On the Design of Cooperative Transmission Schemes

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Abstract

In this paper, a new cooperative transmission scheme is proposed that enjoys some important advantages over similar protocols. First, it achieves cooperative diversity without relying on orthogonal subspaces (e.g., different spreading codes or frequency bands), allowing full rate transmission. Second, its performance degrades gracefully as the path loss between cooperating partners increases, never falling below that of non-cooperative protocols.

1 Introduction

Multipath fading is the predominant factor limiting the speed and reliability of wireless communication systems. Spatial diversity, a powerful means to mitigate fading, is unfortunately not available when communicating between a pair of single-antenna terminals. In ad-hoc network applications, however, nearby single-antenna sources can *cooperatively transmit* to a far-away destination, thereby leveraging the spatial diversity inherent to a "virtual" multi-antenna source.

Several cooperative schemes have been proposed. Sendonaris et al. [4, 5] proposed a scheme in which sources utilize different spreading codes to communicate with the destination as well as among cooperative partners. Laneman et al. [2, 3] designed a cooperative scheme in which sources communicate with their partners and the destination using non-overlapping time slots. Both of these schemes rely on orthogonal subspaces for cooperation, essentially trading rate for diversity. In this paper, we present a scheme which does not rely on orthogonal subspaces, allowing a more efficient use of resources.

2 The Proposed Scheme

For simplicity, we consider the case of two source nodes and one destination node, each with a single antenna. The channels between the sources are assumed to be quasi-static flat Rayleigh fading and the noises at each receiving antenna are additive, white and Gaussian. We assume that the inter-source channel gain is known by both sources as well as the destination, though the source-destination channel gains are known only by the destination (i.e., not the sources).

In the proposed scheme, sources transmit once per frame, where a frame is defined by two consecutive time slots. Each source transmits a linear combination of its current symbol and the (noisy) signal received from its partner during the last time slot. For source j and frame k, we denote the broadcast and repetition gains by a_j and b_j, respectively, the information symbol by $x_{j,k}$, and the transmitted signal by $t_{j,k}$. At startup the transmitted signals will take the form

$$t_{1,0} = a_1 x_{1,0} \tag{1}$$
$$t_{2,0} = a_2 x_{2,0} + b_2(h t_{1,0} + \sigma_2 w_{2,0}) \tag{2}$$
$$t_{1,1} = a_1 x_{1,1} + b_1(h t_{2,0} + \sigma_1 w_{1,0}) \tag{3}$$
$$t_{2,1} = a_2 x_{2,1} + b_2(h t_{1,1} + \sigma_2 w_{2,1}) \tag{4}$$

where h denotes the inter-source channel gain and $\sigma_j w_{j,k}$ the noise observed by the j^{th} source during the k^{th} frame. (We assume that $w_{j,k}$ has unit variance.) The corresponding signals received by the destination node are:

$$y_{1,0} = g_1 t_{1,0} + v_{1,0} \tag{5}$$
$$y_{2,0} = g_2 t_{2,0} + v_{2,0} \tag{6}$$
$$y_{1,1} = g_1 t_{1,1} + v_{1,1} \tag{7}$$
$$y_{2,1} = g_2 t_{2,1} + v_{2,1} \tag{8}$$

where g_j is the gain of the channel connecting source j to the destination and $v_{j,k}$ the destination noise of variance σ_v^2. Note that, in this scheme, sources are either transmitting or receiving but not both. The broadcast and repetition gains $\{a_j, b_j\}$ are chosen (experimentally, for now) to minimize outage probability at the destination. As a consequence of symmetry, a_1 and a_2, as well as b_1 and b_2, will have the same optimal value. Thus, we assume that broadcast and repetition gains are the same at each source and omit the subscripts, yielding $\{a, b\}$.

3 System Model

In order to develop an efficient system model for the proposed scheme, we define the following frame-based quantities:

$$\mathbf{x}_{1,k} \triangleq [x_{1,k}, 0]^t \qquad \mathbf{x}_{2,k} \triangleq [0, x_{2,k}]^t \qquad \mathbf{x}_k \triangleq [x_{1,k}, x_{2,k}]^t$$
$$\mathbf{w}_{1,k} \triangleq [0, w_{1,k}]^t \qquad \mathbf{w}_{2,k} \triangleq [w_{2,k}, 0]^t \qquad \mathbf{t}_k \triangleq [t_{1,k}, t_{2,k}]^t$$
$$\mathbf{r}_{1,k} \triangleq [t_{1,k}, r_{1,k}]^t \qquad \mathbf{r}_{2,k} \triangleq [r_{2,k}, t_{2,k}]^t \qquad \mathbf{y}_k \triangleq [y_{1,k}, y_{2,k}]^t$$
$$\mathbf{v}_k \triangleq [v_{1,k}, v_{2,k}]^t$$

where $r_{j,k}$ is source j's received signal during the k^{th} frame:

$$r_{1,0} = h t_{2,0} + \sigma_1 w_{1,0}$$
$$r_{2,0} = h t_{1,0} + \sigma_2 w_{2,0}$$
$$r_{1,1} = h t_{2,1} + \sigma_1 w_{1,1}$$
$$r_{2,1} = h t_{1,1} + \sigma_2 w_{2,1}$$

Using these definitions, the frame-based counterparts of (1)-(4) and (5)-(8) can be written

$$\mathbf{t}_{k+1} = A\mathbf{x}_{k+1} + F_1\mathbf{r}_{1,k} + F_2\mathbf{r}_{2,k+1} \tag{9}$$

$$\mathbf{y}_k = G\mathbf{t}_k + \mathbf{v}_k \tag{10}$$

where A, G, F_1 and F_2 are defined as:

$$A \triangleq \begin{bmatrix} a & 0 \\ 0 & a \end{bmatrix} \qquad G \triangleq \begin{bmatrix} g_1 & 0 \\ 0 & g_2 \end{bmatrix}$$

$$F_1 \triangleq \begin{bmatrix} 0 & b \\ 0 & 0 \end{bmatrix} \qquad F_2 \triangleq \begin{bmatrix} 0 & 0 \\ b & 0 \end{bmatrix}$$

Defining H_1, H_2, N_1 and N_2 as:

$$H_1 \triangleq \begin{bmatrix} 1 & 0 \\ 0 & h \end{bmatrix} \qquad H_2 \triangleq \begin{bmatrix} h & 0 \\ 0 & 1 \end{bmatrix}$$

$$N_1 \triangleq \begin{bmatrix} 0 & 0 \\ 0 & \sigma_1 \end{bmatrix} \qquad N_2 \triangleq \begin{bmatrix} \sigma_2 & 0 \\ 0 & 0 \end{bmatrix}$$

allows $\mathbf{r}_{j,k}$ to be expressed in terms of $\mathbf{t}_k$ as:

$$\mathbf{r}_{j,k} = H_j\mathbf{t}_k + N_j\mathbf{w}_{j,k} \tag{11}$$

Plugging (11) into (9) and doing some manipulations results in the following state-space representation:

$$\mathbf{t}_{k+1} = F_t\mathbf{t}_k + F_x\mathbf{x}_{k+1} + F_w\mathbf{w}_{k+1} \tag{12}$$

$$\mathbf{y}_k = G\mathbf{t}_k + \mathbf{v}_k \tag{13}$$

where:

$$F_t \triangleq (I - F_2H_2)^{-1}F_1H_1 \tag{14}$$

$$F_x \triangleq (I - F_2H_2)^{-1}A \tag{15}$$

$$F_w \triangleq (I - F_2H_2)^{-1} \tag{16}$$

$$\mathbf{w}_k \triangleq F_1N_1\mathbf{w}_{1,k-1} + F_2N_2\mathbf{w}_{2,k} \tag{17}$$

Examining the statistics of $\mathbf{w}_k$, hereafter referred to as the state noise, reveals that it is a white Gaussian noise process with covariance matrix:

$$\Sigma_{\mathbf{w}} = \begin{bmatrix} |b|^2\sigma_1^2 & 0 \\ 0 & |b|^2\sigma_2^2 \end{bmatrix} \tag{18}$$

Equations (12) and (13) are the system model that will be used in the rest of this paper.

4 Outage Analysis

In this section, we obtain the achievable rate region, which can be used to compute outage probability through mont carlo simulations. Outage probability will serve as both a metric of performance for our scheme and the criteria for optimization of broadcast and repetition gains $\{a, b\}$. For this purpose, the data processing inequality can be used to obtain a simpler system model. Assume that we apply a reversible system to destination signal, $\mathbf{y}_k$, to get another signal $\overline{\mathbf{y}}_k$. As this system is reversible, it does not have any effect on outage probability calculations. Things become very simple if we choose this system to be the one that inverts the effects of transmission scheme and fading. In that case:

$$\overline{\mathbf{y}}_k = \mathbf{x}_{1,k} + \mathbf{x}_{2,k} + \mathbf{n}_k \tag{19}$$

In (19), $\mathbf{n}_k$ is a vector-valued Gaussian random sequence with zeros mean and an autocorrelation function with only three non-zero values:

$$R_{\mathbf{n}}[-1] = \begin{bmatrix} 0 & 0 \\ \delta^* & 0 \end{bmatrix} \qquad R_{\mathbf{n}}[0] = \begin{bmatrix} \alpha & \beta^* \\ \beta & \gamma \end{bmatrix} \qquad R_{\mathbf{n}}[1] = \begin{bmatrix} 0 & \delta \\ 0 & 0 \end{bmatrix} \tag{20}$$

where α, β, γ and δ are defined as:

$$\begin{aligned}
\alpha &\triangleq \frac{|b|^2}{|a|^2}\sigma^2 + (\frac{1}{|a|^2|g_1|^2} + \frac{|b|^2|h|^2}{|a|^2|g_2|^2})\sigma_v^2 \\
\beta &\triangleq -\frac{bh}{|a|^2|g_1|^2}\sigma_v^2 \\
\gamma &\triangleq \frac{|b|^2}{|a|^2}\sigma^2 + (\frac{1}{|a|^2|g_2|^2} + \frac{|b|^2|h|^2}{|a|^2|g_1|^2})\sigma_v^2 \\
\delta &\triangleq -\frac{bh}{|a|^2|g_2|^2}\sigma_v^2
\end{aligned}$$

In the above expression, it is assumed that σ_1^2 and σ_2^2 are both equal to σ^2. As $\mathbf{n}_k$ is a colored noise, the multiple access channel defined by (19) does not come under the class of discrete memoryless channels [7]. To get around this problem, we define the following quantities:

$$\begin{aligned}
\underline{\mathbf{x}}_{j,k}^{(N)} &\triangleq [\mathbf{x}_{j,(k-1)N+1}^t, \mathbf{x}_{j,(k-1)N+2}^t, \ldots, \mathbf{x}_{j,kN}^t]^t \\
\underline{\mathbf{n}}_{k}^{(N)} &\triangleq [\mathbf{n}_{(k-1)N+1}^t, \mathbf{n}_{(k-1)N+2}^t, \ldots, \mathbf{n}_{kN}^t]^t \\
\underline{\overline{\mathbf{y}}}_{k}^{(N)} &\triangleq [\overline{\mathbf{y}}_{(k-1)N+1}^t, \overline{\mathbf{y}}_{(k-1)N+2}^t, \ldots, \overline{\mathbf{y}}_{kN}^t]^t
\end{aligned}$$

from the above expressions it is evident that:

$$\underline{\overline{\mathbf{y}}}_{k}^{(N)} = \underline{\mathbf{x}}_{1,k}^{(N)} + \underline{\mathbf{x}}_{2,k}^{(N)} + \underline{\mathbf{n}}_{k}^{(N)} \tag{21}$$

$\underline{\mathbf{n}}_{k}^{(N)}$ is also a vector-valued Gaussian random sequence with zero mean and an autocorrelation function with only three non-zero values:

$$R_{\underline{\mathbf{n}}^{(N)}}[0] = \begin{bmatrix} \alpha & \beta^* & 0 & 0 & \cdots & 0 \\ \beta & \gamma & \delta^* & 0 & \cdots & 0 \\ 0 & \delta & \alpha & \beta^* & \cdots & 0 \\ 0 & 0 & \beta & \gamma & \cdots & 0 \\ \vdots & \vdots & \vdots & \vdots & \ddots & \\ 0 & 0 & 0 & 0 & & \gamma \end{bmatrix}_{2N\times 2N} \qquad R_{\underline{\mathbf{n}}^{(N)}}[1] = \begin{bmatrix} 0 & \cdots & 0 & \delta \\ 0 & \cdots & 0 & 0 \\ \vdots & \ddots & 0 & 0 \\ 0 & \cdots & 0 & 0 \end{bmatrix}_{2N\times 2N} \tag{22}$$

(23)

$$R_{\underline{\mathbf{n}}^{(N)}}[-1] = R_{\underline{\mathbf{n}}^{(N)}}[1]^H$$

However, careful examination of (22) reveals that $\underline{\mathbf{n}}_k^{(N)}$ and $\underline{\mathbf{n}}_{k+1}^{(N)}$ are correlated through only one out of their $2N$ elements. Thus for sufficiently large N, $\underline{\mathbf{n}}_k^{(N)}$ can be considered as an essentially white Gaussian sequence. So we can drop the subscript k from (21) and consider it as a discrete memoryless multiple access channel with noise covariance matrix, $\Sigma_{\underline{\mathbf{n}}^{(N)}}$, being equal to $R_{\underline{\mathbf{n}}^{(N)}}[0]$.

$$\underline{\overline{\mathbf{y}}}^{(N)} = \underline{\mathbf{x}}_1^{(N)} + \underline{\mathbf{x}}_2^{(N)} + \underline{\mathbf{n}}^{(N)} \tag{24}$$

The achievable rate region for this discrete memoryless multiple access channels is known to be the closure of the convex hull of all $(r_1^{(N)}, r_2^{(N)})$ satisfying:

$$\begin{aligned} r_1^{(N)} &< I(\underline{\mathbf{x}}_1^{(N)}; \underline{\overline{\mathbf{y}}}^{(N)} | \underline{\mathbf{x}}_2^{(N)}) \\ r_2^{(N)} &< I(\underline{\mathbf{x}}_2^{(N)}; \underline{\overline{\mathbf{y}}}^{(N)} | \underline{\mathbf{x}}_1^{(N)}) \\ r_1^{(N)} + r_2^{(N)} &< I(\underline{\mathbf{x}}_1^{(N)}, \underline{\mathbf{x}}_2^{(N)}; \underline{\overline{\mathbf{y}}}^{(N)}) \end{aligned}$$

for some product distribution on $\underline{\mathbf{x}}_1^{(N)}$ and $\underline{\mathbf{x}}_2^{(N)}$ [7]. In the above expressions, $r_j^{(N)}$ is j^{th} source's rate for N channel uses, thus a rate of r bits per channel use is achievable by each of the source nodes if r satisfies:

$$r < min(c_{1|2}, c_{2|1}, c_{1,2})$$

where:

$$\begin{aligned} c_{1|2} &\triangleq \lim_{N\to\infty} \frac{1}{N} I(\underline{\mathbf{x}}_1^{(N)}; \underline{\overline{\mathbf{y}}}^{(N)} | \underline{\mathbf{x}}_2^{(N)}) \\ c_{2|1} &\triangleq \lim_{N\to\infty} \frac{1}{N} I(\underline{\mathbf{x}}_2^{(N)}; \underline{\overline{\mathbf{y}}}^{(N)} | \underline{\mathbf{x}}_1^{(N)}) \\ c_{1,2} &\triangleq \lim_{N\to\infty} \frac{1}{2N} I(\underline{\mathbf{x}}_1^{(N)}, \underline{\mathbf{x}}_2^{(N)}; \underline{\overline{\mathbf{y}}}^{(N)}) \end{aligned}$$

As $\Sigma_{\underline{\mathbf{n}}^{(N)}}$ has a banded structure, derivation of $c_{1|2}$, $c_{2|1}$ and $c_{1,2}$ is straight forward. It can be shown that for independent Gaussian $x_{j,k}$'s with zero-mean and variance E_x, $c_{1|2}$, $c_{2|1}$ and $c_{1,2}$ are given by:

$$c_{1|2} = \log_2(\frac{\lambda}{\lambda_{1|2}}) \qquad c_{2|1} = \log_2(\frac{\lambda}{\lambda_{2|1}}) \qquad c_{1,2} = \frac{1}{2}\log_2(\frac{\lambda}{\lambda_{1,2}})$$

where:

$$\lambda \triangleq \begin{cases} \frac{\alpha\gamma - |\beta|^2 - |\delta|^2 - \sqrt{(\alpha\gamma - |\beta|^2 - |\delta|^2)^2 - 4|\beta|^2|\delta|^2}}{2|\beta|^2|\delta|^2} & : \beta\delta \neq 0 \\ \frac{1}{\alpha\gamma} & : \beta\delta = 0 \end{cases}$$

$\lambda_{1|2}$, $\lambda_{2|1}$ and $\lambda_{1,2}$ have very similar expressions. For deriving $\lambda_{1|2}$ and $\lambda_{2|1}$, α and γ in the above expression should be replaced with $\alpha + E_x$ and $\gamma + E_x$, respectively. For deriving $\lambda_{1,2}$, both of the replacements should be done.
The outage probability is defined as:

$$P_{out} = Pr(r > min(c_{1|2}, c_{2|1}, c_{1,2}))$$

where r is the tried rate.

5 Gain Optimization

Here, good values for the broadcast and repetition gains are investigated through simulations. For a fair comparison, we fix the average transmitted energy

$$E_t \triangleq E\{t_{j,k} t^*_{j,k}\}$$

to some fixed value, say E_x: the averaged energy of the constellation used. To do this, the repetition gain must be within the range:

$$b_{max} \geq |b| \geq 0 \tag{25}$$

where

$$b_{max} = \sqrt{\frac{E_x}{|h|^2 E_x + \sigma^2}} \tag{26}$$

As before, it is assumed that σ_1^2 and σ_2^2 are both equal to σ^2. It is also required to set the broadcast gain to:

$$|a| = \sqrt{1 - |b/b_{max}|^2} \tag{27}$$

It is useful to define the following quantities:

$$\begin{aligned} d &= b/b_{max} \\ SNR_S &= 10\log(|h|^2 E_x/\sigma^2) \\ SNR_{SA} &= 10\log(E_x/\sigma^2) \\ SNR_{DA} &= 10\log(E_x/\sigma_v^2) \end{aligned} \tag{28}$$

where d, SNR_S, SNR_{SA} and SNR_{DA} will be called as cooperation coefficient, source SNR, average source SNR and average destination SNR, respectively. Based on simulations, we propose the following rule for selection of the cooperation coefficient:

$$d = \begin{cases} 0 & : -5dB > SNR_S \\ 0.25 & : 5dB > SNR_S > -5dB \\ 0.50 & : SNR_S > 5dB \end{cases}$$

For example, Fig. 1 indicates that the optimal value for d at SNR_S equal to $10dB$, is 0.5.It should be noted that once the cooperation coefficient, d, is determined, the broadcast and repetition gains should be computed using (26)-(28). As is evident from the expressions given in the previous section, the phase of the broadcast and repetition gains do not have any effect on the outage probability.

6 Symbol Detection

To derive a system model that is suitable for detection purposes, we need to further manipulate (12) and (13). First we split the transmitted signal, i.e. $\mathbf{t}_k$, into two parts: $\mathbf{t}_{\mathbf{x},k}$ and $\mathbf{t}_{\mathbf{w},k}$, where:

$$\mathbf{t}_{\mathbf{x},k+1} \triangleq F_t \mathbf{t}_{\mathbf{x},k} + F_x \mathbf{x}_{k+1} \tag{29}$$

$$\mathbf{t}_{\mathbf{w},k+1} \triangleq F_t \mathbf{t}_{\mathbf{w},k} + F_w \mathbf{w}_{k+1} \tag{30}$$

from these definitions, it is evident that:

$$\mathbf{t}_k = \mathbf{t}_{\mathbf{x},k} + \mathbf{t}_{\mathbf{w},k}$$

It is also necessary to define the following superframe-based quantities:

$$\begin{aligned}
\underline{\mathbf{x}}_k &\triangleq [\mathbf{x}_k^t, \mathbf{x}_{k+1}^t, \ldots, \mathbf{x}_{k+N-1}^t]^t \\
\underline{\mathbf{y}}_k &\triangleq [\mathbf{y}_k^t, \mathbf{y}_{k+1}^t, \ldots, \mathbf{y}_{k+N-1}^t]^t \\
\underline{\mathbf{n}}_k &\triangleq [\mathbf{n}_k^t, \mathbf{n}_{k+1}^t, \ldots, \mathbf{n}_{k+N-1}^t]^t
\end{aligned}$$

where $N-1$ "future frames" are being used to detect the "current frame", i.e. $\mathbf{x}_k$. In the above expression, $\mathbf{n}_k$ is defined as:

$$\mathbf{n}_k \triangleq G\mathbf{t}_{\mathbf{w},k} + \mathbf{v}_k$$

Using these definitions and the state-space model of the system given by (10), (12) and (29)-(30), it can be shown that:

$$\underline{\mathbf{z}}_k = H\underline{\mathbf{x}}_k + \underline{\mathbf{n}}_k \tag{31}$$

where $\underline{\mathbf{z}}_k$ and H are defined as:

$$\underline{\mathbf{z}}_k \triangleq \underline{\mathbf{y}}_k - \begin{bmatrix} GF_t \\ GF_t^2 \\ \vdots \\ GF_t^N \end{bmatrix} \mathbf{t}_{\mathbf{x},k-1} \tag{32}$$

$$H \triangleq \begin{bmatrix} GF_x & 0 & 0 & \cdots & 0 \\ GF_tF_x & GF_x & 0 & \cdots & 0 \\ \vdots & \vdots & & \ddots & \vdots \\ GF_t^{N-1}F_x & GF_t^{N-2}F_x & & \cdots & GF_x \end{bmatrix} \tag{33}$$

and that $\underline{\mathbf{n}}_k$ has a covariance matrix $\Sigma_{\underline{\mathbf{n}}}$ equal to:

$$\begin{bmatrix} \Sigma_{\mathbf{v}} + G\Sigma_{\mathbf{t_w}}G^H & G(F_t\Sigma_{\mathbf{t_w}})^H G^H & \cdots & G(F_t^{N-1}\Sigma_{\mathbf{t_w}})^H G^H \\ G(F_t\Sigma_{\mathbf{t_w}})G^H & \Sigma_{\mathbf{v}} + G\Sigma_{\mathbf{t_w}}G^H & \cdots & G(F_t^{N-2}\Sigma_{\mathbf{t_w}})^H G^H \\ \vdots & \vdots & \ddots & \vdots \\ G(F_t^{N-1}\Sigma_{\mathbf{t_w}})G^H & G(F_t^{N-2}\Sigma_{\mathbf{t_w}})G^H & \cdots & \Sigma_{\mathbf{v}} + G\Sigma_{\mathbf{t_w}}G^H \end{bmatrix}$$

In the above expression, $\Sigma_{\mathbf{t_w}}$ denotes the covariance matrix of $\mathbf{t}_{\mathbf{w},k}$. Using (30), it can be shown that $\Sigma_{\mathbf{t_w}}$ is the solution of the following lyapunov equation:

$$\Sigma_{\mathbf{t_w}} = F_t\Sigma_{\mathbf{t_w}}F_t^H + F_w\Sigma_{\mathbf{w}}F_w^H$$

Equation (31) is the system model that is used for detection. To detect the symbols transmitted during the k^{th} frame, i.e. $\mathbf{x}_k$, the first step is to compute $\underline{\mathbf{z}}_k$ using (32) (It is assumed that the previous frames, i.e. $\mathbf{x}_i$ for $i < k$, have already been detected, thus $\mathbf{t}_{\mathbf{x},k-1}$ is known). A QAM extension of the PDA algorithm [6] is then applied to (31).Once $\mathbf{x}_k$ is detected, $\mathbf{t}_{\mathbf{x},k}$ and $\underline{\mathbf{z}}_{k+1}$ which are needed to detect the next frame can be computed.

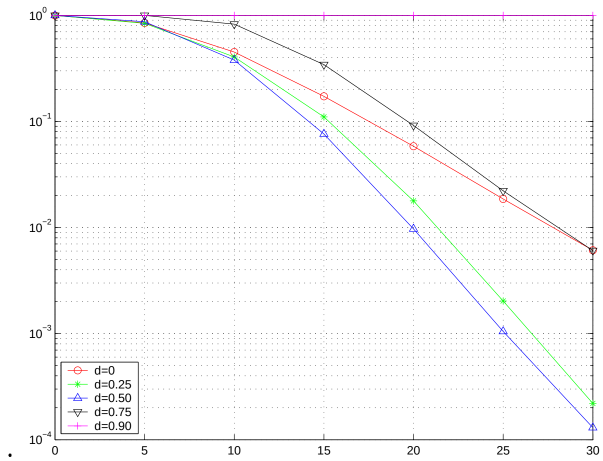

Figure 1: P_{out} vs. SNR_{DA} for $SNR_S = 10dB$. $r = 2bits$

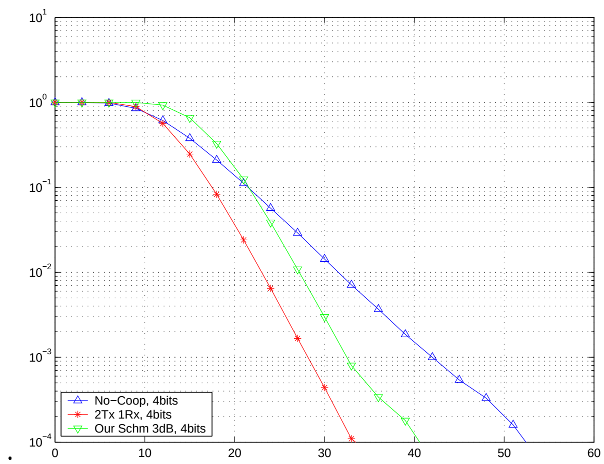

Figure 2: P_{out} vs. SNR_{DA} for various schemes.

7 Discussion and Conclusion

An efficient cooperative scheme that enjoys important advantages over similar protocols was proposed. The first advantage of the proposed scheme is that it achieves cooperative diversity at full rate. Fig. 2 shows that the scheme achieves two levels of diversity while Fig. 3 and Fig. 4 demonstrate how the proposed scheme, as a result of being full rate, outperforms the scheme proposed by Laneman et al [3], specially at high rates. The second advantage of the scheme is its robustness to inter-source channel quality. Fig. 5 shows that the scheme's outage probability, even when the offset is as low as $3dB$, is comparable to that of noiseless inter-source scenario. Fig. 6 shows how close the performance of the PDA detector is to the associated Matched Filter Bound (MFB). This implies that incorporation of channel codes is easy because there is no need for feeding information forward and backward between the equalizer and decoder. Though not presented here, the scheme can be easily extended to an arbitrary number of source nodes.

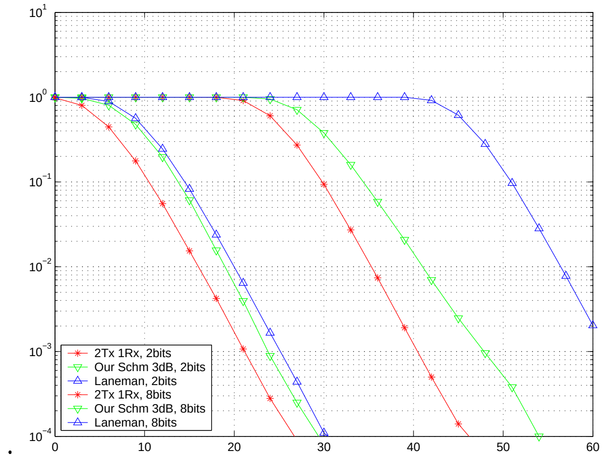

Figure 3: P_{out} vs. SNR_{DA} for various schemes.

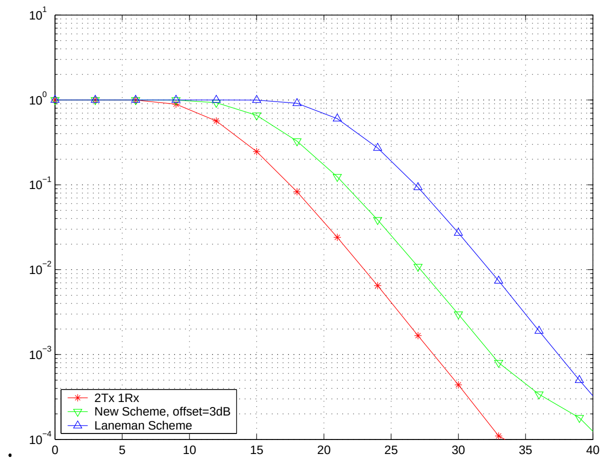

Figure 4: Comparison of P_{out} vs. SNR_{DA} for various schemes. $r = 4bits$

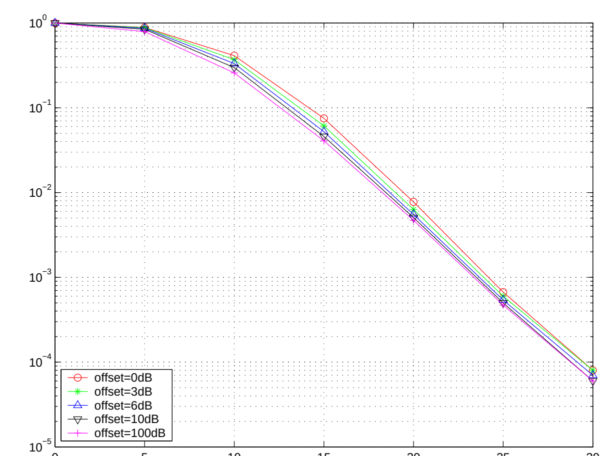

Figure 5: P_{out} vs. SNR_{DA} for various offsets, i.e. $SNR_{SA} = SNR_{DA} + offset$. $r = 2bits$

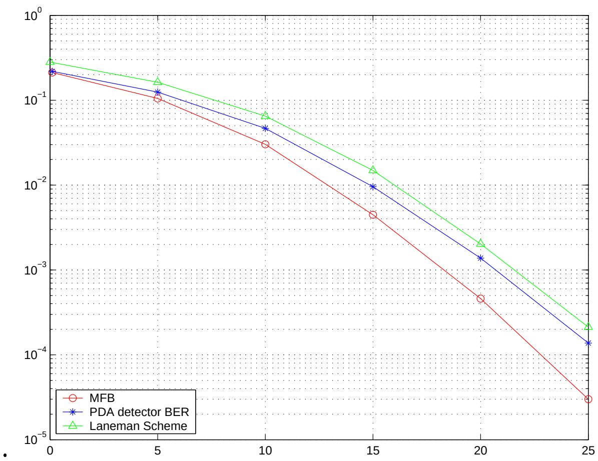

Figure 6: Comparison of BER vs SNR_{DA} for the proposed and Laneman et al's scheme. $r = 4bits$ and $offset = 3dB$.

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