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Performance Analysis of the SIR M2M Cooperative Networks

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Abstract

The exact closed-form outage probability (OP) expressions of the multiple-mobile-relay-based mobile-to-mobile (M2M) cooperative networks over N-Nakagami fading channels are derived for selection incremental relaying (SIR). Then the OP performance under different conditions is evaluated through numerical simulations. The numerical simulation results coincide with the theoretical results well, and the accuracy of the analytical results is verified. The simulation results showed that: the fading coefficient, the number of cascaded components, the relative geometrical gain, and the power-allocation parameter have an important influence on the OP performance.

Keywords: *M2M communication, N-Nakagami fading channels, selection incremental relaying, outage probability*

1. Introduction

Mobile-to-mobile (M2M) communication has attracted wide research interest in recent years. It is widely employed in many popular wireless communication systems, such as mobile ad-hoc networks and vehicle-to-vehicle networks [1]. When both the transmitter and receiver are in motion, the double-Rayleigh fading model has been found to be applicable [2]. Extending this model to the more realistic Nakagami fading, a double-Nakagami fading model has also been considered [3]. A generalization of this model, the N-Nakagami distribution, which is the product of N Nakagami random variables which are statistically independent but not necessarily identically distributed, was introduced and analyzed in [4].

Cooperative diversity has been proposed as a promising solution for the high data-rate coverage required in M2M communication networks. Using amplify-and-forward (AF) relaying scheme, [5] investigated pairwise error probability (PEP) for the cooperative inter-vehicular communication (IVC) system over double-Nakagami fading channels. Based on decode-and-forward (DF) relaying scheme, [6]investigated the exact symbol error rate(SER) and asymptotic SER expressions of the MR-M2M system by using the widely studied moment generating function(MGF) approach over double-Nakagami fading channels. In [7], the symbol error probability (SEP) expressions for the multiple-mobile-relay-based M2M system were derived by MGF approach for adaptive DF (ADF) relaying and fixed-gain AF (FAF) relaying over double-Nakagami fading channels.

For adaptive relaying scheme, there are selection relaying (SR) and incremental relaying (IR) [8, 9]. In [8], the authors investigated a closed-form expression for outage probability (OP) of the SR cooperative networks over Nakagami-m fading channel. An IR cooperation scheme employing orthogonal space-time block codes (OSTBC) over Rayleigh fading channels was proposed in [9]. For the SR cooperative networks, the relay will forward the message if it can decode the message successfully. However, in the case that the destination can decode the message successfully, the transmission of the relay is

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not necessary. The utilization rate of time and frequency resources is lower. While in IR cooperative networks, when the destination can't decode the message correctly, the relay will forward the message without considering the condition of the source-relay link. If the channel quality of source-relay link is poor, the relay may not decode the message correctly and then cause error propagation. To solve these problems, [10] proposed a novel cooperative scheme called selection incremental relaying (SIR), which combined SR with IR. The closed-form expressions for the OP of both single relay and opportunistic relay strategies are derived over Nakagami-m fading channels. But, it ignored the direct transmission between the source and its destination.

However, to the best knowledge of the author, the OP performance of the SIR M2M cooperative networks over N-Nakagami fading channels has not been considered in the literature. In the present work, we extend our analysis for N-Nakagami case which subsumes double-Nakagami in [5-7]as special cases. The direct transmission between the source and destination is also considered. The exact closed form OP expressions are derived for SIR M2M cooperative networks over N-Nakagami fading channels.

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

2. The System Model

We consider a multiple-mobile-relay-based M2M cooperative networks model, namely a single mobile source (MS) node, L mobile relay (MR) nodes, and a single mobile destination (MD) node. The nodes operate in half-duplex mode, which are equipped with a single pair of transmitter and receiver antennas.

According to [5], we let d_{SD}, $d_{\mathrm{SR}l}$, and $d_{\mathrm{RD}l}$ represent the distances of MS→MD, MS→MR$_l$, and MR$_l$→MD links, respectively. Assuming the path loss between MS→MD to be unity, the relative gain of MS→MR$_l$ and MR$_l$→MD links are defined as $G_{\mathrm{SR}l}=(d_{\mathrm{SD}}/d_{\mathrm{SR}l})^v$ and $G_{\mathrm{RD}l} = (d_{\mathrm{SD}}/d_{\mathrm{RD}l})^v$, respectively ,where v is the path loss coefficient[11]. We further define the relative geometrical gain $\mu_l = G_{\mathrm{SR}l}/G_{\mathrm{RD}l}$ (in decibels), which indicates the location of the lth relay with respect to the source and destination[5]. When the lth relay is close to the destination node, the values of μ_l are negative. When the lth relay is close to the source node, the values of μ_l are positive. When the lth relay has the same distance to the source and destination nodes, μ_l is 0dB.

Let $h=h_k$, $k\in\{\mathrm{SD}, \mathrm{SR}l, \mathrm{RD}l\}$, represent the complex channel coefficients of MS→MD, MS→MR$_l$, and MR$_l$→MD links, respectively, which follow N-Nakagami distribution. Therefore h is assumed to be a product of statistically independent, but not necessarily identically distributed, N independent random variables

$$h = \prod_{i=1}^{N} a_i \tag{1}$$

where N is the number of cascaded components, a_i is a Nakagami distributed random variable with probability density function (PDF)

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

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

The PDF of h is given by[4]

$$f_h(h) = \frac{2}{h\prod_{i=1}^{N}\Gamma(m_i)} G_{0,N}^{N,0}\left[h^2 \prod_{i=1}^{N} \frac{m_i}{\Omega_i} \Big|_{m_1,\ldots,m_N}^{-} \right] \tag{3}$$

where G[·] is the Meijer's G-function .

Let $y=|h_k|^2$, $k\in\{\mathrm{SD}, \mathrm{SR}l, \mathrm{RD}l\}$, so that $y_{\mathrm{SD}}=|h_{\mathrm{SD}}|^2$, $y_{\mathrm{SR}l}=|h_{\mathrm{SR}l}|^2$, and $y_{\mathrm{RD}l}=|h_{\mathrm{RD}l}|^2$.The corresponding cumulative density functions (CDF) of y can be derived as[4]

$$F_y(y)=\frac{1}{\prod_{i=1}^{N}\Gamma(m_i)}G_{1,N+1}^{N,1}\left[y\prod_{i=1}^{N}\frac{m_i}{\Omega_i}\Big|_{m_1,\ldots,m_N,0}^{1}\right] \tag{4}$$

By taking the first derivative of (4) with respect to y, the corresponding PDF can be obtained as

$$f_y(y)=\frac{1}{y\prod_{i=1}^{N}\Gamma(m_i)}G_{0,N}^{N,0}\left[y\prod_{i=1}^{N}\frac{m_i}{\Omega_i}\Big|_{m_1,\ldots,m_N}^{-}\right] \tag{5}$$

During the first time slot, the received signals r_{SD} and $r_{\mathrm{SR}l}$ at the MD and MR_l can be written as [5]

$$r_{SD}=\sqrt{KE}h_{SD}x+n_D \tag{6}$$

$$r_{SRl}=\sqrt{G_{SRl}KE}h_{SRl}x+n_{SRl} \tag{7}$$

where x denotes the transmitted signal, n_{SRl} and n_{D} are the zero-mean complex Gaussian random variables with variance $N_0/2$ per dimension. Here, E is the total energy which is used by both source and relay terminals during two time slots. K is the power-allocation parameter that controls the fraction of power reserved for the broadcasting phase. If K=0.5, the equal power allocation (EPA) scheme is used.

During the second time slot, only the best relay decides whether to activate by comparing the instantaneous SNR γ_{SD} to a threshold γ_T. γ_{SD} denotes the instantaneous SNR of the MS to MD link. In our scheme, the best relay is selected based on the following criterion

$$\gamma_R=\max_{1\le l\le L}(\gamma_{SRl}) \tag{8}$$

where

$$\gamma_{SRl}=\frac{KG_{SRl}\left|h_{SRl}\right|^2E}{N_0}=KG_{SRl}\left|h_{SRl}\right|^2\bar{\gamma} \tag{9}$$

If $\gamma_{SD}>\gamma_T$, the MD will broadcast a 'success' message to the MS and the best relay. Then MS will transmit the next message, and the best relay remains silent. The output SNR at the destination can then be calculated as

$$\gamma_1=\gamma_{SD} \tag{10}$$

where

$$\gamma_{SD}=\frac{K\left|h_{SD}\right|^2E}{N_0}=K\left|h_{SD}\right|^2\bar{\gamma} \tag{11}$$

If $\gamma_{SD}<\gamma_T$, the MD will broadcast a 'failure' message to the MS and the best relay. The best relay decides whether to decode and retransmit the signal to the MD by comparing the instantaneous SNR γ_R to a threshold γ_P.

If $\gamma_R<\gamma_P$, the best relay remains silent. The output SNR at the destination can then be calculated as

$$\gamma_2=\gamma_{SD} \tag{12}$$

If $\gamma_R>\gamma_P$, the best relay decodes and retransmits the signal to the MD. Selection combining (SC) method is used at the MD. The output SNR at the destination can then be calculated as

$$\gamma_{SC}=\max(\gamma_{SD},\gamma_{RD}) \tag{13}$$

where

$$\gamma_{RD} = \frac{(1-K)G_{RD}\left|h_{RD}\right|^2 E}{N_0} = (1-K)G_{RD}\left|h_{RD}\right|^2 \bar{\gamma} \tag{14}$$

3. The OP for the SIR M2M Cooperative Networks

In this section, the exact closed form OP expressions for the SIR M2M cooperative networks are derived.

Thus, we can obtain the OP of the output SNR at the destination as

$$\begin{aligned} P_{out} &= \Pr(\gamma_{SD} > \gamma_T, \gamma_1 < \gamma_{th}) + \Pr(\gamma_{SD} < \gamma_T, \gamma_R < \gamma_P, \gamma_2 < \gamma_{th}) \\ &\quad + \Pr(\gamma_{SD} < \gamma_T, \gamma_R > \gamma_P, \gamma_{SC} < \gamma_{th}) \end{aligned} \tag{15}$$

where γ_{th} is a given threshold.

If $\gamma_{th} > \gamma_T$, as γ_R, γ_{SD} and γ_{RD} are mutually independent random variables, (15) can be simplified and derived as follows:

$$\begin{aligned} P_{out} &= \Pr(\gamma_T < \gamma_{SD} < \gamma_{th}) + \Pr(\gamma_{SD} < \gamma_T, \gamma_R < \gamma_P) \\ &\quad + \Pr(\gamma_{SD} < \gamma_T, \gamma_R > \gamma_P, \gamma_{RD} < \gamma_{th}) \\ &= F_{\gamma_{SD}}(\gamma_{th}) - F_{\gamma_{SD}}(\gamma_T) + F_{\gamma_{SD}}(\gamma_T)\Big(F_{\gamma_R}(\gamma_P) + \big(1 - F_{\gamma_R}(\gamma_P)\big)F_{\gamma_{RD}}(\gamma_{th})\Big) \end{aligned} \tag{16}$$

If $\gamma_{th} < \gamma_T$, (15) can be simplified and derived as follows:

$$\begin{aligned} P_{out} &= \Pr(\gamma_{SD} < \gamma_{th}, \gamma_R < \gamma_P) + \Pr(\gamma_{SD} < \gamma_{th}, \gamma_R > \gamma_P, \gamma_{RD} < \gamma_{th}) \\ &= F_{\gamma_{SD}}(\gamma_{th}) F_{\gamma_R}(\gamma_P) + F_{\gamma_{SD}}(\gamma_{th})\big(1 - F_{\gamma_R}(\gamma_P)\big) F_{\gamma_{RD}}(\gamma_{th}) \end{aligned} \tag{17}$$

The CDF of γ_{SD} can be given as[4]

$$F_{\gamma_{SD}}(r) = \frac{1}{\prod_{i=1}^{N}\Gamma(m_i)} G_{1,N+1}^{N,1}\left[\frac{r}{\overline{\gamma_{SD}}}\prod_{i=1}^{N}\frac{m_i}{\Omega_i}\Big|_{m_1,\ldots.,m_N,0}^{1}\right] \tag{18}$$

where

$$\overline{\gamma_{SD}} = K\bar{\gamma} \tag{19}$$

The CDF of γ_{R} can be given as

$$\begin{aligned} F_{\gamma_R}(r) &= \prod_{l=1}^{L} P(\gamma_{SRl} \le r) = \prod_{l=1}^{L} F_{\gamma_{SRl}}(r) \\ &= \prod_{l=1}^{L} \frac{1}{\prod_{j=1}^{N}\Gamma(m_j)} G_{1,N+1}^{N,1}\left[\frac{r}{\overline{\gamma_{SRl}}}\prod_{j=1}^{N}\frac{m_j}{\Omega_j}\Big|_{m_1,\ldots.,m_N,0}^{1}\right] \end{aligned} \tag{20}$$

where

$$\overline{\gamma_{SRl}} = KG_{SRl}\bar{\gamma} \tag{21}$$

The CDF of γ_{RD} can be given as

$$F_{\gamma_{RD}}(r) = \frac{1}{\prod_{jj=1}^{N}\Gamma(m_{jj})} G^{N,1}_{1,N+1}\left[\frac{r}{\overline{\gamma_{RD}}}\prod_{i=1}^{N}\frac{m_{jj}}{\Omega_{jj}}\Big|^{1}_{m_1,\ldots,m_N,0}\right] \tag{22}$$

where

$$\overline{\gamma_{RD}} = (1-K)G_{RD}\bar{\gamma} \tag{23}$$

As a result, substituting (18), (20), (22) in (16) and (17), we can obtain the OP of the SIR M2M cooperative networks.

4. Numerical Results

In this section, some numerical results are presented to illustrate and verify the OP results obtained in the previous sections.

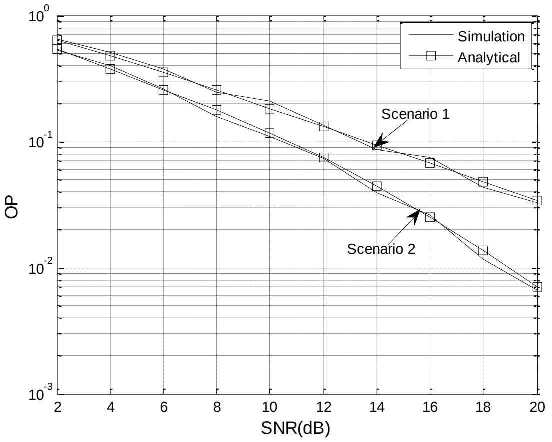

Figure 1. The OP Performance over N-Nakagami Fading Channels when $\gamma_{th} > \gamma_T$

Figure 1 presents the OP performance of the SIR M2M cooperative networks over N-Nakagami fading channels when $\gamma_{th} > \gamma_T$. The relative geometrical gain μ=0dB. The power-allocation parameter K=0.5. The number of cascaded components N=2. The number of mobile relays L=3. The given threshold γ_{th}=2dB, γ_T=0dB, γ_p=2dB. Here, we consider the following scenarios based on the combinations of the number of cascaded components N and fading coefficient m:

(1)Scenario 1: $m_{\mathrm{SD}} = 1$, $m_{\mathrm{SR}l} = 1$, $m_{\mathrm{RD}l} = 1$ and $N_{\mathrm{SD}} = 2$, $N_{\mathrm{SR}l} = N_{\mathrm{RD}l} = 2$. ($l$=1,2,3)
(2)Scenario 2: $m_{\mathrm{SD}}=2$, $m_{\mathrm{SR}l}=2$, $m_{\mathrm{RD}l} = 2$ and $N_{\mathrm{SD}} = 2$, $N_{\mathrm{SR}l} = N_{\mathrm{RD}l}=2$. ($l$=1,2,3)

From Figure 1,we can obtain that, the numerical simulation results coincide with the theoretical results well，and the accuracy of the analytical results is verified. With the SNR increased, the OP performance is improved. For example, in scenario 2, when SNR=10dB, the OP is 1×10^{-1}, SNR=12dB, the OP is 7.5×10^{-2}. With the fading coefficient m increased, the OP is reduced gradually.

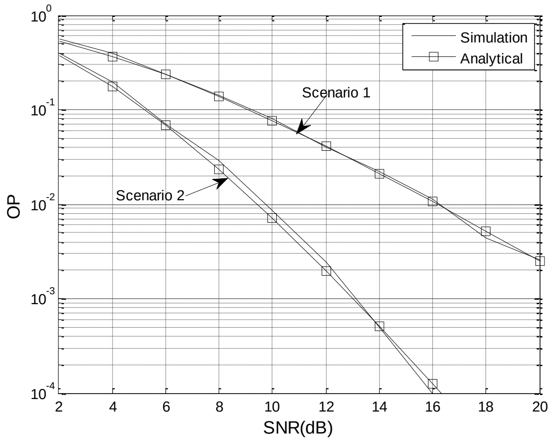

Figure 2. The OP Performance over N-Nakagami Fading Channels when $\gamma_{th} < \gamma_T$

Figure 2 presents the OP performance of the SIR M2M cooperative networks over N-Nakagami fading channels when $\gamma_{th}<\gamma_T$. The relative geometrical gain μ=0dB. The power-allocation parameter K=0.5. The number of cascaded components N=2. The number of mobile relays L=2. The given threshold γ_{th}=0dB, γ_T=2dB, γ_p=2dB. Here, we consider the following scenarios based on the combinations of the number of cascaded components N and fading coefficient m:

(1)Scenario 1: $m_{\mathrm{SD}} = 1$, $m_{\mathrm{SR}l} = 1$, $m_{\mathrm{RD}l} =1$ and $N_{\mathrm{SD}} =2$, $N_{\mathrm{SR}l} = N_{\mathrm{RD}l} =2$. ($l$=1,2)
(2)Scenario 2: $m_{\mathrm{SD}}=2$, $m_{\mathrm{SR}l} =2$, $m_{\mathrm{RD}l} =2$ and $N_{\mathrm{SD}} =2$, $N_{\mathrm{SR}l} =N_{\mathrm{RD}l}=2$. ($l$=1,2)

From Figure 2,we can obtain that, the numerical simulation results coincide with the theoretical results well，and the accuracy of the analytical results is verified. With the SNR increased, the OP performance is improved. For example, in scenario 1, when SNR=12dB, the OP is 4×10^{-2}, SNR=14dB, the OP is 2×10^{-2}. With the fading coefficient m increased, the OP is reduced gradually.

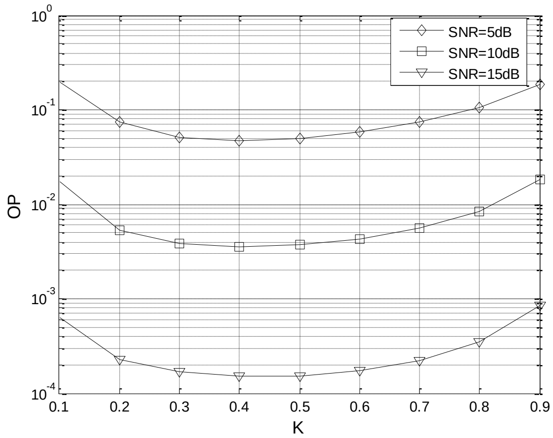

Figure 3. The Effect of the Power-allocation Parameter *K* on the OP Performance

Figure 3 presents the effect of the power-allocation parameter K on the OP performance of the SIR M2M cooperative networks over N-Nakagami fading channels with various values of SNR. The number of cascaded components N=2. The fading coefficient m=2. The relative geometrical gain μ=0dB. The given threshold γ_{th}=2dB, γ_T=4dB, γ_p=2dB. The number of mobile relays L=2.Simulation results show that the OP performance is improved with the SNR increased. For example, when K=0.6, SNR=5dB, the OP is 6×10^{-2}, SNR=10dB, the OP is 5.5×10^{-3}, SNR=15dB, the OP is 2×10^{-4}. When SNR=5dB, the optimum value of K is 0.4 approximately; SNR=10dB, the optimum value of K is 0.4 approximately; SNR=15dB, the optimum value of K is 0.4 approximately.

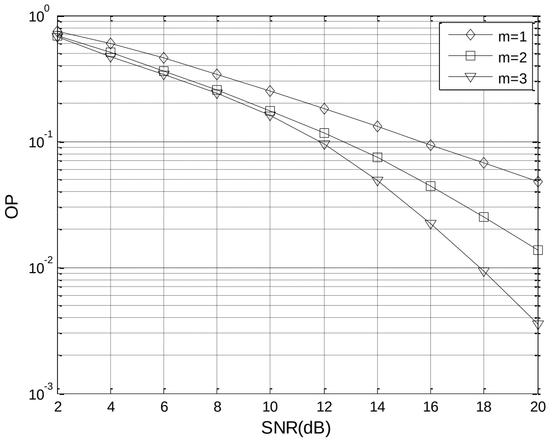

Figure 4. The Effect of the Fading Coefficient *m* on the OP Performance

Figure 4 presents the effect of the fading coefficient m on the OP performance of the SIR M2M cooperative networks over N-Nakagami fading channels. The number of cascaded components N=2.The fading coefficient m=1, 2, 3. The relative geometrical gain μ=0dB. The given threshold γ_{th}=2dB, γ_T=0dB, γ_p=2dB.The power-allocation parameter K=0.5. The number of mobile relays L=3.Simulation results show that the OP performance is improved with the fading coefficient m increased. For example, when SNR=14dB, m=1, the OP is 1.5×10^{-1}, m=2, the OP is 8×10^{-2}, m=3, the OP is 5×10^{-2}. When the m is fixed, with the increase of SNR, the OP is reduced gradually.

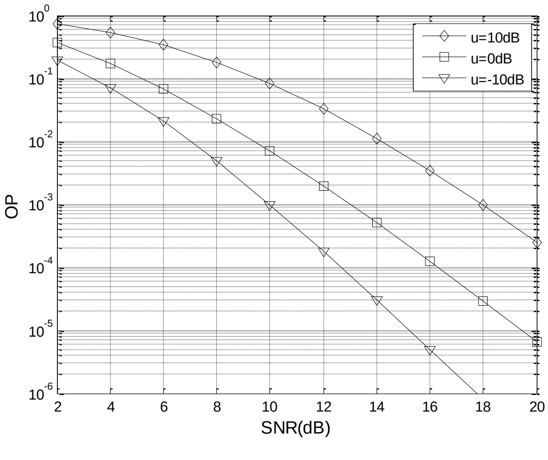

Figure 5. The Effect of the Relative Geometrical Gain *μ* on the OP Performance

Figure 5 presents the effect of the relative geometrical gain μ on the OP performance of the SIR M2M cooperative networks over N-Nakagami fading channels. The number of cascaded components N=2. The fading coefficient m=2. The relative geometrical gain μ=10dB, 0dB,-10dB. The given threshold γ_{th}=0dB, γ_T=2dB, γ_p=2dB.The power-allocation parameter K=0.5. The number of mobile relays L=2.Simulation results show that the

OP performance is improved as μ reduced. For example, when SNR=12dB, μ=10dB, the OP is 3×10^{-2}, μ=0dB, the OP is 5×10^{-4}, μ=-10dB, the OP is 2×10^{-4}. With the increase of SNR, the OP between them is reduced gradually.

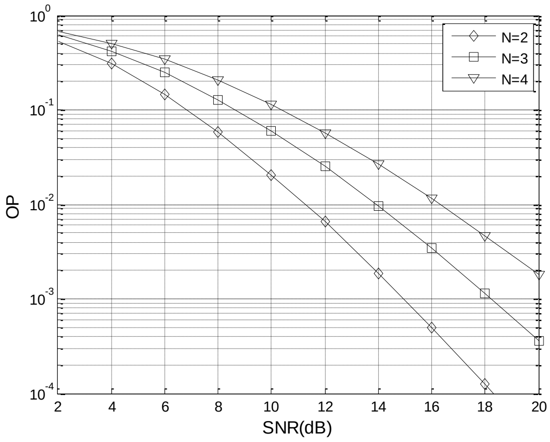

Figure 6. The Effect of the Number of Cascaded Components *N* on the OP Performance

Figure 6 presents the effect of the number of cascaded components *N* on the OP performance of the SIR M2M cooperative networks over N-Nakagami fading channels. The number of cascaded components *N*=2, 3, 4, which respectively denotes the 2-Nakagami, 3-Nakagami, 4-Nakagami fading channels. The fading coefficient *m*=2. The relative geometrical gain μ=0dB. The given threshold γ_{th}=2dB, γ_T=4dB, γ_p=2dB. The power-allocation parameter *K*=0.5. The number of mobile relays *L*=2.Simulation results show that the OP performance is degraded as *N* increased. For example, when SNR=12dB, *N*=2, the OP is 6.5×10^{-3}, *N*=3, the OP is 2.5×10^{-2}, *N*=4, the OP is 5.5×10^{-2}.This because the fading severity of the cascaded channels increases as *N* increased. When the *N* is fixed, with the increase of SNR, the OP is reduced gradually.

5. Conclusions

The exact closed-form OP expressions for the SIR M2M cooperative networks over N-Nakagami fading channels are derived in this paper. The simulation results show that: the fading coefficient *m*, the number of cascaded components *N*, the relative geometrical gain μ, and the power-allocation parameter *K* have an important influence on the OP performance. The expressions derived here are simple to compute and thus complete and accurate performance results can easily be obtained with negligible computational effort. In the future, we will consider the impact of the correlated channels on the OP performance of the SIR M2M cooperative networks.

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