Hindawi Publishing Corporation
Mathematical Problems in Engineering
Volume 2016, Article ID 9187438, 6 pages
http://dx.doi.org/10.1155/2016/9187438

Research Article

Joint TAS and Power Allocation for SDF Relaying M2M Cooperative Networks

Lingwei Xu,[1] Hao Zhang,[1,2] and Jingjing Wang[3]

[1] *College of Information Science and Engineering, Ocean University of China, Qingdao 266100, China*
[2] *Department of Electrical and Computer Engineering, University of Victoria, Victoria, BC, Canada V8W 2Y2*
[3] *Department of Information Science and Technology, Qingdao University of Science & Technology, Qingdao 266061, China*

Correspondence should be addressed to Lingwei Xu; gaomilaojia2009@163.com

Received 15 November 2015; Accepted 17 March 2016

Academic Editor: Muhammad N. Akram

The outage probability (OP) performance of multiple-relay-based selective decode-and-forward (SDF) relaying mobile-to-mobile (M2M) networks with transmit antenna selection (TAS) over N-Nakagami fading channels is investigated. The exact closed-form expressions for OP of the optimal and suboptimal TAS schemes 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 optimal TAS scheme has a better OP performance than suboptimal TAS scheme. Further, the power allocation parameter has an important influence on the OP performance.

1. Introduction

In recent years, mobile application development is swiftly expanding because users prefer to continue their social, entertainment, and business activities while on the go. Analysts predict explosive growth in traffic demand on mobile broadband systems over the coming years due to the popularity of streaming video, gaming, and other social media services [1]. Mobile-to-mobile (M2M) communication has attracted wide research interest. It is widely employed in many popular wireless communication systems, such as intervehicular communications, intelligent highway applications, and mobile ad hoc applications. However, the classical Rayleigh, Rician, or Nakagami fading channels have been found not to be applicable in M2M communication [2]. It has been observed that the effects of fading may be far severe than what can be modeled using the Nakagami distribution. Experimental results and theoretical analysis demonstrate that cascaded fading channels provide an accurate statistical model for M2M communication [3]. The double-Rayleigh model and double-Nakagami model are adopted to provide a realistic description of the M2M channel in [4, 5]. Afterwards, using Meijer's G-function, the N-Nakagami model is introduced and analyzed in [6]. Double-Nakagami is a special case of N-Nakagami with $N = 2$. In [2], the authors provided a tutorial survey on channel models for mobile-to-mobile (M2M) cooperative communication systems. The N-Rayleigh and N-Nakagami models were used to describe the analytical modeling of M2M channels.

Cooperative communication has emerged as a core component of future wireless networks. It has been actively studied and considered in the standardization process of next-generation Broadband Wireless Access Networks (BWANs) such as Third Generation Partnership Project (3GPP), Long Term Evolution (LTE) Advanced, and IEEE 802.16 m [7]. Using fixed-gain amplify-and-forward (FAF) relaying, the pairwise error probability (PEP) of two relay-assisted vehicular scenarios over double-Nakagami fading channels was obtained in [8]. In [9], closed-form expressions for OP of selective decode-and-forward (SDF) relaying M2M cooperative networks with relay selection over N-Nakagami fading channels were derived. By moment generating function (MGF) approach, the authors derived the lower bound on the exact average symbol error probability (ASEP) expressions for AF relaying M2M system over N-Nakagami fading channels in [10]. Exact average bit error probability (BEP)

expressions for mobile-relay-based M2M cooperative networks with incremental DF (IDF) relaying over N-Nakagami fading channels were derived in [11].

Multiple-input-multiple-output (MIMO) arises as a promising tool to enhance the reliability and capacity of wireless systems. When channel state information (CSI) is available at the source and destination, MIMO beamforming (BF) schemes are implemented by maximum-ratio-transmission (MRT) or maximum-ratio-combining (MRC) at the transmitter and receiver, respectively [12]. The beamforming and combining scheme was analyzed in DF MIMO cooperative systems over Nakagami-m fading channels, and the closed-form expressions for ASEP were derived in [13]. However, multiple radio frequency chains must be implemented in MIMO-BF systems, and it brings a corresponding increase in hardware complexity. Transmit antenna selection (TAS) arises as a practical way of reducing the system complexity while achieving the full diversity order. A new source TAS was proposed based on both channel state information and transmission scheme for the MIMO DF relay networks in [14]. A unified asymptotic framework for TAS in MIMO multirelay networks over Rician, Nakagami-m, Weibull, and generalized-K fading channels was proposed in [15], and closed-form expressions for the OP and symbol error rate (SER) of AF relaying were derived.

However, to the best knowledge of the author, the OP performance of SDF relaying M2M networks with TAS and power allocation over N-Nakagami fading channels has not been investigated in the literature. 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 exact closed-form OP expressions for the optimal and suboptimal TAS schemes.

(2) A power allocation minimization problem is formulated to determine the optimum power distribution between the broadcasting and relaying phases.

(3) The accuracy of the analytical results under different conditions is verified through numerical simulations. Results are presented which show that the optimal TAS scheme has a better OP performance than suboptimal TAS scheme. It is further shown that power allocation parameter has an important influence on the OP performance.

(4) The derived OP expressions can be used to evaluate the OP performance of the vehicular communication networks employed in intervehicular communications, intelligent highway applications and mobile ad hoc applications.

The rest of the paper is organized as follows: the multiple-mobile-relay-based M2M system model is presented in Section 2. Section 3 provides the exact closed-form OP expressions for optimal TAS scheme. The exact closed-form OP expressions for suboptimal TAS scheme are derived in Section 4. Monte Carlo results are presented in Section 5 to verify the analytical results. Concluding remarks are given in Section 6.

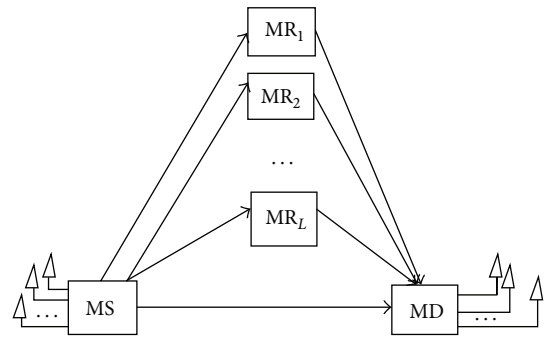

Figure 1: The system model.

2. The System and Channel Model

2.1. System Model. The cooperation model consists of a single mobile source (MS) node, L mobile relay (MR) nodes, and a single mobile destination (MD) node, as shown in Figure 1. The nodes operate in half-duplex mode, MS is equipped with N_t antennas, and MD is equipped with N_r antennas, whereas MR is equipped with a single antenna. It is assumed that the perfect channel state information (CSI) is available at the MS, MR, and MD nodes. The MR nodes utilize their individual uplink CSI to select the best MR that yields the maximum received SNR. The best MR sends flag packets to the MD, announcing that it is ready to cooperate. The MD utilizes the downlink CSI to calculate the received SNR from the best MR. The MD orders the received SNR from N_t source antennas and then feeds back the index of the selected source antenna that yields the maximum received SNR to MS.

We assume that N_t antennas at MS and N_r antennas at MD have the same distance to the relay nodes. Using the approach in [8], the relative gain of the MS to MD link is $G_{\mathrm{SD}} = 1$, the relative gain of the MS to MR$_l$ link is $G_{\mathrm{SR}l} = (d_{\mathrm{SD}}/d_{\mathrm{SR}l})^{\nu}$, and the relative gain of the MR$_l$ to MD link is $G_{\mathrm{RD}l} = (d_{\mathrm{SD}}/d_{\mathrm{RD}l})^{\nu}$, where ν is the path loss coefficient and d_{SD}, $d_{\mathrm{SR}l}$, and $d_{\mathrm{RD}l}$ represent the distances of the MS to MD, MS to MR$_l$, and MR$_l$ to MD links, respectively [16]. To indicate the location of MR$_l$ with respect to MS and MD, the relative geometrical gain $\mu_l = G_{\mathrm{SR}l}/G_{\mathrm{RD}l}$ (in decibels) is defined. When MR$_l$ has the same distance to MS and MD, μ_l is 1 (0 dB). When MR$_l$ is close to MD, μ_l has negative values. When MR$_l$ is close to MS, μ_l has positive values.

Let MS$_i$ denote the ith transmit antenna at MS and let 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 MS$_i \rightarrow$ MD$_j$, MS$_i \rightarrow$ MR$_l$, and MR$_l \rightarrow$ MD$_j$ links, respectively. Assuming that the ith antenna at MS is used to

transmit the signal, during the first time slot, the received signal $r_{\mathrm{SD}ij}$ at MD_j can be written as

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

The received signal $r_{\mathrm{SR}il}$ at MR_l can be written as

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

where x denotes the transmitted signal with zero mean and unit variance 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 ($0 \le K \le 1$).

During the second time slot, only the best MR decides whether to decode and forward the signal to the MD_j by comparing the instantaneous SNR $\gamma_{\mathrm{SR}i}$ to a threshold γ_T, where $\gamma_{\mathrm{SR}i}$ represents the SNR of the link between MS_i and the best MR. The best MR is selected based on the following criterion:

$$\gamma_{\mathrm{SR}i} = \max_{1\le l\le L}\left(\gamma_{\mathrm{SR}il}\right), \tag{3}$$

where $\gamma_{\mathrm{SR}il}$ represents the SNR of $\mathrm{MS}_i \to \mathrm{MR}_l$ link and

$$\gamma_{\mathrm{SR}il} = KG_{\mathrm{SR}il}\left|h_{\mathrm{SR}il}\right|^2\overline{\gamma}, \qquad \overline{\gamma} = \frac{E}{N_0}. \tag{4}$$

If $\gamma_{\mathrm{SR}i} < \gamma_T$, the MS_i will transmit the next message, and the best MR remains silent. The output SNR at the MD_j can then be calculated as

$$\gamma_{0ij} = \gamma_{\mathrm{SD}ij}, \tag{5}$$

where

$$\gamma_{\mathrm{SD}ij} = K\left|h_{\mathrm{SD}ij}\right|^2\overline{\gamma}. \tag{6}$$

If $\gamma_{\mathrm{SR}i} > \gamma_T$, the best MR then decodes the signal from the MS_i and generates a signal x_r that is forwarded to the MD_j. Based on the DF cooperation protocol, the received signal at the MD_j is given by

$$r_{\mathrm{RD}j} = \sqrt{(1-K)G_{\mathrm{RD}j}E}h_{\mathrm{RD}j}x_r + n_{\mathrm{RD}j}, \tag{7}$$

where $n_{\mathrm{RD}j}$ is a conditionally zero-mean complex Gaussian random variable with variance $N_0/2$ per dimension.

Maximum-ratio-combining (MRC) and equal gain combining (EGC) have better performance compared with selection combining (SC) but they require higher receiver complexity. MRC and EGC need all or some of the channel state information, such as fading amplitude and phase from all the received signals. SC only selects one diversity branch with maximum instantaneous SNR. To simplify the receiver structure, we use the SC scheme. If SC method is used at MD_j, the output SNR can then be calculated as

$$\gamma_{\mathrm{SC}ij} = \max\left(\gamma_{\mathrm{SD}ij}, \gamma_{\mathrm{RD}j}\right), \tag{8}$$

where $\gamma_{\mathrm{RD}j}$ represents the SNR of the link between the best MR and MD_j.

Using SC method at MD, the output SNR can then be calculated as

$$\gamma_{\mathrm{SC}_i} = \max_{1\le j\le N_r}\left(\gamma_{ij}\right), \tag{9}$$

where

$$\gamma_{ij} = \begin{cases} \gamma_{0ij}, & \gamma_{\mathrm{SR}i} < \gamma_T \\ \gamma_{\mathrm{SC}ij}, & \gamma_{\mathrm{SR}i} > \gamma_T. \end{cases} \tag{10}$$

The optimal TAS scheme should select the transmit antenna w that maximizes the output SNR at MD, namely,

$$w = \max_{1\le i\le N_t}\left(\gamma_{\mathrm{SC}_i}\right) = \max_{1\le i\le N_t,\, 1\le j\le N_r}\left(\gamma_{ij}\right). \tag{11}$$

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

$$g = \max_{1\le i\le N_t,\, 1\le j\le N_r}\left(\gamma_{\mathrm{SD}ij}\right). \tag{12}$$

2.2. Channel Model. We assume that the links in the system are subject to independently and identically distributed (i.n.i.d) N-Nakagami fading. h follows N-Nakagami distribution, which is given as [4]

$$h = \prod_{t=1}^{N} a_t, \tag{13}$$

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

$$f(a) = \frac{2m^m}{\Omega^m\Gamma(m)}a^{2m-1}\exp\left(-\frac{m}{\Omega}a^2\right); \tag{14}$$

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

Using the approach in [4], the PDF of h is given by

$$f(h) = \frac{2}{h\prod_{t=1}^{N}\Gamma(m_t)}G_{0,N}^{N,0}\left[h^2\prod_{t=1}^{N}\frac{m_t}{\Omega_t}\Bigg|_{m_1,\ldots,m_N}^{-}\right], \tag{15}$$

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

Let $y = |h_k|^2$ represent the square of the amplitude of h_k. The corresponding CDF and PDF of y can be given as [4]

$$F(y) = \frac{1}{\prod_{t=1}^{N}\Gamma(m_t)}G_{1,N+1}^{N,1}\left[y\prod_{t=1}^{N}\frac{m_t}{\Omega_t}\Bigg|_{m_1,\ldots,m_N,0}^{1}\right], \qquad f(y) = \frac{1}{y\prod_{t=1}^{N}\Gamma(m_t)}G_{0,N}^{N,0}\left[y\prod_{t=1}^{N}\frac{m_t}{\Omega_t}\Bigg|_{m_1,\ldots,m_N}^{-}\right]. \tag{16}$$

3. The OP of Optimal TAS Scheme

The OP of optimal TAS scheme can be expressed as

$$\begin{aligned} F_{\text{optimal}} &= \Pr\left(\max_{1\le i\le N_t,\, 1\le j\le N_r}\left(\gamma_{ij}\right) < \gamma_{\text{th}}\right) \\ &= \left(\Pr\left(\gamma_{\text{SR}ij} < \gamma_T, \gamma_{0ij} < \gamma_{\text{th}}\right)\right. \\ &\quad \left.+ \Pr\left(\gamma_{\text{SR}ij} > \gamma_T, \gamma_{\text{SC}ij} < \gamma_{\text{th}}\right)\right)^{N_t\times N_r} = \left(G_1\right. \\ &\quad \left.+ G_2\right)^{N_t\times N_r}, \end{aligned} \tag{17}$$

where γ_{th} is a given threshold for correct detection at the MD.

G_1 is evaluated as

$$\begin{aligned} G_1 &= \frac{1}{\prod_{d=1}^{N}\Gamma\left(m_d\right)} G_{1,N+1}^{N,1}\left[\frac{\gamma_{\text{th}}}{\overline{\gamma_{\text{SD}}}}\prod_{d=1}^{N}\frac{m_d}{\Omega_d}\Bigg|_{m_1,\ldots,m_N,0}^{1}\right] \\ &\quad \cdot\left(\frac{1}{\prod_{t=1}^{N}\Gamma\left(m_t\right)} G_{1,N+1}^{N,1}\left[\frac{\gamma_T}{\overline{\gamma_{\text{SR}}}}\prod_{t=1}^{N}\frac{m_t}{\Omega_t}\Bigg|_{m_1,\ldots,m_N,0}^{1}\right]\right)^{L}, \\ \overline{\gamma_{\text{SD}}} &= K\overline{\gamma}, \\ \overline{\gamma_{\text{SR}}} &= KG_{\text{SR}}\overline{\gamma}. \end{aligned} \tag{18}$$

Next, G_2 is evaluated:

$$\begin{aligned} G_2 &= \frac{1}{\prod_{d=1}^{N}\Gamma\left(m_d\right)} G_{1,N+1}^{N,1}\left[\frac{\gamma_{\text{th}}}{\overline{\gamma_{\text{SD}}}}\prod_{d=1}^{N}\frac{m_d}{\Omega_d}\Bigg|_{m_1,\ldots,m_N,0}^{1}\right] \\ &\quad \cdot\frac{1}{\prod_{tt=1}^{N}\Gamma\left(m_{tt}\right)} G_{1,N+1}^{N,1}\left[\frac{\gamma_{\text{th}}}{\overline{\gamma_{\text{RD}}}}\prod_{tt=1}^{N}\frac{m_{tt}}{\Omega_{tt}}\Bigg|_{m_1,\ldots,m_N,0}^{1}\right]\left(1\right. \\ &\quad \left.-\left(\frac{1}{\prod_{t=1}^{N}\Gamma\left(m_t\right)} G_{1,N+1}^{N,1}\left[\frac{\gamma_T}{\overline{\gamma_{\text{SR}}}}\prod_{t=1}^{N}\frac{m_t}{\Omega_t}\Bigg|_{m_1,\ldots,m_N,0}^{1}\right]\right)^{L}\right), \\ \overline{\gamma_{\text{RD}}} &= \left(1-K\right)G_{\text{RD}}\overline{\gamma}. \end{aligned} \tag{19}$$

4. The OP of Suboptimal TAS Scheme

The OP of suboptimal TAS scheme can be expressed as

$$\begin{aligned} F_{\text{suboptimal}} &= \Pr\left(\gamma_{\text{SR}} < \gamma_T, \gamma_0 < \gamma_{\text{th}}\right) \\ &\quad + \Pr\left(\gamma_{\text{SR}} > \gamma_T, \gamma_{\text{SC}} < \gamma_{\text{th}}\right) \\ &= \Pr\left(\gamma_{\text{SR}} < \gamma_T, \gamma_{\text{SD}g} < \gamma_{\text{th}}\right) \\ &\quad + \Pr\left(\gamma_{\text{SR}} > \gamma_T, \gamma_{\text{SC}} < \gamma_{\text{th}}\right) \\ &= GG_1 + GG_2. \end{aligned} \tag{20}$$

GG_1 can be given as

$$\begin{aligned} GG_1 &= \Pr\left(\gamma_{\text{SR}} < \gamma_T, \gamma_{\text{SD}g} < \gamma_{\text{th}}\right) = \left(\frac{1}{\prod_{d=1}^{N}\Gamma\left(m_d\right)}\right. \\ &\quad \left.\cdot G_{1,N+1}^{N,1}\left[\frac{\gamma_{\text{th}}}{\overline{\gamma_{\text{SD}}}}\prod_{d=1}^{N}\frac{m_d}{\Omega_d}\Bigg|_{m_1,\ldots,m_N,0}^{1}\right]\right)^{N_t\times N_r} \\ &\quad \cdot\left(\frac{1}{\prod_{t=1}^{N}\Gamma\left(m_t\right)} G_{1,N+1}^{N,1}\left[\frac{\gamma_T}{\overline{\gamma_{\text{SR}}}}\prod_{t=1}^{N}\frac{m_t}{\Omega_t}\Bigg|_{m_1,\ldots,m_N,0}^{1}\right]\right)^{L}. \end{aligned} \tag{21}$$

GG_2 can be given as

$$\begin{aligned} GG_2 &= \Pr\left(\gamma_{\text{SR}} > \gamma_T, \max\left(\gamma_{\text{SD}g}, \gamma_{\text{RD}}\right) < \gamma_{\text{th}}\right) \\ &= \left(\frac{1}{\prod_{d=1}^{N}\Gamma\left(m_d\right)} G_{1,N+1}^{N,1}\left[\frac{\gamma_{\text{th}}}{\overline{\gamma_{\text{SD}}}}\prod_{d=1}^{N}\frac{m_d}{\Omega_d}\Bigg|_{m_1,\ldots,m_N,0}^{1}\right]\right)^{N_t\times N_r} \\ &\quad \cdot\frac{1}{\prod_{tt=1}^{N}\Gamma\left(m_{tt}\right)} G_{1,N+1}^{N,1}\left[\frac{\gamma_{\text{th}}}{\overline{\gamma_{\text{RD}}}}\prod_{tt=1}^{N}\frac{m_{tt}}{\Omega_{tt}}\Bigg|_{m_1,\ldots,m_N,0}^{1}\right]\left(1\right. \\ &\quad \left.-\left(\frac{1}{\prod_{t=1}^{N}\Gamma\left(m_t\right)} G_{1,N+1}^{N,1}\left[\frac{\gamma_T}{\overline{\gamma_{\text{SR}}}}\prod_{t=1}^{N}\frac{m_t}{\Omega_t}\Bigg|_{m_1,\ldots,m_N,0}^{1}\right]\right)^{L}\right). \end{aligned} \tag{22}$$

5. Numerical Results

In this section, we present Monte Carlo simulations to confirm the derived analytical results. Additionally, random number simulation was done to confirm the validity of the analytical approach. All the computations were done in MATLAB and some of the integrals were verified through MAPLE. The links between MS to MD, MS to MR, and MR to MD are modeled as N-Nakagami distribution. The total energy is $E = 1$. The fading coefficient is $m = 1, 2, 3$, the number of cascaded components is $N = 2, 3, 4$, and the number of transmit antennas is $N_t = 1, 2, 3$, respectively.

Figure 2 presents the OP performance of optimal TAS scheme. Figure 3 presents the OP performance of suboptimal TAS scheme. The number of cascaded components is $N = 2$. The fading coefficient is $m = 2$. The power allocation parameter is $K = 0.5$. The number of transmit antennas is $N_t = 1, 2, 3$. The number of mobile relays is $L = 2$. The number of receive antennas is $N_r = 1$. The relative geometrical gain is $\mu = 0$ dB. The given threshold is $\gamma_{\text{th}} = 5$ dB, $\gamma_T = 2$ dB. In order to verify the analytical results, we have also plotted Monte Carlo results. It shows that the analytical results match perfectly with the Monte Carlo results. As expected, the OP performance is improved as the number of transmit antennas increased. For example, when optimal TAS scheme is used, SNR = 10 dB, the OP is 2.6×10^{-1} when $N_t = 1$, 6.9×10^{-2} when $N_t = 2$, and 1.8×10^{-2} when $N_t = 3$. With N_t fixed, an increase in the SNR decreases the OP.

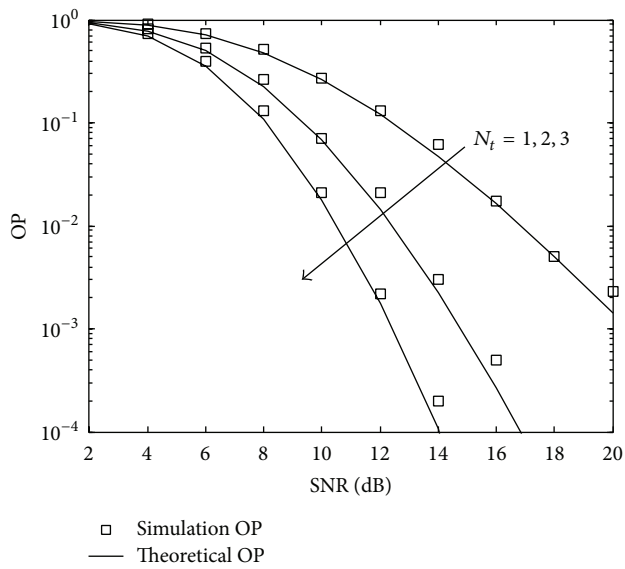

Figure 2: The OP performance of optimal TAS scheme.

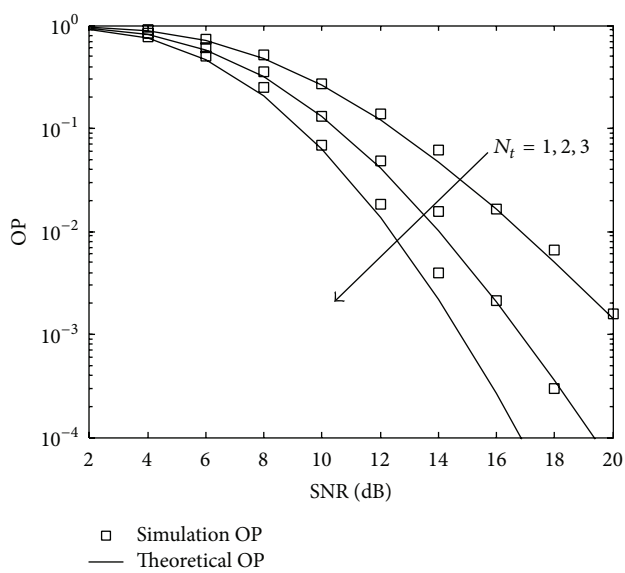

Figure 3: The OP performance of suboptimal TAS scheme.

In Figure 4, we compare OP performance of optimal and suboptimal TAS schemes for different numbers of antennas N_t. The number of cascaded components is $N = 2$. The fading coefficient is $m = 2$. The power allocation parameter is $K = 0.5$. The relative geometrical gain is $\mu = 0$ dB. The number of transmit antennas is $N_t = 2, 3$. The number of mobile relays is $L = 2$. The number of receive antennas is $N_r = 1$. The given threshold is $\gamma_{\text{th}} = 5$ dB, $\gamma_T = 2$ dB. To avoid clutter, we have not plotted the simulation based results. In all cases, as expected, when N_t is fixed, optimal TAS scheme has a better OP performance than suboptimal TAS scheme in all SNR regimes. As predicted by our analysis, the performance gap between two TAS schemes decreases as N_t is increased. The OP performance gap between optimal TAS scheme with $N_t = 2$ and suboptimal TAS scheme with $N_t = 3$ is negligible.

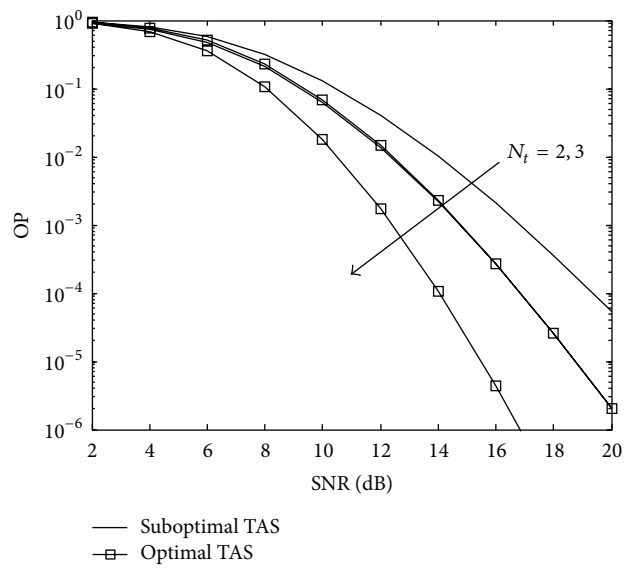

Figure 4: The OP performance comparison of two TAS schemes.

Table 1: OPA parameters K.

SNR	$\mu = 5$ dB	$\mu = 0$ dB	$\mu = -5$ dB
0	0.99	0.46	0.57
5	0.99	0.45	0.55
10	0.52	0.44	0.51
15	0.50	0.45	0.48
20	0.50	0.47	0.46

Figure 5 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 transmit antennas is $N_t = 2$. The number of mobile relays is $L = 2$. The number of receive antennas is $N_r = 2$. The given threshold is $\gamma_{\text{th}} = 5$ dB, $\gamma_T = 3$ dB. Simulation results show that the OP performance is improved with the SNR increased. For example, when $K = 0.7$, the OP is 3.3×10^{-1} with SNR = 5 dB, 4.9×10^{-3} with SNR = 10 dB, and 1.1×10^{-6} with SNR = 15 dB. When SNR = 5 dB, the optimum value of K is 0.99; SNR = 10 dB, the optimum value of K is 0.63; SNR = 15 dB, the optimum value of K is 0. 54. This indicates that the equal power allocation (EPA) scheme is not the best scheme.

Unfortunately, an analytical solution for power allocation values K in the general case is very difficult. 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 the relative geometrical gain μ. 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, 0 dB, -5 dB, the number of transmit antennas is $N_t = 2$, the number of mobile relays is $L = 2$, the number of receive antennas is

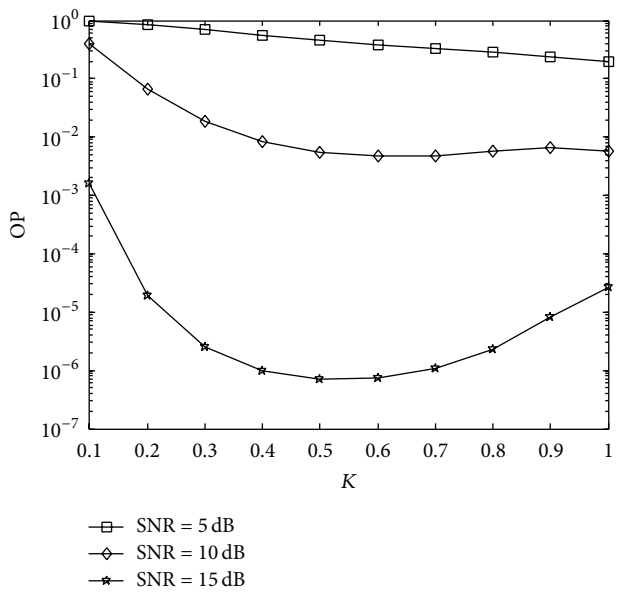

Figure 5: The effect of the power allocation parameter K on the OP performance.

$N_r = 2$, and the given threshold is $\gamma_{\text{th}} = 5$ dB, $\gamma_T = 3$ dB. For example, when $\mu = 5$ dB, 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 more than 50% of the power should be used in broadcast phase.

6. Conclusions

The exact closed-form OP expressions for SDF relaying M2M networks with TAS over N-Nakagami fading channels are derived in this paper. The simulation results show that optimal TAS scheme has a better OP performance than suboptimal TAS scheme. It was also shown that the power allocation parameter K has an important influence on the OP performance. The given expressions can be used to evaluate the OP performance of vehicular communication networks employed in intervehicular, intelligent highway, and mobile ad hoc applications. In the future, we will consider the impact of correlated channels on the OP performance.

Competing Interests

The authors declare that they have no competing interests.

Acknowledgments

This project was supported by National Natural Science Foundation of China (no. 61304222, no. 61301139), Natural Science Foundation of Shandong Province (no. ZR2012FQ021), and Shandong Province Outstanding Young Scientist Award Fund (no. 2014BSE28032).

References

[1] S. Mumtaz, K. Mohammed, S. Huq, and J. Rodriguez, "Direct mobile-to-mobile communication: paradigm for 5G," *IEEE Wireless Communications*, vol. 21, no. 5, pp. 14–23, 2014.

[2] B. Talha and M. Pätzold, "Channel models for mobile-to-mobile cooperative communication systems: a state of the art review," *IEEE Vehicular Technology Magazine*, vol. 6, no. 2, pp. 33–43, 2011.

[3] J. Salo, H. M. El-Sallabi, and P. Vainikainen, "Statistical analysis of the multiple scattering radio channel," *IEEE Transactions on Antennas and Propagation*, vol. 54, no. 11, pp. 3114–3124, 2006.

[4] M. Uysal, "Diversity analysis of space-time coding in cascaded Rayleigh fading channels," *IEEE Communications Letters*, vol. 10, no. 3, pp. 165–167, 2006.

[5] F. K. Gong, J. Ge, and N. Zhang, "SER analysis of the mobile-relay-based M2M communication over double nakagami-m fading channels," *IEEE Communications Letters*, vol. 15, no. 1, pp. 34–36, 2011.

[6] G. K. Karagiannidis, N. C. Sagias, and P. T. Mathiopoulos, "N*Nakagami: a novel stochastic model for cascaded fading channels," *IEEE Transactions on Communications*, vol. 55, no. 8, pp. 1453–1458, 2007.

[7] E. Dahlman, S. Parkvall, and J. Skold, *4G: LTE/LTE-Advanced for Mobile Broadband*, Academic Press, New York, NY, USA, 2011.

[8] H. Ilhan, M. Uysal, and I. Altunbaş, "Cooperative diversity for intervehicular communication: performance analysis and optimization," *IEEE Transactions on Vehicular Technology*, vol. 58, no. 7, pp. 3301–3310, 2009.

[9] L. W. Xu, H. Zhang, and T. A. Gulliver, "Performance analysis of the threshold digital relaying M2M system," *International Journal of Signal Processing, Image Processing and Pattern Recognition*, vol. 8, no. 3, pp. 357–366, 2015.

[10] L. W. Xu, H. Zhang, T. T. Lu, X. Liu, and Z. Q. Wei, "Performance analysis of the mobile-relay-based M2M communication over N-Nakagami fading channels," *Journal of Applied Science and Engineering*, vol. 18, no. 3, pp. 309–314, 2015.

[11] L. W. Xu, H. Zhang, and T. A. Gulliver, "Performance analysis of IDF relaying M2M cooperative networks over N-Nakagami fading channels," *KSII Transactions on Internet & Information Systems*, vol. 9, no. 10, pp. 3983–4001, 2015.

[12] G. Amarasuriya, C. Tellambura, and M. Ardakani, "Performance analysis of hop-by-hop beamforming for dual-hop MIMO AF relay networks," *IEEE Transactions on Communications*, vol. 60, no. 7, pp. 1823–1837, 2012.

[13] M. K. Arti and M. R. Bhatnagar, "Performance analysis of hop-by-hop beamforming and combining in DF MIMO relay system over Nakagami-m fading channels," *IEEE Communications Letters*, vol. 17, no. 11, pp. 2081–2083, 2013.

[14] X. Jin, J.-S. No, and D.-J. Shin, "Source transmit antenna selection for MIMO decode-and-forward relay networks," *IEEE Transactions on Signal Processing*, vol. 61, no. 7, pp. 1657–1662, 2013.

[15] P. L. Yeoh, M. Elkashlan, N. Yang, D. B. D. Costa, and T. Q. Duong, "Unified analysis of transmit antenna selection in MIMO multirelay networks," *IEEE Transactions on Vehicular Technology*, vol. 62, no. 2, pp. 933–939, 2013.

[16] H. Ochiai, P. Mitran, and V. Tarokh, "Variable-rate two-phase collaborative communication protocols for wireless networks," *IEEE Transactions on Information Theory*, vol. 52, no. 9, pp. 4299–4313, 2006.