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Selection Combiner in Time-Varying Amplify Forward Cooperative Communication

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Abstract: This research presents the diversity combining schemes for Multiple Symbol Double Differential Sphere Detection (MSDDSD) in a time-varying amplify-and-forward wireless cooperative communication network. Four diversity combiners, including direct combiner, Maximal Ratio Combiner (MRC), semi MRC and Selection Combiner (SC) are demonstrated and explained in details. A comprehensive error probability and outage probability performance analysis are carried through the flat fading Rayleigh environment for semi MRC and SC. Specifically, error performance analysis is obtained using the PDF for SC detectors. Finally, power allocation expression based on error performance minimization approach is presented for the proposed SC performance optimization. It is observed that the performance analysis matches well with the simulation results. Furthermore, the proposed SC scheme offers better performance among the conventional MRC and direct combiner schemes in the presence of frequency offsets.

Keywords: Amplify-and-forward, Selection Combiner (SC), frequency offsets, Multiple Symbol Double Differential Sphere Detection (MSDDSD)

1. Introduction

Cooperative diversity appears to be one of the promising approaches to encounter the challenging requirement for the next-generation of broadband systems such as WiMAX and 3GPP LTE-Advanced [1] concerning fading mitigation, coverage, capacity, reliability, diversity and to overcome the unpredictable characteristics of the channel [2-6]. Nevertheless, high mobility, limited transmission range as well as bandwidth, and unreliable noisy channels create a harsh environment for communication.

At the destination, the detection schemes play a vital role to detect the incoming signals correctly. The detection schemes can be categorized as coherent and non-coherent. Coherent detection requires the complex Channel State Information (CSI) estimation at the receiver [7,8]. On the contrary, non-coherent detection [9] such as differential decoder do not require CSI in order to recover the data [10,11]. This is because rather than analysing the phase that corresponds to the coherent signal, differential decoder determine the phase difference based on the previously and presently received signal and efficient decoding relies on constant response of the channel from one time sample to the ext. Then, the decision variable is computed to obtain the optimized gain for Maximum Ratio Combiner (MRC) requiring the instantaneous channel knowledge of the relayed channel, which is unknown. Therefore, a group of fixed gains has been determined in [12-18] so as to obtain the statistical knowledge of the communication channel. Most of the existing literature on differential transmission networks [19] assume a flat-fading environment [20]. Though, this consideration is unjustified as cooperative communications are mainly applied in the wireless mobile system, whereby the users are mobile. Furthermore, previous studies have primarily concentrated on omitting channel knowledge without considering the effect of frequency offsets [2,4,21,23].

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Based on the proposed system model and multiple symbol based Double Differential (DD) detection in [23], one step further is taken at the destination to improve the network's performance. The previous research employing direct combiner is extended with other diversity combining techniques such as, conventional MRC, semi MRC and SC under time-varying channels [24,25]. SC is selected among the other diversity combining schemes due to its approach that does not depends on the channel knowledge [26]. A comprehensive error probability and outage probability performance analysis are carried through the flat fading Rayleigh environment for semi MRC and SC. Specifically, PEP expressions for the semi MRC detectors are derived based on the MGF. Contrarily, PDF analysis expression is derived to measure the system outage probability. For SC detectors, the error performance analysis is obtained using the PDF. Finally, power allocation expression based on error performance minimization approach is presented for the proposed SC performance optimization.

2.0 System Model

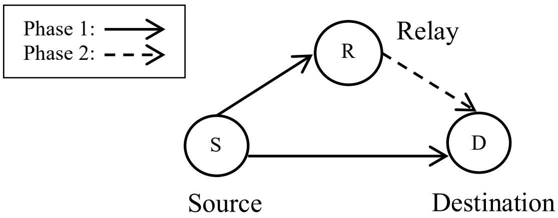

Fig. 1 - Proposed system model [27]

Considering three terminals of one source, one relay and one destination, the system model in this section is similar to Fig. 1. By exploiting the wireless channel, a doubly-differential encoded signal is transmitted from the source via two transmission links i.e., towards the fixed-in AF relay and directly to the destination. In order to attain the diversity of cooperation network, the transmitted signals from both relayed and direct links are combined using some combining schemes. From [28], MRC has been proposed under slow fading channels as:

$$\varsigma = \frac{1}{N_0}\varsigma_{s,d} + \frac{1}{N_0(1 + G\sigma_{r,d}^2)}\varsigma_{s,r,d} \quad (1)$$

where G is the relay amplification gain, N_0 represents the noise and $\sigma_{r,d}^2$ denotes noise variance of relay-destination link. It can be seen from (1) that statistical knowledge of all wireless channels are required. Thus, in order to avoid the channel and frequency offset estimation, SC scheme is proposed. For selection combining approach, only the best relayed signal possessing the highest signal magnitude among the relayed signals is chosen. Then, the receiver at the destination will consider the signal from the source as well as the one from the best relayed signal and select the one with a larger SNR for decoding purpose [29]. The block diagram of the Double Differential Amplify Forward (DDAF) network employing SC scheme at the destination is portrayed in Fig. 2.

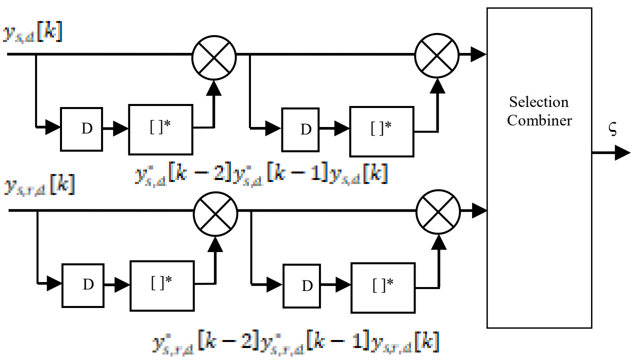

Fig. 2 - The block diagram of SC scheme at the receiver

For DDAF network employing Binary Pulse Shift Keying (BPSK) constellations, the decision variables at the destination for direct, $\varsigma_{s,d}$ and relayed link $\varsigma_{s,r,d}$ are computed from the three latest received symbols $z[n], z[n-1]$ and $z[n-2]$ are written as:

$$\varsigma_{s,d} = R\{(z_{s,d}[n]z_{s,d}^{*}[n-1]) \\ (z_{s,d}[n-1]z_{s,d}^{*}[n-2])^{*}\} \tag{2}$$

$$\varsigma_{s,r,d} = R\{(z_{s,r,d}[l]z_{s,r,d}^{*}[l-1]) \\ (z_{s,r,d}[l-1]z_{s,r,d}^{*}[l-2])^{*}\} \tag{3}$$

The decision variables are then, compared in terms of the larger magnitude of the links. Hence the decoded output of the SC $\hat{x}[k]$ can be obtained as:

$$\hat{x}[k] = \begin{cases} -1 & if\ |\varsigma_{s,d}| \geq \varsigma_{s,r,d} \\ +1 & otherwise \end{cases} \tag{4}$$

3.0 Performance Analysis of Selection Combiner

It is assumed that $s[0] = s[1] = p[1] = 1$ as an initialization. Since only direct link and single relay link is considered, the probability of error can be given by [17] as:

$$P_b(E) = \Pr(|\varsigma_{s,d}| > \varsigma_{s,r,d}) + \Pr(|\varsigma_{s,r,d}| > \varsigma_{s,d}) \tag{5}$$

Since $\varsigma_{s,d}$ and $\varsigma_{s,r,d}$ have different distributions, the probability of error (5) is computed separately. By averaging over the Probability Density Function (PDF) of $\varsigma_{s,d}$ and $\varsigma_{s,r,d}$, the average error probability can be expressed as:

$$P_b(E_1) = \Pr(|\varsigma_{s,d}| > \varsigma_{s,r,d}) = \int_{-\infty}^{0}\int_{0}^{-z} f_{\varsigma_{s,d}}(z) f_{\varsigma_{s,r,d}}(r)\, dr\, dy \\ = \int_{-\infty}^{0} f_{\varsigma_{s,d}}(z)\left[F_{|\varsigma_{s,r,d}|}(-z) - F_{|\varsigma_{s,r,d}|}(0)\right] dz \tag{6}$$

and

$$P_b(E_2) = \Pr(|\varsigma_{s,d}| > \varsigma_{s,r,d}) = \int_{-\infty}^{0}\int_{0}^{-z} f_{\varsigma_{s,r,d}}(z) f_{\varsigma_{s,d}}(r)\, dr\, dy \\ = \int_{-\infty}^{0} f_{\varsigma_{s,r,d}}(z)\left[F_{|\varsigma_{s,d}|}(-z) - F_{|\varsigma_{s,d}|}(0)\right] dz \tag{7}$$

From (6) and (7), it is known that, the PDF of ς is related to its Cumulative Density Function (CDF), $F_{\varsigma}(\varsigma)$ by:

$$f_{\varsigma}(z) = \frac{dF_{\varsigma}(z)}{d\varsigma} \tag{8}$$

The CDF of $\varsigma_{s,d}$ and $\varsigma_{s,r,d}$ can be obtained as:

$$F_{|\varsigma_{s,d}|}(z) = \Pr(|\varsigma_{s,d}| \leq z) \\ = Pr(-z \leq |\varsigma_{s,d}| \leq z) \\ = F_{\varsigma_{s,d}}(z) - F_{\varsigma_{s,d}}(-z) \tag{9}$$

and

$$F_{|\varsigma_{s,r,d}|}(z) = \Pr(|\varsigma_{s,r,d}| \leq z) \\ = Pr(-z \leq |\varsigma_{s,r,d}| \leq z) \\ = F_{\varsigma_{s,r,d}}(z) - F_{\varsigma_{s,r,d}}(-z) \tag{10}$$

In order to proceed with the computation of the probability error, the PDFs and CDFs of the decision variables, $\varsigma_{s,d}$ and $\varsigma_{s,r,d}$ are required. The individual time-varying channel based on autoregressive AR(2) is given by [30]:

$$h_{s,r}[k] = \alpha_{s,r}^2 h_{s,r}[k-2] + \alpha_{s,r}\varepsilon_{s,r}[k-1] + \varepsilon_{s,r}[k] \tag{11}$$

where $\varepsilon_{s,r}$ represents white noise error term for source-relay link. For a relayed channel, it is given as:

$$h[k] = \alpha^2 h[k-2] + \alpha h_{s,r}[k-2]\varepsilon_{s,r}[k] \tag{12}$$

where $\alpha^2 = (\alpha_{s,r}\alpha_{r,d})^2 \leq 1$ is the autocorrelation of the relayed channel.

By substituting the source-destination channel model of

$$h[k] = \alpha_{r,d}^2 h[k-2]h_{s,r}[k-1] + \alpha_{r,d}h_{s,r}[k-2]h[k-1] + 2\sqrt{1-\alpha_{r,d}^2}h_{s,r}[k-2]h_{s,r}[k-1]\varepsilon_{r,d}[k] \tag{13}$$

and the transmitted symbols $x[k]$ into

$$y_{s,d}[n] = P_S h_{s,d} e^{j2\pi f_{s,d}n} z[k] + e_{s,d}[n] \tag{14}$$

one gets:

$$y_{s,d}[k] = \alpha^2 x[k] y_{s,d}[k-2] e^{j2\pi f_{s,d}[k]} + \tilde{\varepsilon}_{s,d}[k] \tag{15}$$

where

$$\tilde{\varepsilon}_{s,d}[k] = \alpha P_S h_{s,d}[k-2]\varepsilon_{s,d}[k-1]e^{j2\pi f_{s,d}[k]}x[k] + \quad P_S h_{s,d}[k-2]\varepsilon_{s,d}[k]e^{j2\pi f_{s,d}[k]}x[k] + \varepsilon_{s,d}[k] \tag{16}$$

with P_S as source power. Similarly, by substituting the relayed channel model transmitted signals and the white Gaussian noise of the time-varying channel and the transmitted symbols into $y_{s,r,d}$, one gets:

$$y_{s,r,d}[k] = \alpha^2 x[k] y_{r,d}[k-2] e^{j2\pi f_{r,d}[k]} + \tilde{\varepsilon}[k] \tag{17}$$

where

$$\tilde{\varepsilon}_{r,d}[k] = \alpha P_S h_{r,d}[k-2]\varepsilon_{r,d}[k-1]e^{j2\pi f_{r,d}[k]}P_S x[k] + \quad P_S h_{r,d}[k-2]\varepsilon_{r,d}[k]e^{j2\pi f_{r,d}[k]}x[k] + \varepsilon_{r,d}[k] \tag{18}$$

Then, substitutes $y_{s,d}$ and $y_{s,r,d}$ into the decision variables from (2) and (3) gives:

$$\varsigma_{s,d} = R\{\alpha^2 x[k]\left|y_{s,d}[k-1]\right|^3 y_{s,d}[k-2] + \left|y_{s,d}[k-1]\right|^2 y_{s,d}^*[k-2]\tilde{\varepsilon}[k] \tag{19}$$

and

$$\varsigma_{s,r,d} = R\{\alpha^2 x[k]\left|y_{s,r,d}[k-1]\right|^3 y_{s,r,d}[k-2] + \left|y_{s,r,d}[k-1]\right|^2 y_{s,r,d}^*[k-2]\tilde{\varepsilon}[k] \tag{20}$$

It can be observed that, conditioned on $y_{s,d}[k-1]$ and $y_{s,d}[k-2]$, the conditional mean, $\mu_{\varsigma_{s,d}}$ and variance $\sigma_{\varsigma_{s,d}}^2$ of the decision variables are computed as:

$$\begin{aligned}
\mu_{\varsigma_{s,d}} &= E\{\varsigma_{s,d}|y_{s,d}[k-1]y_{s,d}[k-2], x[k] = +1\} \\
&= \alpha_{s,d}^2\left|y_{s,d}[k-2]\right|^3 y_{s,d}[k-2] + E\{R\{|y_{s,d}[k-1]|^2 y_{s,d}^*[k-2]\tilde{\varepsilon}[k]\}\} \\
&= \alpha_{s,d}^2\left|y_{s,d}[k-1]\right|^3 y_{s,d}[k-2] - \alpha_{s,d}^2 E\{R\{\varepsilon[k-1]y_{s,d}|[k-1]|^2 y_{s,d}[k-2]\}\} \\
&= \alpha_{s,d}^2\left|y_{s,d}[k-1]\right|^3 y_{s,d}[k-2] - \frac{\alpha_{s,d}^2}{\rho_o+1}[\left|y_{s,d}[k-1]\right|^3 y_{s,d}[k-2]] \\
&= \frac{\alpha_{s,d}^2\rho_o}{\rho_o+1}[|y_{s,d}[k-1]|^3 y_{s,d}[k-2]]
\end{aligned} \tag{21}$$

where $E(\cdot)$ represents the expectation and

$$\sigma^2_{\varsigma_{s,d}} = Var\{\varsigma_{s,d}|y_{s,d}[k-1]y_{s,d}[k-2], x[k] = +1\}$$
$$= Var\{\alpha^2_{s,d}|y_{s,d}[k-2]|^3 y_{s,d}[k-2] + |y_{s,d}[k-1]|^2 y^*_{s,d}[k-2]\tilde{\varepsilon}[k]\}$$
$$= Var\{|y_{s,d}[k-1]|^2 y^*_{s,d}[k-2]\tilde{\varepsilon}[k]\}$$
$$= \frac{1}{2}N_0|y_{s,d}[k-2]|^2|y_{s,d}[k-1]|^2 + \frac{1}{2}N_0\frac{\alpha^2_{s,d}\rho_0}{\rho_0+1}|y_{s,d}[k-2]|^2|y_{s,d}[k-1]|^2 +$$
$$\frac{1}{2}N_0(1-\alpha_0^2)\rho_0|y_{s,d}[k-2]|^2|y_{s,d}[k-1]|^2$$
$$= \frac{1}{2}N_0\left\{1 + \frac{\alpha^2_{s,d}\rho_0}{\rho_0+1} + (1-\alpha^2_{s,d})\rho_0\right\}$$
$$|y_{s,d}[k-2]|^2|y_{s,d}[k-1]|^2 \quad (22)$$

Additionally, conditioned on $y_{r,d}[k-1]$ and $y_{r,d}[k-2]$, the conditional mean, $\mu_{\varsigma_{s,r,d}}$as well as variance of the decision variables, $\sigma^2_{\varsigma_{s,r,d}}$ are computed as:

$$\mu_{\varsigma_{s,r,d}} = E\{\varsigma_{s,r,d}|y_{r,d}[k-1]y_{r,d}[k-2], x[k] = +1\}$$
$$= \alpha^2_{r,d}|y_{r,d}[k-2]|^3 y_{r,d}[k-2] + E\{R\{|y_{r,d}[k-1]|^2 y^*_{r,d}[k-2]\tilde{\varepsilon}[k]\}\}$$
$$= \alpha^2_{r,d}|y_{r,d}[k-1]|^3 y_{r,d}[k-2] - \alpha^2_{r,d}E\{R\{\varepsilon[k-1]y_{r,d}|[k-1]|^2 y_{r,d}[k-2]\}\}$$
$$= \alpha^2_{r,d}|y_{r,d}[k-1]|^3 y_{r,d}[k-2] - \frac{\alpha^2_{r,d}}{\rho_1+1}[|y_{r,d}[k-1]|^3 y_{r,d}[k-2]]$$
$$= \frac{\alpha^2_{r,d}\rho_1}{\rho_1+1}[|y_{r,d}[k-1]|^3 y_{r,d}[k-2]] \quad (23)$$

and

$$\sigma^2_{\varsigma_{s,r,d}} = Var\{\varsigma_{s,r,d}|y_{r,d}[k-1]y_{r,d}[k-2], x[k] = +1\}$$
$$= Var\{\alpha^2_{r,d}|y_{r,d}[k-2]|^3 y_{r,d}[k-2] + |y_{r,d}[k-1]|^2 y^*_{r,d}[k-2]\tilde{\varepsilon}[k]\}$$
$$= Var\{|y_{r,d}[k-1]|^2 y^*_{r,d}[k-2]\tilde{\varepsilon}[k]\}$$
$$= \frac{1}{2}N_0|y_{r,d}[k-2]|^2|y_{r,d}[k-1]|^2 + \frac{1}{2}N_0\frac{\alpha^2_{r,d}\rho_1}{\rho_0+1}|y_{r,d}[k-2]|^2|y_{r,d}[k-1]|^2 +$$
$$\frac{1}{2}N_0(1-\alpha_2^2)\rho_1|y_{r,d}[k-2]|^2|y_{r,d}[k-1]|^2$$
$$= \frac{1}{2}N_0\left\{1 + \frac{\alpha^2_{r,d}\rho_1}{\rho_0+1} + (1-\alpha_2^2)\rho_0\right\}|y_{s,d}$$
$$[k-2]|^2|y_{s,d}[k-1]|^2 \quad (24)$$

The conditional PDF of $\varsigma_{s,d}$ can be computed based on [31]:

$$f_{\varsigma_{s,d}}(z|y_{s,d}) = \frac{1}{(\sigma^2_{\varsigma_{s,d}})}e^{\left(\frac{(z-2\mu_{\varsigma_{s,d}})}{2\sigma^2_{\varsigma_{s,d}}}\right)} \quad (25)$$

Since the distribution of the channel $h_{s,d}$ is $y_{s,d} \sim \mathcal{CN}(0, N_0(1+\rho_0))$, therefore $|y_{s,d}|^2 = N_0^2(1+\rho_0)^2)$. Its PDF is obtained as [32]:

$$f_{y_{s,d}}(z) = \frac{\exp\left(-\frac{z}{N_0(1+\rho_0)}\right)}{N_0(1+\rho_0)} \quad (26)$$

By taking the average of (26) over the distribution of $y_{s,d}$, the PDF of $\varsigma_{s,d}$ is given as [33]:

$$f_{\varsigma_{s,d}}(z) = \begin{cases} B_0 e^{(C_0 z)}, & z < 0 \\ B_0 e^{(-D_0 z)}, & z \geq 0 \end{cases} \quad (27)$$

where

$$B_0 = \frac{1}{N_0(1+\rho_0)} \tag{28}$$

$$C_0 = \frac{2}{N_0(1-\alpha_0{}^2)\rho_0} \tag{29}$$

$$D_0 = \frac{2}{N_0(1+\alpha_0{}^2)\rho_0} \tag{30}$$

Then, the CDF of $\varsigma_{s,d}$ is obtained.
For $z < 0$,

$$F_{\varsigma_{s,d}}(z) = \int_{-z}^{0} B_0 e^{C_0 z} dz = \frac{B_0}{C_0}[1 - e^{-C_0 z}] \tag{31}$$

For $z \geq 0$,

$$F_{\varsigma_{s,d}}(z) = \int_{0}^{z} B_0 e^{-D_0 z} dz = -\frac{B_0}{D_0}[e^{-D_0 z} - 1] \tag{32}$$

The CDF of $|\varsigma_{s,d}|$ is expressed by substituting (32) into (9) as:

$$\begin{aligned} F_{|\varsigma_{s,d}|}(z) &= F_{\varsigma_{s,d}}(z) - F_{\varsigma_{s,d}}(-z) \\ &= -\frac{B_0}{D_0}(e^{D_0 z} - 1) - \frac{B_0}{C_0}(1 - e^{-C_0 z}) \end{aligned} \tag{33}$$

Similarly, for the relayed link, the conditional PDF of $\varsigma_{s,r,d}$ is written as:

$$f_{\varsigma_{s,r,d}}(z|y_{s,r,d}, h_{r,d}) = \frac{1}{(\sigma^2_{\varsigma_{s,r,d}})} e^{\left(\frac{z-2\mu_{\varsigma_{s,r,d}}}{2\sigma^2_{\varsigma_{s,r,d}}}\right)} \tag{34}$$

Since the distribution of the channel $h_{s,r,d}$ is $y_{s,r,d} \sim \mathcal{CN}(0, \sigma_w{}^2(1+\rho_1))$, therefore $|y_{s,r,d}|^2 = \sigma_w{}^2(1+\rho_1)^2)$. Its PDF is obtained as [32]:

$$f_{y_{s,r,d}}(z_1) = \frac{\exp\left(-\frac{z_1}{\sigma_w{}^2(1+\rho_1)}\right)}{\sigma_w{}^2(1+\rho_1)} \tag{35}$$

By taking the average of (35) over the distribution of $y_{s,r,d}$, the PDF of $\varsigma_{s,r,d}$ is given as [33]:

$$f_{\varsigma_{s,r,d}}(z|h_{r,d}) = \begin{cases} B_1 e^{(C_1 z)}, & z \leq 0 \\ B_1 e^{(-D_1 z)}, & z \geq 0 \end{cases} \tag{36}$$

where

$$B_1 = \frac{1}{\sigma_w{}^2(1+\rho_1)} \tag{37}$$

$$C_1 = \frac{2}{\sigma_w{}^2(1-\alpha_1{}^2)\rho_1} \tag{38}$$

$$D_1 = \frac{2}{\sigma_w{}^2(1+\alpha_1{}^2)\rho_1} \tag{39}$$

Then, the CDF of $\varsigma_{s,r,d}$ is obtained.
For $z < 0$,

$$F_{\varsigma_{s,r,d}}(z) = \int_{-z}^{0} B_1 e^{C_1 z} dz = \frac{B_1}{C_1}[1 - e^{-C_1 z}] \tag{40}$$

For $z \geq 0$,

$$F_{\varsigma_{s,r,d}}(z) = \int_{0}^{z} B_1 e^{-D_1 z} dz = -\frac{B_1}{D_1}[e^{-D_1 z} - 1] \tag{41}$$

The CDF of $|\varsigma_{s,r,d}|$ conditioned on $h_{r,d}$ is expressed by substituting (40) into (11) as:

$$\begin{aligned} F_{|\varsigma_{s,r,d}|}(z|h_{r,d}) &= F_{\varsigma_{s,r,d}}(z) - F_{\varsigma_{s,r,d}}(-z) \\ &= -\frac{B_1}{D_1}(e^{-D_1 z} - 1) - \frac{B_1}{C_1}(1 - e^{-C_0 z}) \end{aligned} \tag{42}$$

Therefore, from (6),

$$\begin{aligned} P_b(E_1|h_{r,d}) &= \int_{-\infty}^{0} f_{\varsigma_{s,d}}(z) \left[F_{|\varsigma_{s,r,d}|}(-z|h_{r,d}) - F_{|\varsigma_{s,r,d}|}(0|h_{r,d})\right] dz \\ &= \int_{-\infty}^{0} B_0 e^{C_0 z} \left(\frac{B_1}{D_1} e^{-D_2 z} - \frac{B_1}{C_1} e^{C_1 z} - \frac{B_1}{D_1} + \frac{B_1}{C_1}\right) dz \\ &= B_0 B_1 \left(\frac{1}{D_1(C_0 - D_1)} + \frac{1}{C_1(C_0 - C_1)}\right) \end{aligned} \tag{43}$$

Similarly, from (7)

$$P_b(E_2|h_{r,d}) = \int_{-\infty}^{0} f_{\varsigma_{s,r,d}}(z|h_{r,d}) \left[F_{|\varsigma_{s,d}|}(-z) - F_{|\varsigma_{s,d}|}(0)\right] dz$$

$$= \int_{-\infty}^{0} B_1 e^{C_1 z} \left(\frac{B_0}{D_0} e^{-D_0 z} - \frac{B_0}{C_0} e^{C_0 z} - \frac{B_0}{D_0} + \frac{B_0}{C_0}\right) dz = B_0 B_1 \left(\frac{1}{D_0(C_1 - D_0)} + \frac{1}{C_1(C_0 - C_1)}\right) \tag{44}$$

Hence, by combining the equation (43) and (44), the conditional probability of error can be expressed as:

$$P_b(E|h_{r,d}) = P_b(E_1|h_{r,d}) + P_b(E_2|h_{r,d}) = B_0 B_1 + \frac{B_0 B_1}{D_1(C_0 - D_1)} + \frac{B_0 B_1}{D_0(C_1 - D_0)} \tag{45}$$

Taking the average over the distribution of $|h_{r,d}|^2 = h$, the conditional probability of error is calculated as:

$$P_b(E) = \int_{0}^{\infty} \left(\frac{B_0 B_1}{C_0 C_1} + \frac{B_0 B_1}{C_0(C_0 - D_1)} + \frac{B_0 B_1}{C_1(C_1 - D_0)}\right) f_h(h)\, dh$$

$$P_b(E) = P_{b1}(E) + P_{b2}(E) + P_{b3}(E) \tag{46}$$

Based on 3.352.4 in [22], $P_{b1}(E)$, $P_{b2}(E)$ and $P_{b3}(E)$ can be solved as:

$$\begin{aligned} P_{b1}(E) &= \int_{0}^{\infty} (B_0 B_1) f_h(h)\, d = B_0 \int_{0}^{\infty} b_1\, (h + b_1) \frac{e^{-\frac{h}{\sigma_{r,d}^2}}}{\sigma_{r,d}^2} dh \\ &= B_0 \left(1 + \frac{1}{G^2(1+\rho_1)\sigma_{r,d}^2} \exp\left(\frac{1}{\sigma_{r,d}^2}\right) E_1\left(\frac{1}{\sigma_{r,d}^2}\right)\right) \end{aligned} \tag{47}$$

with $E_i(\mu) = \int_{1}^{\infty} \frac{e^{\mu x}}{x} dx$ indicates the exponential integral function.

$P_{b2}(E)$ is computed as follows:

$$P_{b2}(E) = \int_0^{\infty} \frac{B_0 B_1}{C_0(C_0 - D_1)} f_h(h)\, dh = \frac{B_0}{C_0} \int_0^{\infty} \frac{b_1}{h + b_1} \frac{1}{\sigma_{r,d}^2} e^{-\frac{h}{\sigma_{r,d}^2}} dh \tag{48}$$

where

$$b_1 = \frac{1 + (1-\alpha)\rho_1 + 1 + (1-\alpha_{s,d})\rho_0}{G^2(1 + (1+\alpha)\rho_1 + \big(1 + (1-\alpha_{s,d})\rho_0\big)} \tag{49}$$

and $P_{b3}(E)$ can be determined as:

$$P_{b3}(E) = \int_0^{\infty} \frac{B_0 B_1}{C_1(C_1 - D_0)} f_h(h)\, dh = \frac{B_0}{C_1} \int_0^{\infty} \frac{2}{G^2(1 + (1-\alpha)\rho_1} \frac{h + \tilde{b}_0}{h + \tilde{b}_1} dh \tag{50}$$

where

$$\tilde{b}_0 = \frac{1 + (1-\alpha_{s,d})\rho_0\rho_1 + 1 + (1-\alpha_{s,d})\rho_0}{G^2(1 + (1+\alpha)\rho_1 + (1+\alpha)\rho_1^2)} \tag{51}$$

$$\tilde{b}_1 = \frac{1 + (1-\alpha)\rho_1 + 1 + (1+\alpha_{s,d})\rho_0}{G^2(1 + (1-\alpha)\rho_1 + \big(1 + (1+\alpha_{s,d})\rho_0\big)} \tag{52}$$

4.0 Numerical Results and Discussion

In this section, Matlab simulation is conducted in order to examine the overall system performance of the proposed semi MRC and SC. The proposed SC scheme is the simplest among all other combining schemes, where only the maximum amplitude of the link is required to determine the near optimum performance of signal combining. DD modulation and demodulation is implemented to the system at the source and destination, respectively. The proposed methods are tested with respect to various channel fading environments. It is assumed that the variance of the complex channel between any pairs of the terminals is normalized to 1 and 10 for fading gains. For instance, $\sigma_{s,d}^2 = \sigma_{s,r}^2 = \sigma_{r,d}^2 = 1$ refers to the scenarios when the relay is located in the middle between the source and destination terminals. $\sigma_{s,d}^2 = 1; \sigma_{s,r}^2 = 1; \sigma_{r,d}^2 = 10$ refers to the scenarios where the relay are located nearer to the destination terminals. On the other hand, $\sigma_{s,d}^2 = 1; \sigma_{s,r}^2 = 10; \sigma_{r,d}^2 = 1$ denotes the scenarios where the relays are located nearer to the source terminal. For all simulations, the relay is fixed to 1 and all channels are slow fading with $f_{D_{s,r}}T_s = f_{D_{r,d}}T_s = f_{D_{s,d}}T_s = 0.001$ is investigated.

In order to give a fair comparison between various combining schemes, the transmit power of the source and the relay(s) of each combiner schemes is equally divided.

4.1 Performance of Error Probability

Fig. 3 and Fig. 4 show the performances of various diversity combining schemes (i.e. direct combiner, MRC, semi MRC and SC) under symmetric case of Rayleigh fading channel. The baseline is the double differentially multiple symbol cooperative communication with conventional MRC scheme. All schemes demonstrate the almost identical curve of performance (i.e. the BER decreases as SNR increases). It is clearly shown that the proposed semi MRC and SC scheme offer better performance as compared to the conventional MRC and direct combiner scheme for a symmetric case with $\sigma_{s,r}^2 = 1; \sigma_{r,d}^2 = 1; \sigma_{s,d}^2 = 1$ and slow fading channels throughout the whole SNR range. Moreover, it can be observed that the performance of the conventional MRC and direct combiner are unable to achieve optimum performance, due to the channel noise variance and the presence of the frequency offsets in the system. Both MRC and direct combining scheme of signal combining is lagging behind 8dB to 10dB and 2dB to 3dB to the optimum combining performance, respectively.

Another interesting phenomenon is that the proposed semi MRC demonstrates a very close performance with the proposed SC scheme. It is reiterated that the semi MRC scheme requires second order channel statistics, which implies that the combining scheme is not suitable for fast fading environment. On the other hand with the proposed SC scheme, the receivers are able to decode the transmitted information signal by selecting the largest magnitudes among the communication links (i.e. the relayed and direct link) without estimating the channel gains or the frequency offsets.

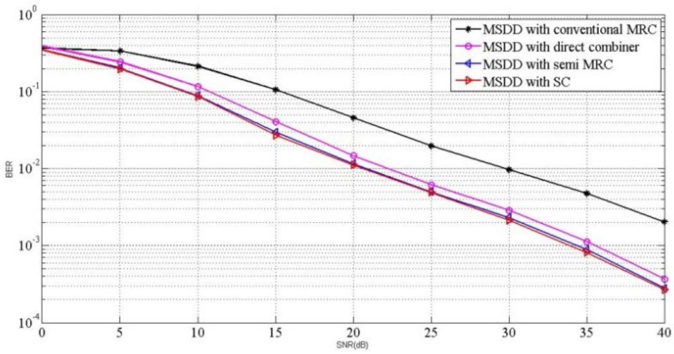

Fig. 3 - Comparison of the BER performance for the conventional MRC, semi MRC, direct combiner and proposed SC scheme based on MSDD when $\sigma_{s,r}^2 = 1; \sigma_{r,d}^2 = 1; \sigma_{s,d}^2 = 1$ for DDBPSK

The simulations are extended to include DDQPSK in Rayleigh channels. Fig. 4 presents results for DDQPSK in a Rayleigh channel. The shape and the relative positioning of the error probability plots are very similar to those of DDBPSK in Rayleigh fading channel as shown in Figure 4.8. The plots for the diversity combining schemes in DDQPSK are shifted at least 4 dB to the right along the SNR axis, compared to the DDBPSK case. For example to obtain the same error probability at 10^{-3}, the SC scheme requires 4 dB more SNR than DDBPSK). This occurs for all the probability plots of other diversity combining schemes.

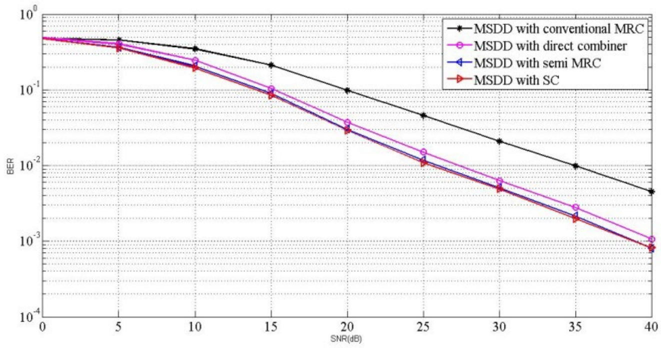

Fig. 4 - Comparison of the BER performance for the conventional MRC, semi MRC, direct combiner and proposed SC scheme based on MSDD when $\sigma_{s,r}^2 = 1; \sigma_{r,d}^2 = 1; \sigma_{s,d}^2 = 1$ for DDQPSK

On the other hand, the error probability plot of conventional MRC for the AF scheme is shifted even more to the right, increasing the performance difference between the SC and conventional MRC in the cooperative systems. Similar to the results of the semi MRC and SC scheme for Double Differential Binary Phase Shift Keying (DDBPSK), both schemes demonstrate a very close performance with each other. It can be observed that the SC scheme performance is slightly better than that of the semi MRC method. This is due to the reason that the semi MRC used the fixed combining weight based on the second-order channel statistics, instead of the instantaneous channel knowledge that are not optimum. It is noted that the conventional MRC requires the noise variance of each communication links in order to obtain the optimum combining weights. However, the noise variance of the relayed link is not available especially in fast fading channels which restrict the receiver from obtaining the perfect instantaneous channel knowledge of the relay-destination link. On the other hand, the tight results between the semi MRC as well as SC allows the used of SC scheme analysis as the performance approximation for the semi MRC scheme under time-varying channels. It is noted that the derivation of the performance analysis for semi MRC under time-varying environment is complicated and challenging.

The SC scheme again outperforms all other schemes and has a performance difference over conventional MRC of around 5 dB at 10^{-2} when the communication channels vary with time. Both simulation results from Fig. 3 and Fig. 4 show that the proposed SC scheme is able to show very close performance as compare to the semi MRC scheme. But the analysis is limited to symmetric fading powers. Thus, the analysis is one step further extended for the network in the context of various terminal's location or different quality channels. These imply that the system will experience different fading powers and fading rates.

In order to calculate the allocation of the optimized power between the source and the relay, the expression of BER in (45) is simulated for a range of power allocation factor $q = P_S / P_T$ where $P_T = P_S + P_R$ is the total power transmitted in the system. The BER curves are plotted versus PAF in Fig. 5 for $\frac{P}{N_0} = 20\ dB$ with DDBPSK. Similar results are obtained when DDQPSK is utilized. Note that for AF relaying network, the optimum power allocation is not modulation-dependent. This is because in the AF cooperative system, the relay amplifies the received signals and retransmit the amplified signals regardless the types of the signals. The power allocation for symmetrical and non-symmetrical cases is tabulated in Table 1 referring to the simulation results from Fig. 5.

The results from Table 1 and Fig. 5 demonstrate that to achieve a low BER around 10^{-3} and 10^{-4}, for strong source-destination and strong source-relay channels, more power is devoted to relay compared to the source. In contrast, when the relay-destination channel becomes stronger than the source- relay channel, equal power allocation between the source and relay is more beneficial to enhance the system performance.

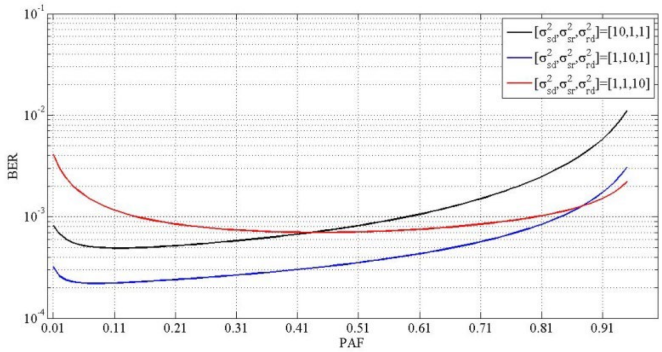

Fig. 5 - Function of BER for PAF at $\frac{P}{N_0} = 20\ dB$

Table 1 - Power allocation for different channel variances

Scenarios	Channel Variances			Power Allocation	
	$\sigma^2_{s,d}$	$\sigma^2_{s,r}$	$\sigma^2_{r,d}$	P_S	P_R
Strong SD	10	1	1	0.08	0.92
Strong SR	1	10	1	0.11	0.89
Strong RD	1	1	10	0.44	0.56

The simulation of the SC scheme with blue solid lines (different legends) and the semi MRC scheme with red blue solid lines under time-varying channels are further analysed. The simulations are depicted in Fig. 6 and Fig. 7 under different fading rates with symmetrical channels.

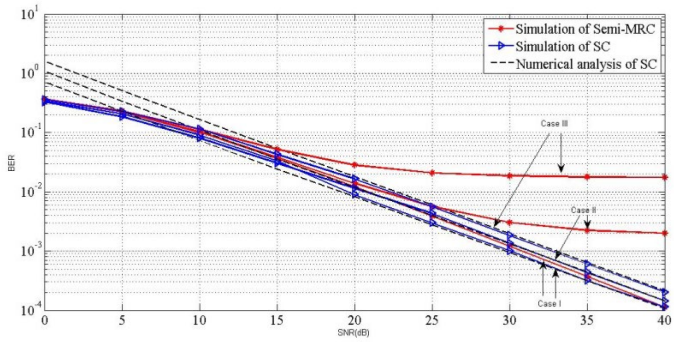

Fig. 6 - Theoretical numerical analysis and simulation BER of the DD-AF system with semi MRC and SC using BPSK under different fading rates and symmetrical channels ($\sigma^2_{s,d} = 1; \sigma^2_{s,r} = 1; \sigma^2_{r,d} = 1$)

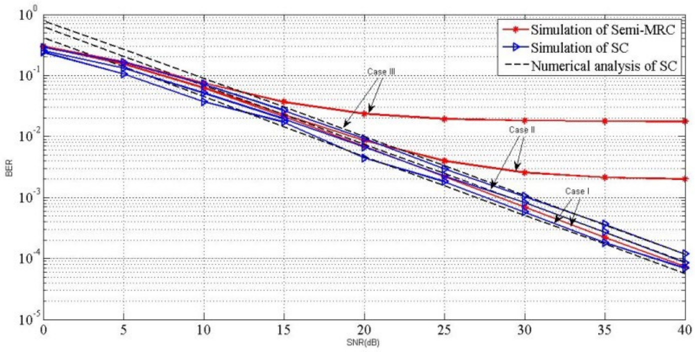

Fig. 7 - Theoretical numerical analysis and simulation BER of the DD-AF system with semi MRC and SC using BPSK under different fading rates and symmetrical channels ($\sigma_{s,d}^2 = 1; \sigma_{s,r}^2 = 10; \sigma_{r,d}^2 = 1$)

It is observed in Case I (slow fading channels) that the BER of the semi MRC and SC scheme decrease consistently with SNR and achieve diversity of two. In Case I for both schemes, error floor does not exist because all the channels involved are slow fading. Furthermore, it can be observed from Fig. 6 and Fig. 7, the proposed scheme benefits from substantial amount of improvement in slowly-faded channel when compared with the semi MRC scheme.

However for Case II, even more performance gain is acquired by for semi MRC scheme due to the time diversity provided by the time-varying channels. The phenomenon leads to irreducible error floor. In fast fading channels, the channels vary and the phenomenon effects both semi MRC and SC scheme for SNR>20dB. In Case I, the BER for the semi MRC gradually diverge from the Case I results. To be more specific, as the SNR increases, the plot finally come to an error floor between 10^{-3} and 10^{-2}. However, the results of the SC scheme shows significant enhancement as compare to the semi MRC scheme for high SNR regime. Furthermore, the SC scheme simulation results are tight to the theoretical numerical analysis results for all fading channel cases.

Moreover, compared to the results of Case II, the BER performance of semi MRC scheme exhibits further degradation (i.e. error floor) that happened earlier at SNR>15 dB for Case III. In this case, a severe deterioration is observed for semi MRC scheme due to the scenario where all channels are fast fading, especially in high SNR regime. As for the SC scheme, the performance suffers slight degradation when compared to the results of Case II due to the effect of channel fadings. However, it can be highlighted that the SC scheme is able to reduce the effect of error floor experienced by the semi MRC scheme when incorporated in fast fading environment. It is observed for all cases that the theoretical numerical analysis results are tight with the simulation results.

Due to the frequency offsets existence in the network, the semi MRC scheme in Case II and III demonstrate poor performance which leads to error floor. Thus, multiple-codeword of $N_c = 10$ with SC scheme is utilized to Case II and III. The BER results are exhibited in Fig. 6 and Fig. 7. From the plots, it can be seen that the semi MRC scheme employed in Case I achieved good performance and due to that reason, its plot can be used as the performance benchmark to see the effectiveness of the SC scheme. Overall, it is seen from the curves that the SC scheme is more appealing in terms of the error performance. The SC scheme has the ability to produce the system performance for Case II and III near to Case I and furthermore effectively alleviate the detrimental effect of frequency offsets. Moreover, the presented scheme is computationally simple and particularly useful when channel knowledge and frequency offset is unknown in the system.

5.0 Conclusion

An MRC and differential SC scheme received signals of a DD AF relaying network employing DDBPSK were studied in time-varying channels at the destination. The new combining weights of MRC were provided based on the second order statistic of the channel. It was observed that the MRC experience severe degradation in the probability of error with the simulation analysis in different time-varying channels. Although the proposed combining weight outperform over the direct combining weights, it requires the knowledge of fading channels. Thus, in order to avoid the estimation of channel and frequency offset at the destination, differential SC is proposed and analysed under different mobility scenarios. Error performance and system outage probability were derived and it showed that the simulation results are validated with the numerical performance analysis. Also, the results showed that the SC performed closely to the MRC scheme which is more complicated, whereby second-order statistic of the channels is required.

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