

Performance Analysis of Regenerative Multi-Receive-Antenna Fixed Relay Networks over Nakagami- m channels

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Abstract—In this paper, we investigate a cooperative system, where the communication between the single-antenna source and destination node is assisted by two multi-receive-antenna fixed relays over flat, slow, Nakagami- m fading environments with integer m . Specially, it is assumed that there is a link between two relays while the direct link (between the source and destination) is blocked. The exact closed-form expression of the end-to-end symbol error rate is derived and validated through various simulation results. It is numerically demonstrated that the system achieves the best performance when one relay locates near the central point of the link between the source and destination while the other locates near the destination. Furthermore, as increasing the number of relay antennas, the system performance becomes better when the relays move towards the destination. For the same relay positions, increasing the fading index m will improve the system performance.

I. INTRODUCTION

Recently, multi-antenna fixed relay (infrastructure-based relay) networks have received much attention because they can incorporate the advantages of multi-antenna technique and cooperative relaying technique [1]–[9]. There are many advantages in such networks, for example, multiple antennas can be employed at fixed relays without concerning about high hardware complexity, more sophisticated signal processing and power consumption to improve the network security and reliability. In cellular networks, multi-antenna fixed relay can significantly extend the coverage and improve the system quality as well as system capacity [10], [11].

Multi-antenna fixed relay may be grouped technically into multi-input multi-output (MIMO) fixed relay [2]–[4] and multi-receive-antenna fixed relay [5]–[7], [10], [11] according to whether or not multiple antennas are used at transmitter side of relays. In this work, we focus on the latter. The works in [10], [11] studied the system, where the single-antenna source node communicates with the single-antenna destination node with the help of many multi-receive-antenna relays. The conclusion in their works is that for a given performance requirement, the multiple antennas at relays can significantly reduce the number of single-antenna relay nodes required in a

network area, thereby, reducing system deployment cost. The work in [5] investigated the cooperative system with one multi-receive-antenna relay node that supports the communication link between the source and the destination over Rayleigh fading. Very recently, in [6], [7], the system where two multi-receive-antenna relay nodes assist the communication from the source to destination (no link between the source and destination but a link exists between two relays) was investigated under flat, Rayleigh fading channels. The works in [6], [7] have derived the system outage probability expression and evaluated the effect of network and channel parameters, such as the number of antennas on relays and relay locations on the system performance.

In this paper, we investigate the system, which is similar to [6], [7]; however, under different four assumptions. Firstly, we assume the system operates under slow, flat, Nakagami- m fading environments with integer m . Secondly, although the high complexity of the relay nodes is not a very important problem in fixed relay networks, it is still better and more attractive to reduce this factor that leads to reduce deployment cost and improving the applicability. So, we will consider the case that only one receive radio frequency (RF) chain is employed at relays [12], [13]. Therefore, the appropriate combining techniques can be used at relays are selection combining (SC) and cascade combining (CC) [14]. Thirdly, the relays forward signals based on the ideal decode-and-forward (DF) protocol (i.e. relay forwards signals only when it can decode correctly) [15]. And lastly, we investigate the system performance in terms of the average symbol error rate (SER).

The purpose of our work is to evaluate the impact of the network and channel parameters including the number of relay antennas, relay locations and channel characteristics on the system performance. These are also the main contributions of our paper. The rest of this paper is organized as follows. In Section II, the system under study will be introduced. The end-to-end symbol error rate in exact closed-form expression of the studied system is derived in detail in Section III. Section IV represents some selected numerical results and discussions.

And finally, the paper is ended with conclusion in Section V.

II. SYSTEM MODEL

The system under study is shown in Fig. 1 including one single-antenna source node S , one single-antenna destination node D and two multi-antenna fixed relay nodes, denoted as R_1 and R_2 . The source S communicates with the destination D via R_1 and R_2 . The direct link from S to D is assumed to be very weak so that it can be omitted, but a link exists between R_1 and R_2 . We assume that the relays are equipped with one transmit antenna, L_1 and L_2 receive antennas on R_1 and R_2 , respectively. In designing multi-antenna based networks, a separate RF chain associated with a distinct antenna is a major problem involving the high complexity and high implementation cost [12]. For this reason, to reduce the high complexity of the relays, we consider the scenario that each relay is employed only one RF chain. For such a scenario, SC and CC technique [14] will be used at R_1 and R_2 , respectively. The overall network operates in half-duplex mode and the relays forward the received signals using selective DF relaying scheme (i.e. the relays only forward the signal if they can decode correctly) [15], [16]. The relays are assumed to be able to perform cyclic redundancy check (CRC) for determining whether the decoded signal is correct or not, but they do not have the capability of error correction. These assumptions lead to an equivalent forwarding condition that the relays only forward signal if they can demodulate the received symbol correctly.

The end-to-end communication in the proposed system experiences three orthogonal time slots. In the first time slot, S broadcasts the signal to R_1 and R_2 through multiple channels. R_1 selects the best signal (i.e. the signal having highest SNR) from L_1 receive antennas by using SC technique. If it can decode the signal correctly, it will forward the signal to R_2 and D in the second time-slot, otherwise it keeps idle. Meanwhile, R_2 selects and buffers the best signal from L_2 receive antennas coming from S in the first time slot and coherently combines it with the best signal from R_1 (if available in the second time slot, and this scheme is called cascade combining (CC) [14]). If R_2 can decode the combined signal correctly, it will forward the re-encoded signals to D in the third time slot, otherwise it keeps silent. Finally, in the third time slot, D combines the signal from R_1 in the second time slot and from R_2 in the third time slot (if available, respectively) by using maximal ratio combining (MRC) technique (i.e. coherently combining signals).

The channels between different pairs of nodes are assumed to experience independent but not necessarily identical (i.i.d.), slow, flat, Nakagami- m fading distribution (integer m). These assumptions involve the various relative distances among nodes, so we can examine the impact of relay locations on the overall system performance. Additionally, for simplicity, we further assume that all the channels suffer the same fading index m . Let $\bar{\gamma}_{ij}$ denote the average signal-to-noise ratio (SNR) between node i and j , where $(i, j) \in \{(S, R_1), (S, R_2), (R_1, R_2), (R_1, D), (R_2, D)\}$. In fixed relay

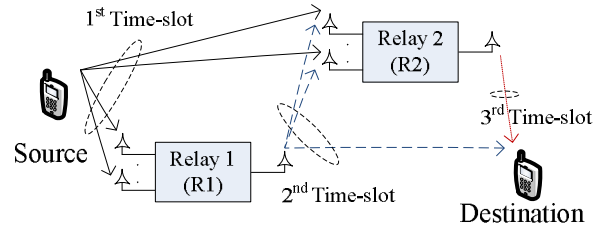


Fig. 1. The multi-antenna fixed relay system under consideration.

networks, the average SNR of the channel between node i and j can be formulated as [6], [7]

$$\bar{\gamma}_{ij} = \frac{\rho}{(2l_{ij}/l_{SD})^\varphi}, \quad (1)$$

where φ is the path loss exponent, l_{ij} is the distance between node i and node j , which is normalized by the reference distance $l_{SD}/2$, ρ represents the average SNR at the reference point. The modulated signals from S , R_1 and R_2 are assumed to be transmitted with unit power.

III. PERFORMANCE ANALYSIS

In this section, we derive the exact closed-form expression of the average end-to-end SER, P_s , with M -ary phase shift keying (M -PSK) modulation following the moment generating function (MGF) based approach [17], therefore, the same derivation process through this paper can be applied for many other modulation formats. Based on the system operation strategies stated early, using the law of total probability [18], the P_s expression can be written as

$$\begin{aligned} P_s = & \Pr[R_1^{idle}, R_2^{idle}] \times P_s[R_1^{idle}, R_2^{idle}] \\ & + \Pr[R_1^{idle}, R_2^{fwd}] \times P_s[R_1^{idle}, R_2^{fwd}] \\ & + \Pr[R_1^{fwd}, R_2^{idle}] \times P_s[R_1^{fwd}, R_2^{idle}] \\ & + \Pr[R_1^{fwd}, R_2^{fwd}] \times P_s[R_1^{fwd}, R_2^{fwd}], \end{aligned} \quad (2)$$

where $R_i^{idle/fwd}$ denotes that $\{R_i\}_{i=1}^2$ will keep idle or forward signal, $\Pr[R_1^{idle/fwd}, R_2^{idle/fwd}]$ is the joint probability of the events that R_1 and R_2 will keep idle or forward signal, and $P_s[R_1^{idle/fwd}, R_2^{idle/fwd}]$ is the end-to-end SER conditioned on the respective state of R_1 and R_2 .

According to the system model, it is obvious that the state of R_2 in the second time slot partially depends on the state of R_1 in the first time slot. Therefore, the joint probability of relay states can be computed as follows: [18]

$$\begin{aligned} \Pr[R_1^{idle}, R_2^{idle}] &= \Pr[R_1^{idle}] \times \Pr[R_2^{idle}|R_1^{idle}], \\ \Pr[R_1^{fwd}, R_2^{idle}] &= \Pr[R_1^{fwd}] \times \Pr[R_2^{idle}|R_1^{fwd}], \\ \Pr[R_1^{idle}, R_2^{fwd}] &= \Pr[R_1^{idle}] \times \Pr[R_2^{fwd}|R_1^{idle}], \\ \Pr[R_1^{fwd}, R_2^{fwd}] &= \Pr[R_1^{fwd}] \times \Pr[R_2^{fwd}|R_1^{fwd}]. \end{aligned} \quad (3)$$

In following subsections, each term in (2) and (3) will be derived in detail.

A. The Joint Probability of the Relay states

1) *The probability* $\Pr[R_1^{idle/fwd}]$: Because R_1 remains idle if it decodes the signal from S incorrectly, the probability R_1 remaining idle $\Pr[R_1^{idle}]$ is the SER on the link $S \rightarrow R_1$ in the first time slot. With SC combining at R_1 , the moment generating function (MGF) of combined SNR γ_{SR_1} defined as $\phi_{\gamma_{SR_1}}(s) = E_{\gamma_{SR_1}}\{\exp(-s\gamma_{SR_1})\}$ is written as [19], [20]

$$\phi_{\gamma_{SR_1}}(s) = \frac{L_1}{\Gamma(m)} \sum_{n=0}^{L_1-1} (-1)^n \binom{L_1-1}{n} \sum_{k=0}^{n(m-1)} \beta_{kn} \times \frac{\Gamma(m+k)}{(n+1)^{m+k}} \left[\frac{1}{1+s c_{SR_1}} \right]^{m+k}, \quad (4)$$

where $c_{SR_1} = \bar{\gamma}_{SR_1}/[m(n+1)]$ and the coefficients β_{kn} in (4) is given by [20]

$$\beta_{kn} = \sum_{i=k-m+1}^k \frac{\beta_{i(n-1)}}{(k-i)!} I_{[0,(n-1)(m-1)]}(i), \quad (5)$$

where $\beta_{00} = \beta_{0n} = 1$, $\beta_{k1} = 1/k!$, $\beta_{1n} = n$ and

$$I_{[a,b]}(n) = \begin{cases} 1, & a \leq n \leq b \\ 0, & \text{otherwise.} \end{cases} \quad (6)$$

Based on the MGF-based approach [17], the SER on a link having the MGF of SNR defined as $\phi_{\gamma}(s) = E_{\gamma}\{\exp(-s\gamma)\}$ with M -PSK modulation is given by [17, eq. 5.78]

$$P_s^{mpsk} = \frac{1}{\pi} \int_0^{\varsigma} \phi_{\gamma} \left(\frac{g}{\sin^2 \theta} \right) d\theta, \quad (7)$$

where $\varsigma = (M-1)\pi/M$ and $g = \sin^2(\pi/M)$. Putting (4) into (7), we have

$$\Pr[R_1^{idle}] = \frac{L_1}{\Gamma(m)} \sum_{n=0}^{L_1-1} (-1)^n \binom{L_1-1}{n} \sum_{k=0}^{n(m-1)} \beta_{kn} \times \frac{\Gamma(m+k)}{(n+1)^{m+k}} I_v(c), \quad (8)$$

where $v = k+m$, $c = g c_{SR_1}$ and the general form of $I_v(c)$ is written as follows:

$$I_v(c) = \frac{1}{\pi} \int_0^{\varsigma} \left(\frac{\sin^2 \theta}{\sin^2 \theta + c} \right)^v d\theta. \quad (9)$$

With the help of [17, eq. 5A.16], the closed-form of $I_v(c)$ can be expressed as

$$I_v(c) = \frac{M-1}{M} - \frac{1}{\pi} \sqrt{\frac{c}{1+c}} \times \left\{ \begin{aligned} & \left(\frac{\pi}{2} + \tan^{-1} \alpha \right) \sum_{k=0}^{v-1} \binom{2k}{k} \frac{1}{(4(1+c))^k} \\ & + \sin(\tan^{-1} \alpha) \sum_{k=1}^{v-1} \sum_{i=1}^k \frac{T_{ik}}{(1+c)^k} \\ & \times [\cos(\tan^{-1} \alpha)]^{2(k-i)+1} \end{aligned} \right\}, \quad (10)$$

where $\alpha = \sqrt{c/c+1} \cot(\pi/M)$ and T_{ik} is given by

$$T_{ik} = \binom{2k}{k} \frac{1}{\binom{2(k-i)}{k-i} 4^i [2(k-i)+1]}. \quad (11)$$

Having the probability that R_1 will keep idle $\Pr[R_1^{idle/fwd}]$ in hands allows ones to obtain the probability that R_1 will be active as $\Pr[R_1^{fwd}] = 1 - \Pr[R_1^{idle}]$.

2) *The probability* $\Pr[R_2^{idle/fwd}|R_1^{idle}]$: The probability $\Pr[R_2^{idle}|R_1^{idle}]$ equals to the SER on the link $S \rightarrow R_2$. Similarly to the derivation of $\Pr[R_1^{idle}]$, we have

$$\Pr[R_2^{idle}|R_1^{idle}] = \frac{L_2}{\Gamma(m)} \sum_{n=0}^{L_2-1} (-1)^n \binom{L_2-1}{n} \sum_{k=0}^{n(m-1)} \beta_{kn} \times \frac{\Gamma(m+k)}{(n+1)^{m+k}} I_{m+k}(c_{SR_2}), \quad (12)$$

where $c_{SR_2} = \bar{\gamma}_{SR_2}/[m(n+1)]$. And therefore, we obtain $\Pr[R_2^{fwd}|R_1^{idle}] = 1 - \Pr[R_2^{idle}|R_1^{idle}]$.

3) *The probability* $\Pr[R_2^{idle/fwd}|R_1^{fwd}]$: In the case R_1 decodes successfully, R_2 performs cascade combining (CC) the signals in the first and the second time slot (i.e. R_2 coherently combines the best signal from S in the first time slot with the best one from R_1 in the second time slot). So the probability of the event that R_2 keeps idle when R_1 forwards signals is the SER after R_2 performs CC technique. Because of the independence assumption on the fading channel amplitudes of the links $S \rightarrow R_2$ and $R_1 \rightarrow R_2$, the MGF of SNR at R_2 after CC combining is written as

$$\phi_{\gamma_{R_2}}^{cc}(s) = \phi_{\gamma_{SR_2}}(s) \times \phi_{\gamma_{R_1 R_2}}(s), \quad (13)$$

where $\phi_{\gamma_{SR_2}}(s)$ is obtained from (4) by substituting L_2 for L_1 and c_{SR_2} for c_{SR_1} . By using the same approach, we can have $\phi_{\gamma_{R_1 R_2}}(s)$ by letting $c_{R_1 R_2} = \bar{\gamma}_{R_1 R_2}/[m(n+1)]$. By putting the resulting expression into (13) and after some manipulations, (13) can be written as

$$\phi_{\gamma_{R_2}}^{cc}(s) = \frac{(L_2)^2}{(\Gamma(m))^2} \sum_{n=0}^{L_2-1} \sum_{k=0}^{L_2-1} (-1)^{n+k} \binom{L_2-1}{n} \binom{L_2-1}{k} \times \sum_{i=0}^{n(m-1)} \sum_{j=0}^{k(m-1)} \beta_{in} \beta_{jk} \frac{\Gamma(n_1)}{(n+1)^{n_1}} \frac{\Gamma(n_2)}{(k+1)^{n_2}} \times (d_1)^{n_1} (d_2)^{n_2} \underbrace{\left[\frac{1}{s+d_1} \right]^{n_1} \left[\frac{1}{s+d_2} \right]^{n_2}}_{A(s)}, \quad (14)$$

where $n_1 = m+i$, $n_2 = m+j$, $d_1 = 1/c_{SR_2}$, $d_2 = 1/c_{R_1 R_2}$. In the special case $d_1 = d_2$, it is easy to recognize that the expression (14) has the same form as (4) resulting in the fact that we easily obtain $\Pr[R_2^{idle}|R_1^{fwd}]$. For brevity, the derivation is omitted here. Applying partial fraction method proposed in [21], [22] (this method has some advantages compared to original Heaviside approach because of avoiding successive differentiations) to the term $A(s)$ in (14), the

expression (14) can be rewritten as

$$\begin{aligned} \phi_{\gamma_{R_2}}^{cc}(s) &= \frac{(L_2)^2}{(\Gamma(m))^2} \sum_{n=0}^{L_2-1} \sum_{k=0}^{L_2-1} (-1)^{n+k} \binom{L_2-1}{n} \binom{L_2-1}{k} \\ &\times \sum_{i=0}^{n(m-1)} \sum_{j=0}^{k(m-1)} \beta_{in} \beta_{jk} \frac{\Gamma(n_1)}{(n+1)^{n_1}} \frac{\Gamma(n_2)}{(k+1)^{n_2}} \\ &\times (d_1)^{n_1} (d_2)^{n_2} \left[\sum_{t=1}^{n_1} \frac{A_{1,t}}{(s+d_1)^t} + \sum_{t=1}^{n_2} \frac{A_{2,t}}{(s+d_2)^t} \right], \end{aligned} \quad (15)$$

where the coefficients $\{A_{1,t}\}_{t=1}^{n_1}$ are calculated as follows

$$A_{1,n_1} = A(s)(s+d_1)^{n_1} \Big|_{s=-d_1} \quad (16)$$

and

$$A_{1,n_1-u} = \left[A(s) - \sum_{z=0}^{u-1} \frac{A_{1,n_1-z}}{(s+d_1)^{n_1-z}} \right] (s+d_1)^{n_1-u} \Big|_{s=-d_1}, \quad (17)$$

where $1 \leq u \leq n_1 - 1$. The coefficients $\{A_{2,t}\}_{t=1}^{n_2}$ are calculated in the same way. Putting (15) into (7), we easily obtain the expression of $\Pr[R_2^{idle}|R_1^{fwd}]$ in (18). So, we have $\Pr[R_2^{fwd}|R_1^{fwd}] = 1 - \Pr[R_2^{idle}|R_1^{fwd}]$. Up to here, we have derived the closed-form expression of the joint probability for the events that R_1 and R_2 fall into any state $\Pr[R_2^{idle/fwd}, R_1^{idle/fwd}]$ by putting the appropriate above results into (3). In next section, we derive the end-to-end SER conditioned on the state of R_1 and R_2 .

B. Conditional end-to-end Symbol Error Rate

Before performing derivation of the conditional end-to-end SER, we recall here that D uses MRC technique to combine the signals from R_1 in the second time slot and from R_2 in the third time slot.

When both R_1 and R_2 fall into idle state, it is obvious to obtain $P_s[R_1^{idle}, R_2^{idle}] = (M-1)/M$.

When R_1 forwards signals and R_2 remains idle, the PDF of end-to-end SNR is the PDF of SNR on the link $R_1 \rightarrow D$, this can be written as [17]

$$p_{\gamma_D}(\gamma)[R_1^{fwd}, R_2^{idle}] = \frac{m^m \gamma^{m-1}}{\bar{\gamma}_{R_1 D}^m \Gamma(m)} \exp\left(-\frac{m\gamma}{\bar{\gamma}_{R_1 D}}\right). \quad (19)$$

The PDF expression in (19) is widely used and the corresponding MGF is given by

$$\begin{aligned} \phi_{\gamma_D}(s)[R_1^{fwd}, R_2^{idle}] &= \int_0^\infty p_{\gamma_{e2e}}(\gamma) [R_1^{fwd}, R_2^{idle}] e^{(-s\gamma)} d\gamma \\ &= \left(\frac{m}{m + s\bar{\gamma}_{R_1 D}} \right)^m. \end{aligned} \quad (20)$$

Putting (20) into (7), we obtain the result, expressed as

$$P_s[R_1^{fwd}, R_2^{idle}] = I_m \left(\frac{g\bar{\gamma}_{R_1 D}}{m} \right). \quad (21)$$

Similarly, when R_1 keeps idle and R_2 forwards signals, it is easily to obtain $P_s[R_1^{idle}, R_2^{fwd}]$ by applying the same process from (19) to (21). The final result can be clearly written as

$$P_s[R_1^{idle}, R_2^{fwd}] = I_m \left(\frac{g\bar{\gamma}_{R_2 D}}{m} \right). \quad (22)$$

When both R_1 and R_2 correctly decode and forward signals to D , the equivalent MGF of output SNR at D using MRC combiner can be calculated by the same method used in (13)

$$\phi_{\gamma_D^{mrc}}(s)[R_1^{fwd}, R_2^{fwd}] = \left[\frac{1}{\left(1 + s\frac{\bar{\gamma}_{R_1 D}}{m}\right) \left(1 + s\frac{\bar{\gamma}_{R_2 D}}{m}\right)} \right]^m. \quad (23)$$

In the particular case $\bar{\gamma}_{R_1 D} = \bar{\gamma}_{R_2 D}$, it is straightforward to obtain the end-to-end SER as

$$P_s[R_1^{fwd}, R_2^{fwd}] = I_{2m} \left(\frac{g\bar{\gamma}_{R_2 D}}{m} \right). \quad (24)$$

Otherwise, using the same partial fraction method used in (15), we have the closed-form expression of $P_s[R_1^{fwd}, R_2^{fwd}]$ as eq. (25) shown at the top of the next page, where the coefficients $\{B_{1,t}\}_{t=1}^m$ are calculated as follows:

$$B_{1,m} = B(s) \left(s + \frac{m}{\bar{\gamma}_{R_1 D}} \right)^m \Big|_{s=-\frac{m}{\bar{\gamma}_{R_1 D}}} \quad (26)$$

and

$$\begin{aligned} B_{1,m-u} &= \left[B(s) - \sum_{z=0}^{u-1} \frac{B_{1,m-z}}{\left(s + \frac{m}{\bar{\gamma}_{R_1 D}} \right)^{m-z}} \right] \\ &\times \left(s + \frac{m}{\bar{\gamma}_{R_1 D}} \right)^{m-u} \Big|_{s=-\frac{m}{\bar{\gamma}_{R_1 D}}}, \end{aligned} \quad (27)$$

where $1 \leq u \leq m-1$ and $B(s)$ is expressed as

$$B(s) = \left[\frac{1}{\left(\frac{m}{s + \bar{\gamma}_{R_1 D}} \right) \left(s + \frac{m}{\bar{\gamma}_{R_2 D}} \right)} \right]^m. \quad (28)$$

The coefficients $\{B_{2,t}\}_{t=1}^m$ are calculated in the same way. Finally, substituting all of the appropriate results derived above into (2), (3), we evidently obtain the exact closed-form expression of the end-to-end SER of the considered system.

IV. NUMERICAL RESULTS AND DISCUSSIONS

In Fig. 2, we plot the end-to-end SER of the studied system by setting $\varphi = 3$, ρ is in the range of $[0, 30]$ dB, $L_1 = L_2 = 3$, $l_{SR_1} = 35$, $l_{SR_2} = 80$, with 32-PSK modulation scheme and $m = 1, 2, 3$. It is clear that the analysis results are well-matched with the Monte-Carlo simulation results. As expected, increasing fading index m will improve the system performance.

Figs. 3, 4, 5 and 6 represent the plots of P_s with respect to the relative distance of R_1 and R_2 to S . We assume that all the nodes locate in a straight line where S and D locate at coordinates $(0, 0)$ and $(0, 100)$, respectively, while R_1 and R_2

$$\Pr[R_2^{idle}|R_1^{fwd}] = \frac{(L_2)^2}{(\Gamma(m))^2} \sum_{n=0}^{L_2-1} \sum_{k=0}^{L_2-1} (-1)^{n+k} \binom{L_2-1}{n} \binom{L_2-1}{k} \sum_{i=0}^{n(m-1)} \sum_{j=0}^{k(m-1)} \beta_{in} \beta_{jk} \frac{\Gamma(n_1)}{(n+1)^{n_1}} \frac{\Gamma(n_2)}{(k+1)^{n_2}} \times \left[(d_2)^{n_2} \sum_{t=1}^{n_1} A_{1,t} (d_1)^{n_1-t} I_t \left(\frac{g}{d_1} \right) + (d_1)^{n_1} \sum_{t=1}^{n_2} A_{2,t} (d_2)^{n_2-t} I_t \left(\frac{g}{d_2} \right) \right]. \quad (18)$$

$$P_s [R_1^{fwd}, R_2^{fwd}] = \left(\frac{m}{\bar{\gamma}_{R_2 D}} \right)^m \sum_{t=1}^m B_{1,t} \left(\frac{m}{\bar{\gamma}_{R_1 D}} \right)^{m-t} I_t \left(\frac{g \bar{\gamma}_{R_1 D}}{m} \right) + \left(\frac{m}{\bar{\gamma}_{R_1 D}} \right)^m \sum_{t=1}^m B_{2,t} \left(\frac{m}{\bar{\gamma}_{R_2 D}} \right)^{m-t} I_t \left(\frac{g \bar{\gamma}_{R_2 D}}{m} \right). \quad (25)$$

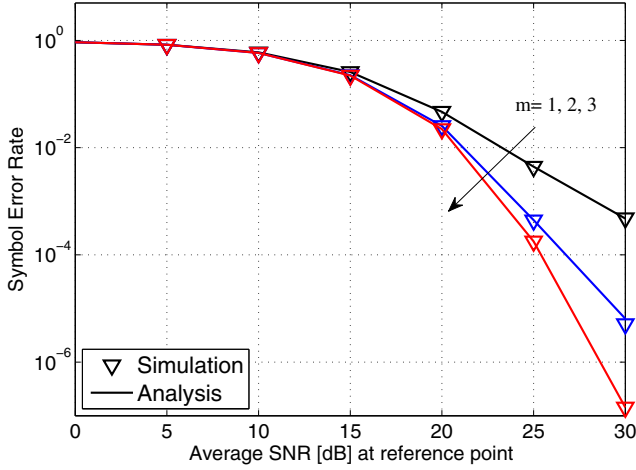


Fig. 2. Symbol error rate with $\varphi = 3$, $l_{SR1} = 35$, $l_{SR2} = 80$, $L_1 = L_2 = 3$, 32-PSK modulation and $m = 1, 2, 3$.

move between S and D . All of these figures are plotted with $\varphi = 3$ and $\rho = 5$ dB. By carefully observing through these plots, it is clearly shown that the best system performance is achieved when R_1 locates near the central point of the link $S \rightarrow D$ while R_2 locates near D . Besides, as increasing the number of receive antennas employed on R_1 or R_2 , the system performance becomes better when R_1 or R_2 moves toward D . These results completely agree with those reported previously in [6], [7]. However, it should be noted here that our assumptions are far different from that in [6], [7]. Furthermore, as increasing the fading index m from 1 in Figs. 3, 4 to 3 in Figs. 5, 6 (i.e. the channels become better), the system performance will improve with the same positions of relays.

V. CONCLUSION

In this paper, we investigated the multi-receive-antenna fixed relay system using selective DF protocol over flat, slow, Nakagami- m fading channels. To reduce complexity, instead of maximal ratio combining, SC and CC techniques are used at relays leading to the fact that only one receive RF chain is needed. The exact closed-form expression of the end-to-end SER was derived and validated through simulations. It is analytically demonstrated that the system gets superior performance when R_1 places near the central point on the

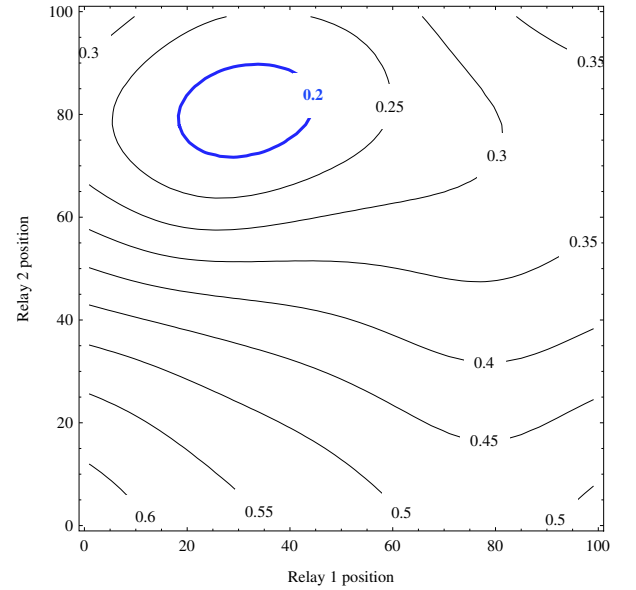


Fig. 3. Contour plot of P_s with $\varphi = 3$, $\rho = 5$ dB, $L_1 = 1$, $L_2 = 5$, 8-PSK modulation and $m = 1$.

link $S \rightarrow D$ while R_2 places near D . Moreover, the system performance will improve if either R_1 or R_2 is employed more antennas and it moves toward the destination, respectively. Finally, increasing fading index m will improve the system performance with the same positions of relays as expected.

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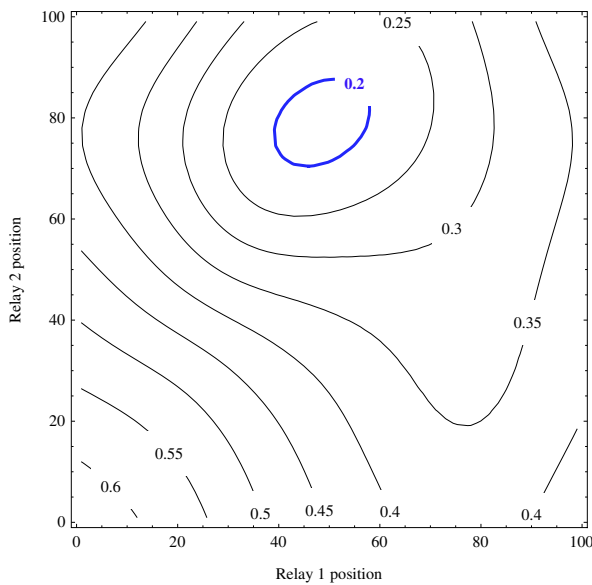


Fig. 4. Contour plot of P_s with $\varphi = 3$, $\rho = 5$ dB, $L_1 = 5$, $L_2 = 1$, 8-PSK modulation and $m = 1$.

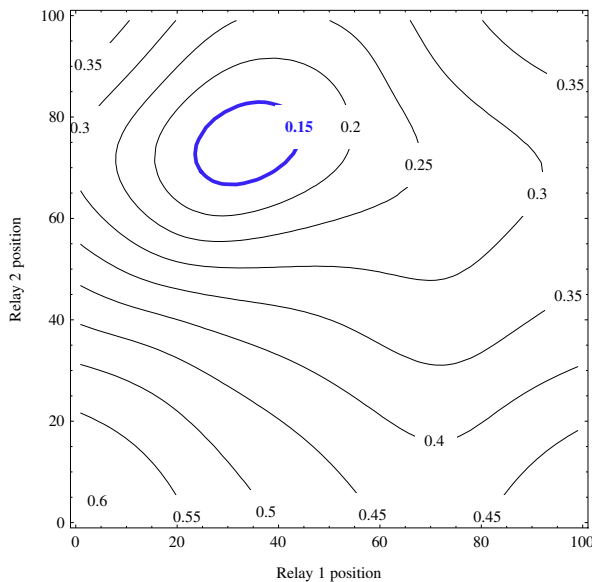


Fig. 5. Contour plot of P_s with $\varphi = 3$, $\rho = 5$ dB, $L_1 = 1$, $L_2 = 5$, 8-PSK modulation and $m = 3$.

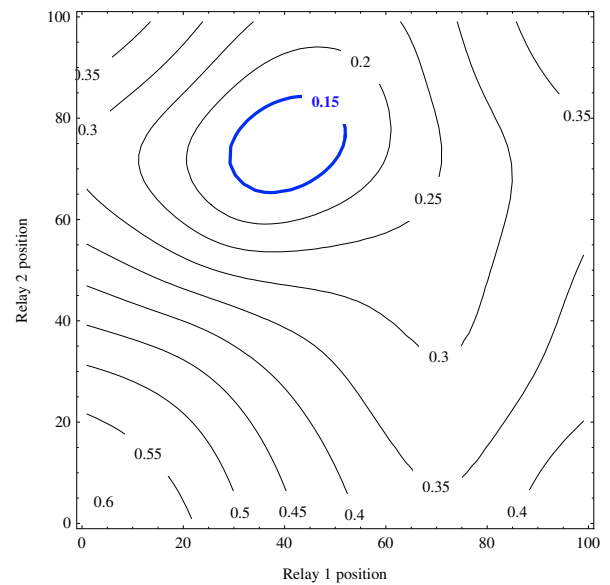


Fig. 6. Contour plot of P_s with $\varphi = 3$, $\rho = 5$ dB, $L_1 = 5$, $L_2 = 1$, 8-PSK modulation and $m = 3$.

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