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JOINT TRANSMIT ANTENNA SELECTION AND POWER ALLOCATION FOR MOBILE-TO-MOBILE COOPERATIVE SYSTEM

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Abstract. *The outage probability (OP) performance of amplify-and-forward (AF) relaying mobile-to-mobile (M2M) system with transmit antenna selection (TAS) over N-Nakagami fading channels is investigated in this paper. The exact closed-form expressions for OP of TAS scheme are derived. The power allocation problem is formulated for performance optimization. Then the OP performance under different conditions is evaluated through numerical simulations to verify the analysis. The simulation results showed that the power-allocation parameter has an important influence on the OP performance.*
Keywords: M2M communication, N-Nakagami fading channels, Amplify-and-forward, Outage probability, Transmit antenna selection, Power allocation

1. **Introduction.** In recent years, mobile-to-mobile (M2M) communication is widely employed in many popular wireless communication systems, such as intelligent highway applications and mobile ad-hoc applications [1]. The double-Nakagami model is adopted to provide a realistic description of M2M channel in [2]. Afterwards, using Meijer's G-function, the N-Nakagami distribution is introduced and analyzed in [3].

Cooperative communication has emerged as a core component of future wireless networks since it provides high data rate communication over large geographical areas. The pairwise error probability (PEP) of amplify-and-forward (AF) relaying over double-Nakagami was obtained in [4]. The lower bound on outage probability (OP) of AF relaying over N-Nakagami fading channels was investigated in [5].

Multiple-input-multiple-output (MIMO) arises as a promising tool to enhance the reliability and capacity of cooperative systems. However, MIMO brings a corresponding increase in hardware complexity. In this situation, transmit antenna selection (TAS) arises as a practical way of reducing the system complexity. In [6], the performance of optimal and suboptimal TAS scheme was investigated. Closed-form expressions for OP of TAS in MIMO multi-relay networks were derived in [7].

However, to the best knowledge of the author, the OP performance of the AF relaying M2M system with TAS over N-Nakagami fading channels has not been investigated. Moreover, most results mentioned above do not take the power allocation into account. This is an important issue and will be discussed in this paper as it affects the OP performance. The main contributions are listed as follows.

1. Closed-form expressions are provided for the probability density function (PDF) and cumulative density functions (CDF) of the signal-to-noise ratio (SNR) over N-Nakagami fading channels. These are used to derive closed-form OP expressions for TAS scheme.
2. A power allocation minimization problem is formulated to determine the optimum transmit power distribution between the broadcast and relay phases.
3. The accuracy of the analytical results under different conditions is verified through numerical simulation. Results are presented which show that the power-allocation parameter has an important influence on the OP performance.

The rest of the paper is organized as follows. The M2M system model is presented in Section 2. Section 3 provides the exact closed-form OP expressions for TAS scheme. Section 4 conducts Monte Carlo simulations to verify the analytical results. Concluding remarks are given in Section 5.

2. The System and Channel Model.

2.1. System model. Consider a cooperation model shown in Figure 1, namely a single mobile source (MS) node, mobile relay (MR) node, and mobile destination (MD) node. The nodes operate in half-duplex mode, MS is equipped with N_t antennas, MD is equipped with N_r antennas, and MR is equipped with N_l antennas.

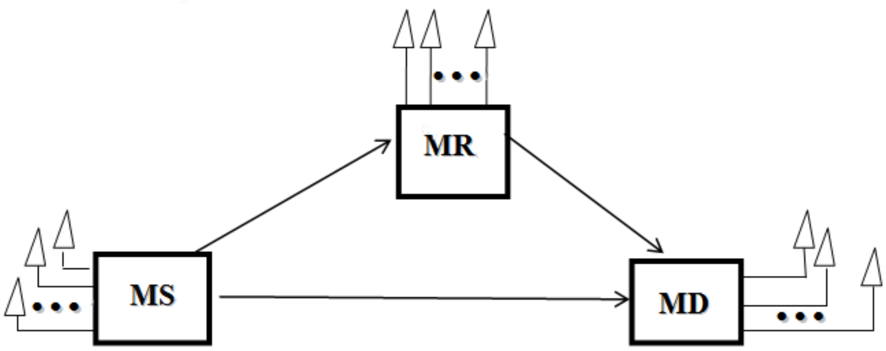

FIGURE 1. The system model

According to [4], the distances of MS $\rightarrow$ MD, MS $\rightarrow$ MR, and MR $\rightarrow$ MD links are represented by d_{SD}, d_{SR}, and d_{RD}, respectively. The relative gain of MS to MD is G_{SD}=1, the relative gains of MS $\rightarrow$ MR and MR $\rightarrow$ MD links are $G_{\mathrm{SR}} = (d_{\mathrm{SD}}/d_{\mathrm{SR}})^v$ and $G_{\mathrm{RD}} = (d_{\mathrm{SD}}/d_{\mathrm{RD}})^v$, respectively, where v is the path loss coefficient [8]. To indicate the location of MR with respect to MS and MD, the relative geometrical gain $\mu = G_{\mathrm{SR}}/G_{\mathrm{RD}}$ (in decibels) is defined. When MR has the same distance to MS and MD, μ is 1 (0 dB).

Let MS_i denote the ith transmit antenna at MS, MR_l denote the lth antenna at MR, MD_j denote the jth receive antenna at MD, so $h = h_k$, $k \in \{\mathrm{SD}ij, \mathrm{SR}il, \mathrm{RD}lj\}$, represent the complex channel coefficients of $\mathrm{MS}_i \rightarrow \mathrm{MD}_j$, $\mathrm{MS}_i \rightarrow \mathrm{MR}_l$, and $\mathrm{MR}_l \rightarrow \mathrm{MD}_j$ links, respectively.

During the first time slot, the received signal $r_{\mathrm{SD}ij}$ and $r_{\mathrm{SR}il}$ can be written as [4]

$$r_{\mathrm{SD}ij} = \sqrt{KE}h_{\mathrm{SD}ij}x + n_{\mathrm{SD}ij} \tag{1}$$

$$r_{\mathrm{SR}il} = \sqrt{G_{\mathrm{SR}il}KE}h_{\mathrm{SR}il}x + n_{\mathrm{SR}il} \tag{2}$$

where x denotes the transmitted signal, and $n_{\mathrm{SR}il}$ and $n_{\mathrm{SD}ij}$ are the zero-mean complex Gaussian random variables with variance $N_0/2$ per dimension. During two time slots, the total energy used by MS and MR is E. K is the power-allocation parameter.

During the second time slot, MR_l amplifies and forwards the signal to MD_j. The received signal at MD_j is, therefore, given by [4]

$$r_{\mathrm{RD}lj} = \sqrt{c_{ilj}E} h_{\mathrm{SR}il} h_{\mathrm{RD}lj} x + n_{\mathrm{RD}lj} \tag{3}$$

where c_{ilj} is the amplification factor, $n_{\mathrm{RD}lj}$ is a zero-mean complex Gaussian random variable with variance $N_0/2$ per dimension.

If selection combining (SC) method is used at MD_j, the output SNR can then be calculated as

$$\gamma_{ij} = \max\left(\gamma_{\mathrm{SD}ij}, \gamma_{\mathrm{SRD}ij}\right) \tag{4}$$

where $\gamma_{\mathrm{SD}ij}$ denotes the SNR of direct link, and $\gamma_{\mathrm{SRD}ij}$ denotes the SNR of end-to-end link.

As far as we know, a convenient mathematical method to obtain $\gamma_{\mathrm{SRD}ij}$ exactly is still unachievable. Here, we adopt the method in [9] to obtain an approximate $\gamma_{\mathrm{SRD}ij}$. At high SNR, the $\gamma_{\mathrm{SRD}ij}$ can be approximated as

$$\gamma_{upij} = \max_{1\le l\le N_l} \left(\min\left(\gamma_{\mathrm{SR}il}, \gamma_{\mathrm{RD}lj}\right)\right) \tag{5}$$

where $\gamma_{\mathrm{SR}il}$ denotes the SNR of $\mathrm{MS}_i \to \mathrm{MR}_l$ link, and $\gamma_{\mathrm{RD}lj}$ denotes the SNR of $\mathrm{MR}_l \to \mathrm{MD}_j$ link.

The output SNR given in (4) can be tightly upper bounded as

$$\gamma_{Aij} = \max(\gamma_{\mathrm{SD}ij}, \gamma_{upij}) \tag{6}$$

The TAS scheme should select the transmit antenna that only maximizes the instantaneous SNR of $\mathrm{MS}_i \to \mathrm{MD}_j$ link, namely

$$w = \max_{\substack{1\le i\le N_t,\\ 1\le j\le N_r}} \left(\gamma_{\mathrm{SD}ij}\right) \tag{7}$$

2.2. **Channel models.** We assume that the links in the system are subject to independently and identically distributed N-Nakagami fading. h follows N-Nakagami distribution, which is given as [3]

$$h = \prod_{t=1}^{N} a_t \tag{8}$$

where N is the number of cascaded components, a_t is a Nakagami distributed random variable with PDF as

$$f(a) = \frac{2m^m}{\Omega^m \Gamma(m)} a^{2m-1} \exp\left(-\frac{m}{\Omega} a^2\right) \tag{9}$$

$\Gamma(\cdot)$ is the Gamma function, m is the fading coefficient and Ω is a scaling factor.

With the help of [3], the PDF of h is given by

$$f_h(h) = \frac{2}{h \prod\limits_{t=1}^{N} \Gamma(m_t)} G_{0,N}^{N,0}\left[h^2 \prod_{t=1}^{N} \frac{m_t}{\Omega_t}\Bigg|_{m_1,\ldots,m_N}^{-}\right] \tag{10}$$

where $G[\cdot]$ is the Meijer's G-function.

3. **The OP of TAS Scheme.** For TAS scheme, the output SNR at MD can then be calculated as

$$\gamma_{\mathrm{SC}} = \max(\gamma_{\mathrm{SD}w}, \gamma_{upw}) \tag{11}$$

The OP of TAS scheme can be expressed as

$$F(\gamma_{th}) = \Pr(\max(\gamma_{\mathrm{SD}w}, \gamma_{upw}) < \gamma_{th}) = \Pr(\gamma_{\mathrm{SD}w} < \gamma_{th}) \Pr(\gamma_{upw} < \gamma_{th})$$
$$= \left(\frac{1}{\prod_{d=1}^{N} \Gamma(m_d)} G_{1,N+1}^{N,1} \left[\frac{\gamma_{th}}{K\gamma_0} \prod_{d=1}^{N} \frac{m_d}{\Omega_d} \Big|_{m_1,\ldots,m_N,0}^{1} \right] \right)^{N_t \times N_r}$$
$$\times \left(\begin{array}{l} \frac{1}{\prod_{t=1}^{N} \Gamma(m_t)} G_{1,N+1}^{N,1} \left[\frac{\gamma_{th}}{KG_{\mathrm{SR}}\gamma_0} \prod_{t=1}^{N} \frac{m_t}{\Omega_t} \Big|_{m_1,\ldots,m_N,0}^{1} \right] + \frac{1}{\prod_{tt=1}^{N} \Gamma(m_{tt})} G_{1,N+1}^{N,1} \left[\frac{\gamma_{th}}{(1-K)G_{\mathrm{RD}}\gamma_0} \prod_{tt=1}^{N} \frac{m_{tt}}{\Omega_{tt}} \Big|_{m_1,\ldots,m_N,0}^{1} \right] \\ -\frac{1}{\prod_{t=1}^{N} \Gamma(m_t) \prod_{tt=1}^{N} \Gamma(m_{tt})} G_{1,N+1}^{N,1} \left[\frac{\gamma_{th}}{KG_{\mathrm{SR}}\gamma_0} \prod_{t=1}^{N} \frac{m_t}{\Omega_t} \Big|_{m_1,\ldots,m_N,0}^{1} \right] G_{1,N+1}^{N,1} \left[\frac{\gamma_{th}}{(1-K)G_{\mathrm{RD}}\gamma_0} \prod_{tt=1}^{N} \frac{m_{tt}}{\Omega_{tt}} \Big|_{m_1,\ldots,m_N,0}^{1} \right] \end{array} \right)^{N_l} \quad (12)$$

where γ_{th} is a given threshold for correct detection at MD, $\gamma_0 = E/N_0$.

4. **Numerical Results.** In this section, we present Monte Carlo simulations to confirm the derived analytical results. All the computations are done in MATLAB and some of the integrals are verified through MAPLE. The total energy is $E = 1$.

Figure 2 presents the OP performance of TAS scheme. The number of cascaded components is $N = 2$. The fading coefficient is $m = 1$. The power-allocation parameter is $K = 0.5$. The given threshold is $\gamma_{th} = 5$dB. The number of antennas is $N_t = 1, 2, 3$, $N_l = 2$, $N_r = 2$. We see that the analytical results obtained by employing the tight bound match perfectly with the simulations. As expected, the OP is improved as N_t increased. For example, when SNR = 12dB, $N_t = 1$, the OP is 1.4×10^{-1}, $N_t = 2$, the OP is 3.6×10^{-2}, $N_t = 3$, the OP is 9.1×10^{-3}. With N_t fixed, an increase in the SNR decreases the OP.

Figure 3 presents the effect of the power-allocation parameter K on the OP performance. The number of cascaded components is $N = 2$. The fading coefficient is $m = 2$. The relative geometrical gain is $\mu = 0$dB. The number of antennas is $N_t = 2$, $N_r = 2$, $N_l = 3$. The given threshold is $\gamma_{th} = 5$dB. Simulation results show that the OP performance is improved with the SNR increased. For example, when $K = 0.5$, the OP is 4.7×10^{-1} with SNR = 5dB, 1.1×10^{-2} with SNR = 10dB, 4.6×10^{-6} with SNR = 15dB. When SNR = 5dB, the optimum value of K is 0.99; SNR = 10dB, the optimum value of K is 0.76; SNR = 15dB, the optimum value of K is 0.71. This indicates that the EPA scheme is not the best scheme.

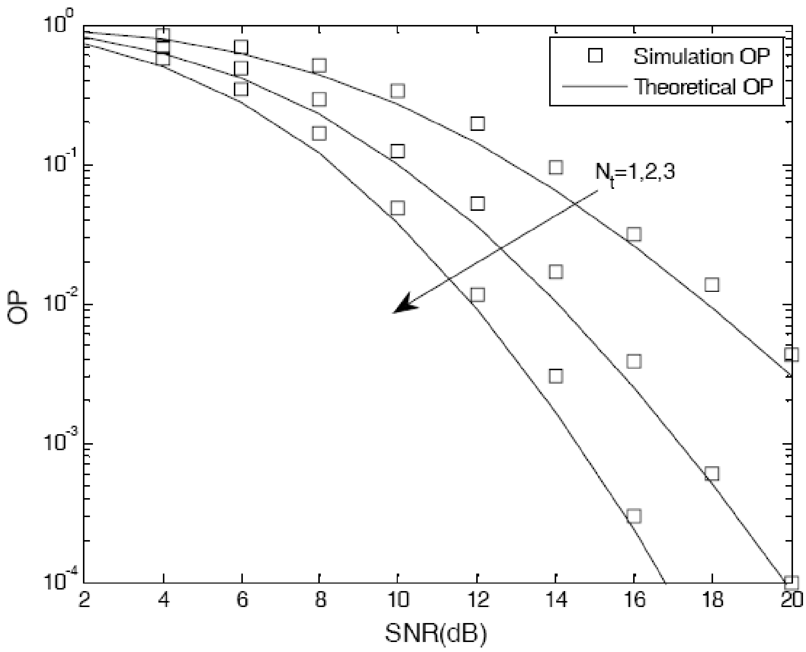

Figure 2. The OP performance of TAS scheme

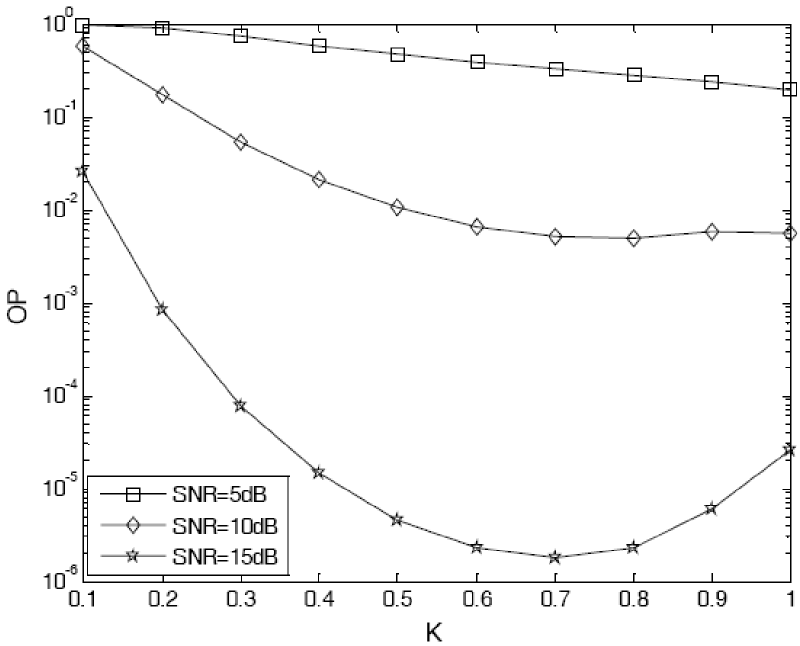

FIGURE 3. The effect of the power-allocation parameter K on the OP performance

TABLE 1. OPA parameters K

SNR	K
0	0.99
5	0.99
10	0.80
15	0.78
20	0.77

From Figure 3, it can readily be checked that these expressions are convex functions with respect to K. We resort to numerical methods to solve this optimization problem. The optimum power allocation (OPA) values can be obtained a priori for given values of operating SNR and propagation parameters. The OPA values can be stored for use as a lookup table in practical implementation.

In Table 1, we present optimum values of K with various values of SNR. We assume that the number of cascaded components is $N = 2$, the fading coefficient is $m = 2$, the relative geometrical gain is $\mu = -5$dB, the number of antennas is $N_t = 2$, $N_r = 2$, $N_l = 3$, and the given threshold is $\gamma_{th} = 5$dB. When the SNR is low, nearly all the power should be used in broadcast phase. As the SNR increased, the optimum values of K are reduced, and less than 80% of the power should be used in broadcast phase.

5. **Conclusions.** The exact closed-form OP expressions for AF relaying M2M system with TAS over N-Nakagami fading channels are derived in this paper. The simulation results show that the power-allocation parameter K has an important influence on the OP performance. Expressions can be used to evaluate the OP of vehicular communication systems such as in inter-vehicular, intelligent highway and mobile ad-hoc applications. In the future, we will consider the impact of correlated channels on the OP.

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