and destination.

The decoding event D_k at time interval $n = k$ is the event that the source message $x_s[k]$ can be decoded at the currently receiving relay. The outage at the relay can be split into two events: if $x_s[k-1]$ was not decoded ($\overline{D}_{k-1}$) the respectively other relay remains silent whereas if it decoded $x_s[k-1]$ the relay must take into account the term $\eta_{r,r} p_r |h_{r,r}|^2 P_s$ as additional interference which cannot be canceled out:

$$D_k : R \leq \begin{cases} \log\left(1 + \frac{p_s\gamma|h_{s,r}|^2}{1+\eta_{r,r}p_r|h_{r,r}|^2\gamma}\right) & \text{if } D_{k-1} \\ \log\left(1 + p_s\gamma\,|h_{s,r}|^2\right) & \text{if } \overline{D}_{k-1} \end{cases} \quad (2)$$

which can be reformulated to obtain the outage probability at the relay:

$$\mathrm{p}_{\mathrm{D}}^{(o)}(\gamma) = \begin{cases} \Pr\left(\frac{p_s\gamma|h_{s,r}|^2}{1+\eta_{r,r}p_r|h_{r,r}|^2\gamma} < g\right) & \text{if } D_{k-1} \\ \Pr\left(p_s\gamma\,|h_{s,r}|^2 < g\right) & \text{if } \overline{D}_{k-1} \end{cases} \quad (3)$$

with $g = 2^R - 1$. Under the assumption that $\mathrm{p}_{\mathrm{D}}^{(o)}[n]$ is time-invariant (verified by computer simulations) it follows (in the following the time indices are omitted) for the expected relay outage probability:

$$\begin{aligned} \mathrm{p}_{\mathrm{D}}^{(o)} = \left(1 - \mathrm{p}_{\mathrm{D}}^{(o)}\right) \cdot \Pr\left(\frac{p_s\gamma\,|h_{s,r}|^2}{1+\eta_{r,r}p_r\,|h_{r,r}|^2\,\gamma} < g\right) \\ + \mathrm{p}_{\mathrm{D}}^{(o)} \cdot \Pr\left(p_s\gamma\,|h_{s,r}|^2 < g\right) \end{aligned} \quad (4)$$

which can be solved in closed form using the sum distribution, the well-known probability function of an exponential random variable for the second term and using the standard ratio distribution and a standard integration for the first term (the derivation and its result is not shown here due to its complexity).

B. Outage Probability $p^{(o)}(\gamma)$ at destination

Using the definition of $\mathrm{p}_{\mathrm{D}}^{(o)}$ the outage event O_k at the destination and time interval $n = k$ has to be defined: This is the event that the source message $x_s[k]$, which is relayed at time interval $k+1$ if D_k holds, cannot be correctly decoded by the destination. Using D_k and O_{k-1} the outage event O_k can be defined to consist of four sub-events. All four sub-events assume the case that D_{k-1} holds since $\overline{D}_{k-1}$ simply models direct transmission (numerical simulations show that the D_{k-1} case gives sufficiently exact results). The four events are:

1) $\overline{D}_k \wedge \overline{O}_{k-1}$: The relay does not send at $n = k+1$ the relayed version of $x_s[k]$. Therefore, $x_s[k]$ interfered by $x_r[k] = \mathrm{f}(x_s[k-1])$ can be used for decoding but $x_r[k]$ is *well known* and can be canceled out.
2) $\overline{D}_k \wedge O_{k-1}$: As 1) but this time $x_r[k]$ is not known and therefore considered as interference.
3) $D_k \wedge \overline{O}_{k-1}$: As 1) but additionally $x_r[k+1] = \mathrm{f}(x_s[k])$ is utilized. Since the source sends at $n = k+1$ the next symbol, $x_s[k+1]$ is seen as an interference term.
4) $D_k \wedge O_{k-1}$: As 3) but $x_r[k]$ is unknown and considered as interference.

Under the assumption that well known components can be perfectly canceled out, the outage probability for cases 1-4 can be obtained:

$$\mathrm{p}_1^{(o)} = \Pr\left(p_s\gamma\,|h_{s,d}|^2 < g\right) \quad (5)$$

$$\mathrm{p}_2^{(o)} = \Pr\left(\frac{p_s\gamma\,|h_{s,d}|^2}{\eta_{r,d}p_r\gamma\,|h_{r,d}|^2 + 1} < g\right) \quad (6)$$

$$\mathrm{p}_3^{(o)} = \Pr\left(p_s\gamma\,|h_{s,d}|^2 + \frac{p_r\gamma\,|h_{r,d}|^2}{\eta_{s,d}p_s\gamma\,|h_{s,d}|^2 + 1} < g\right) \quad (7)$$

$$\mathrm{p}_4^{(o)} = \Pr\left(\frac{p_s\gamma\,|h_{s,d}|^2}{\eta_{r,d}p_r\gamma\,|h_{r,d}|^2 + 1} + \frac{p_r\gamma\,|h_{r,d}|^2}{\eta_{s,d}p_s\gamma\,|h_{s,d}|^2 + 1} < g\right) \quad (8)$$

where in (5) the CDF of an exponential random variable is used, (6) can be solved using the same derivation as for (4) and (7) and (8) can only be analytically solved since the solution leads to the exponential integral. Again assuming that

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two successive outage probabilites are i.i.d. (which implies for instance $\mathrm{p}^{(o)}[k] = \mathrm{p}^{(o)}[k-1]$) it follows for the outage probability at the destination:

$$\begin{aligned}\mathrm{p}^{(o)} =& \left(1-\mathrm{p}_\mathrm{D}^{(o)}\right)\cdot\left(\mathrm{p}^{(o)}\mathrm{p}_4^{(o)} + \left(1-\mathrm{p}^{(o)}\right)\mathrm{p}_3^{(o)}\right) \\ &+ \mathrm{p}_\mathrm{D}^{(o)}\left(\mathrm{p}^{(o)}\mathrm{p}_2^{(o)} + \left(1-\mathrm{p}^{(o)}\right)\mathrm{p}_1^{(o)}\right) \end{aligned} \tag{9}$$

$$= \frac{\left(1-\mathrm{p}_\mathrm{D}^{(o)}\right)\left(\mathrm{p}_3^{(o)}-\mathrm{p}_1^{(o)}\right) + \mathrm{p}_1^{(o)}}{1-\left[\mathrm{p}_\mathrm{D}^{(o)}\left(\mathrm{p}_2^{(o)}-\mathrm{p}_1^{(o)}\right) + \left(1-\mathrm{p}_\mathrm{D}^{(o)}\right)\left(\mathrm{p}_4^{(o)}-\mathrm{p}_3^{(o)}\right)\right]}. \tag{10}$$

The results of the outage analysis are shown in Fig. 2 and discussed in section VI.

C. Performance limits

Since the presented outage analysis leads to quite involved expressions, two approximations are derived in the following.

1) Low SNR/small η approximation: The first approximation is obtained by considering $\eta_{i,j}\gamma \ll 1$, i.e. either a very good separation between different transmissions at the receiver or a very low SNR. In both cases $\eta_{i,j}\gamma$ tends to zero and the decoding probability is well approximated by

$$\mathrm{p}_\mathrm{D}^{(o)}(\gamma) = \Pr\left(p_s\gamma\left|h_{s,r}\right|^2 < g\right) \tag{11}$$

and the mutual information I between source and destination is

$$I = \begin{cases}\log\left(1+p_s\gamma\left|h_{s,d}\right|^2\right) & \text{if } \overline{D}_{n-1} \\ \log\left(1+p_s\gamma\left|h_{s,d}\right|^2 + p_r\gamma\left|h_{r,d}\right|^2\right) & \text{if } D_{n-1}\end{cases} \tag{12}$$

which results in a much simpler, second order diversity expression (the result is already given for relaying by Herhold *et al.* in [12] with twice the rate necessary).

2) High SNR approximation: The second approximation is valid for $\eta_{i,j}\gamma \gg 1$ (since $\eta \le 1$ holds, it follows that $SNR \gg 1$ which actually is the high SNR approximation). For the outage probability at the relay the following approximation can be made:

$$\lim_{\gamma\to\infty}\mathrm{p}_\mathrm{D}^{(o)} = \frac{\Pr\left(\frac{p_s\gamma|h_{s,r}|^2}{1+\eta_{r,r}p_r|h_{r,r}|^2\gamma} < g\right)}{1+\Pr\left(\frac{p_s\gamma|h_{s,r}|^2}{1+\eta_{r,r}p_r|h_{r,r}|^2\gamma} < g\right)} \tag{13}$$

$$= \frac{\eta_{r,r}\lambda_{s,r}g}{\lambda_{r,r}+2\eta_{r,r}\lambda_{s,r}g}. \tag{14}$$

Since $\lambda_{s,r} > 0$ and $\eta_{r,r} > 0$ (assuming a realistic environment) it follows that there is an error floor $\lim_{\gamma\to\infty}\mathrm{p}_\mathrm{D}^{(o)} > 0$. Furthermore (5)-(8) are approximated by

$$\lim_{\gamma\to\infty}\mathrm{p}_1^{(o)} = \lambda_{s,d}\frac{g}{\gamma} \tag{15}$$

$$\lim_{\gamma\to\infty}\mathrm{p}_2^{(o)} = 1-\frac{\lambda_{r,d}}{\lambda_{r,d}+\eta_{r,d}\lambda_{s,d}g} > 0 \tag{16}$$

$$\lim_{\gamma\to\infty}\mathrm{p}_3^{(o)} = \frac{\lambda_{s,d}}{\gamma}\left[g+\frac{\lambda_{s,d}}{\lambda_{r,d}\eta_{s,d}}\log\left(\frac{\lambda_{s,d}}{\eta_{s,d}\lambda_{r,d}g+\lambda_{s,d}}\right)\right] \tag{17}$$

$$\lim_{\gamma\to\infty}\mathrm{p}_4^{(o)} = q \tag{18}$$

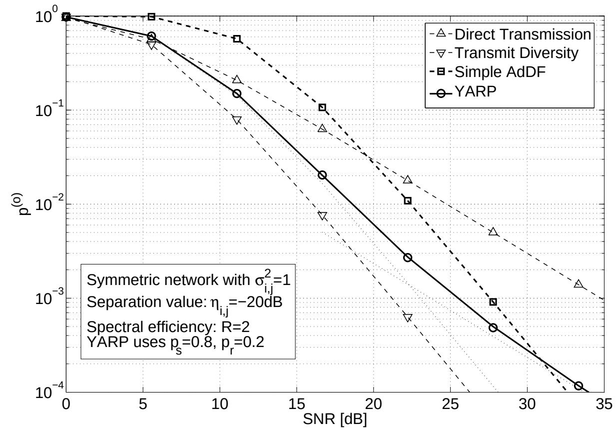

Fig. 2. Probability of outage at destination. $R = 2$ denotes the spectral efficiency for the direct transmission case. Dotted lines show the low and high SNR approximation and circles the simulation result for the YARP (whereas the high SNR approximation uses the upper bound from (19)).

with

$$u(1) \ge \quad q \quad \ge u(2) \tag{19}$$

$$u(l) = \frac{\lambda_{s,d}}{\lambda_{s,d}+\frac{l\cdot\lambda_{r,d}}{\eta_{r,d}(2^R-1)}}\frac{\lambda_{r,d}}{\lambda_{r,d}+\frac{l\cdot\lambda_{s,d}}{\eta_{s,d}(2^R-1)}}. \tag{20}$$

Inserting (14)-(20) in (10) yields an approximation for the outage probability at the destination. This approximation is used in section VI for further analysis and to show the performance in the low and high SNR regime.

VI. Evaluation

Fig. 2 shows the resulting outage probability for the novel protocol in comparison to direct transmission, transmit diversity and Simple AdDF. Furthermore the low SNR approximation (with perfect separation, i.e. $\eta_{i,j} = 0$) and the high SNR approximation (a separation of $\eta_{i,j} = -20dB$ is used) is shown. A first look shows that both the low SNR and high SNR bound are fairly good and that the protocol achieves second order diversity for small $\eta_{i,j}$ and low SNR, and first order diversity for large $\eta_{i,j}$/high SNR.

A further analysis of this behaviour requires a more detailed view on the high SNR approximation. Consider the outage probability given by (10) to analytically obtain the diversity order of YARP in the high SNR regime. On the first view one can see that $\mathrm{p}_3^{(o)}$ in (17) is in any case smaller than $\mathrm{p}_1^{(o)}$ in (15) since (17) is the sum of (15) and a logarithm. The denominator of this logarithm is in any case greater than the nominator ($\eta_{s,d}$, $\lambda_{r,d}$ and R are positive values) and therefore the logarithm is strictly negative. Using the substitutions

$$a = \mathrm{p}_\mathrm{D}^{(o)}, \quad b = \mathrm{p}_2^{(o)}, \quad c = \mathrm{p}_4^{(o)}, \quad u = \mathrm{p}_1^{(o)}\gamma, \quad v = \mathrm{p}_3^{(o)}\gamma$$

(10) can be reformulated to be (using the parameter $\epsilon \ge 1$)

$$\mathrm{p}^{(o)} = \frac{\epsilon\cdot\frac{v}{\gamma}}{1-\left[a\left(b-\frac{u}{\gamma}\right)+(1-a)\left(c-\frac{v}{\gamma}\right)\right]} \tag{21}$$

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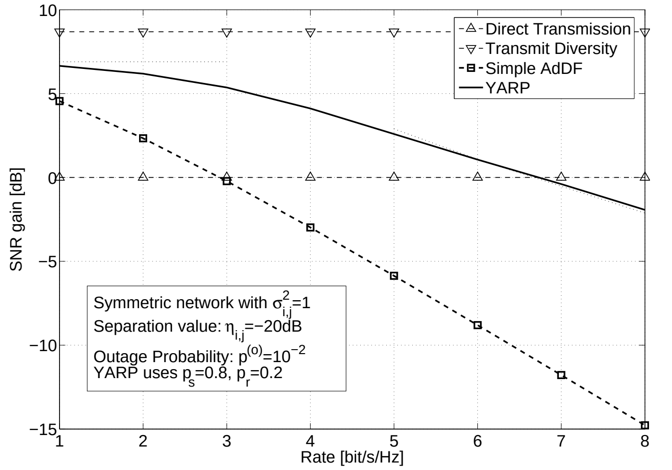

Fig. 3. SNR gain over direct transmission. Dotted lines show the low and high SNR approximation (whereas the high SNR approximation uses the upper bound from (19)).

and after further manipulation it follows

$$\frac{\log \mathrm{p}^{(o)}}{\log \gamma} = \frac{\log(\epsilon v)}{\log \gamma} - 1 \tag{22}$$

$$- \frac{\log\left(1-\left[a\left(b-\frac{u}{\gamma}\right)+(1-a)\left(c-\frac{v}{\gamma}\right)\right]\right)}{\log \gamma}. \tag{23}$$

Since the argument of the numerator in the first term is constant (see (17)) and since it can be shown that the argument of the numerator in the third term is always greater than 0 (therefore resulting in an error floor) it follows for the diversity

$$-\lim_{\gamma\to\infty} \frac{\log \mathrm{p}^{(o)}}{\log \gamma} = 1. \tag{24}$$

This shows that the protocol only achieves first order diversity in the high SNR regime. On the other hand, applying the results of [12] it can be shown that the protocol achieves second order diversity in the low SNR regime.

The superior performance in the low SNR regime is emphasized in Fig. 3 which shows the SNR gain as function of spectral efficiency of the analyzed protocol over direct transmission. At low SNR YARP outperforms Simple AdDF and direct transmission for rates $R \leq 6$ given an outage probability $p^{(o)} = 10^{-2}$. Although our work concentrates on the low SNR regime which is of interest in wireless communication, it can be assumed that the picture changes if lower outage probabilities are considered since the diversity order decreases for higher SNR values.

VII. Conclusions and Further Work

In this paper we presented a novel cooperative relaying protocol which avoids increased spectral efficiencies on the individual links. Under the assumption that no channel state information at the transmitter and feedback from the destination is available, YARP outperforms conventional relaying, direct transmission and Simple AdDF in the low SNR regime. We also showed that for a target outage probability of $\mathrm{p}^{(o)} = 10^{-2}$, YARP offers benefits over direct transmission even for higher rates up to $R = 6$. On the other hand considering the high SNR behaviour, YARP is outperformed by Simple AdDF. Nevertheless, since the application of this protocol are low SNR scenarios offering some way of interference cancellation, YARP can be seen as a serious alternative for direct transmission and relaying protocols.

One way to utilize YARP is a hybrid protocol which uses Simple AdDF in the high SNR regime and YARP in the low SNR regime. This *hybrid* usage makes cooperative relaying attractive for a wider range of applications not restricted to a specific SNR regime. Other applications include scenarios where only a direct link is *guaranteed* and relay links might be possible. In those scenarios it is imaginable to adaptively turn on/off cooperative relaying – without feedback from the destination and without any additional signalling overhead which is necessary for other protocols to change the spectral efficiency at the user terminal and base station.

Further investigations of the presented protocol should include Bit Error Rate (BER) performance evaluation in comparison to Simple AdDF. This analysis should be done both in a single-user and a multi-user scenario, e. g. in a CDMA-based system with realistic separation values resulting from the spreading code orthogonality. Furthermore it should be analyzed if further improvements are possible by using other forwarding methods instead of Decode-And-Forward, e. g. Amplify-And-Forward or Decode-And-Reencode.

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