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Outage Probability Analysis of the VAF Relaying M2M Networks

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Abstract

Based on variable-gain amplify-and-forward (VAF) relaying scheme, the lower bound on outage probability (OP) of the mobile-relay-based mobile-to-mobile (M2M) networks over N-Nakagami fading channels is investigated in this paper. By the method of the harmonic mean of positive random variables, the exact closed form expression of the lower bound on OP is derived. 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, harmonic mean, 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 communication [1]. When both the transmitter and receiver are in motion, the double-Rayleigh fading model has been shown to be applicable [2]. Extending this model by characterizing the fading between each pair of the transmit and receive antennas as Nakagami, the double-Nakagami fading model has also been considered [3]. The N-Nakagami distribution was introduced in [4] as the product of N statistically independent, but not necessarily identically distributed, Nakagami random variables.

As far as we known, in M2M communication field, many papers have made a lot of achievements, such as channel simulation, modeling and statistics analysis [5-8]. By utilizing the autocorrelation characteristics of the M2M link, [5] derived the channel estimation error on cooperative communications. Using amplify-and-forward (AF) relaying scheme, [6] 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, [7]investigated the exact symbol error rate(SER) and the asymptotic SER expressions of the MR-M2M system by using the widely studied moment generating function(MGF) approach over double-Nakagami fading channels. In [8], by MGF approach, the authors derived the approximate SER expressions for fixed-gain AF (FAF) relaying over double-Nakagami fading channels.

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However, to the best knowledge of the author, the outage probability (OP) performance of the variable-gain amplify-and-forward (VAF) relaying M2M networks over N-Nakagami fading channels has not been considered in the literature. Thus in this paper, we present the analysis for the N-Nakagami case which subsumes the double-Nakagami results in [6-8] as special cases. Based on the method of the harmonic mean of positive random variables in[9], the exact closed form expression of the lower bound on OP is derived for VAF relaying over N-Nakagami fading channels.

The rest of the paper is organized as follows. The VAF relaying M2M networks model is presented in Section 2. Section 3 provides the lower bound on OP for VAF relaying. 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 three-node cooperation model, namely mobile source (S), mobile relay (R), and mobile destination (D) nodes. The nodes operate in half-duplex mode, which are equipped with a single pair of transmitter and receiver antennas.

According to [6], we let d_{SD}, d_{SR}, and d_{RD} represent the distances of source-to-destination (S→D), source-to-relay (S→R),and relay-to-destination (R→D) links, respectively. Assuming the path loss between S→D to be unity, the relative gain of S→R and R→D links are defined as $G_{SR} = (d_{SD}/d_{SR})^v$ and $G_{RD} = (d_{SD}/d_{RD})^v$, respectively, where v is the path loss coefficient[10]. We further define the relative geometrical gain $\mu = G_{SR}/G_{RD}$ (in decibels), which indicates the location of the relay with respect to the source and destination [6]. When the relay is close to the destination node, the values of μ are negative. When the relay is close to the source node, the values of μ are positive. When the relay has the same distance to the source and destination nodes, μ is 0dB.

Let $h=h_k$, $k\in\{SD, SR, RD\}$, represent the complex channel coefficients of S→D, S→R, and R→D 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 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 $y=|h_k|^2$, $k\in\{SD, SR, RD\}$, so that $y_{SD}=|h_{SD}|^2$, $y_{SR}=|h_{SR}|^2$, and $y_{RD}=|h_{RD}|^2$. 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

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

Based on the AF cooperation protocol, the received signals r_{SD} and r_{SR} at the R and D during the first time slot can be written as [6]

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

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

where x denotes the transmitted signal, n_{SR} 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, the relay terminal normalizes the received signal r_{SR} and retransmits the resulting signal. After proper normalization, the received signal at the destination is therefore given by [6]

$$r_{RD} = \sqrt{cE}\,h_{SR}h_{RD}\,x + n_{RD} \tag{8}$$

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

For variable-gain AF (VAF), c is given as[6]

$$c = \frac{K(1-K)G_{SR}G_{RD}E/N_0}{1 + KG_{SR}\left|h_{SR}\right|^2 E/N_0 + (1-K)G_{RD}\left|h_{RD}\right|^2 E/N_0} \tag{9}$$

If selection combining (SC) method is used at the destination, the output SNR at the destination can then be calculated as [6]

$$\gamma_{SC} = \max(\gamma_{SD}, \gamma_{SRD}) \tag{10}$$

where γ_{SRD} denotes the end-to-end SNR at the destination, and

$$\gamma_{SRD} = \frac{\gamma_{SR}\gamma_{RD}}{1+\gamma_{SR}+\gamma_{RD}} \tag{11}$$

$$\gamma_{SR} = \frac{KG_{SR}\left|h_{SR}\right|^2 E}{N_0} = KG_{SR}\left|h_{SR}\right|^2\bar{\gamma} \tag{12}$$

$$\gamma_{RD} = \frac{(1-K)G_{RD}\left|h_{RD}\right|^2 E}{N_0} = (1-K)G_{RD}\left|h_{RD}\right|^2\bar{\gamma} \tag{13}$$

$$\gamma_{SD} = \frac{K\left|h_{SD}\right|^2 E}{N_0} = K\left|h_{SD}\right|^2\bar{\gamma} \tag{14}$$

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

$$F_{\gamma_{SC}}(r) = F_{\gamma_{SD}}(r)F_{\gamma_{SRD}}(r) \tag{15}$$

and the PDF as

$$f_{\gamma_{SC}}(r) = f_{\gamma_{SD}}(r) F_{\gamma_{SRD}}(r) + F_{\gamma_{SD}}(r) f_{\gamma_{SRD}}(r) \tag{16}$$

The CDF of the γ_{SD} can be given as[4]

$$F_{\gamma_{SD}}(r) = \frac{1}{\prod_{i=1}^{N} \Gamma(m_i)} G_{1,N+1}^{N,1}\left[\frac{r}{\overline{\gamma_{SD}}} \prod_{i=1}^{N} \frac{m_i}{\Omega_i} \middle|_{m_1,\ldots,m_N,0}^{1} \right] \tag{17}$$

where

$$\overline{\gamma_{SD}} = K\bar{\gamma} \tag{18}$$

By taking the first derivative of (17) with respect to *r*, the corresponding PDF can be obtained as

$$f_{\gamma_{SD}}(r) = \frac{1}{r\prod_{i=1}^{N} \Gamma(m_i)} G_{0,N}^{N,0}\left[\frac{r}{\overline{\gamma_{SD}}} \prod_{i=1}^{N} \frac{m_i}{\Omega_i} \middle|_{m_1,\ldots,m_N}^{-} \right] \tag{19}$$

It is difficult to obtain a closed form expression for the CDF of the $\gamma_{SRD.}$ But we can obtain the lower bound on CDF of the γ_{SRD}. So we can obtain the lower bound on OP for the VAF relaying. In the following subsections, we shall evaluate the lower bound on OP for the VAF relaying.

3. The Lower Bound on OP for VAF Relaying

By using the same method in [9] and at high SNR by ignoring the 1 in (11), the SNR γ_{SRD} can be approximated as

$$\gamma_{eqq} = \frac{\gamma_{SR}\gamma_{RD}}{\gamma_{SR} + \gamma_{RD}} = \frac{1}{2} \frac{2}{\frac{1}{\gamma_{SR}} + \frac{1}{\gamma_{RD}}} \tag{20}$$

By using the well-known inequality in [11], we can obtain an upper bound

$$\gamma_{eqq} < \gamma_{upp} = \min(\gamma_{SR}, \gamma_{RD}) \tag{21}$$

When we use the upper bound γ_{upp}, instead of γ_{SRD}, then the CDF is lower bounded, i.e.

$$F_{\gamma_{SRD}}(r) > F_{\gamma_{upp}}(r) \tag{22}$$

Because γ_{SR} and γ_{RD} are independent, the CDF of the γ_{upp} is given as[12]

$$\begin{aligned} F_{\gamma_{upp}}(r) &= 1 - P\{\gamma_{SR} > r, \gamma_{RD} > r\} \\ &= 1 - P\{\gamma_{SR} > r\} P\{\gamma_{RD} > r\} \end{aligned} \tag{23}$$

where

$$P\{\gamma_{SR} > r\} = 1 - \int_0^r f_{\gamma_{SR}}(x)dx$$

$$= 1 - \int_0^r \frac{1}{x\prod_{t=1}^{N}\Gamma(m_j)} G_{0,N}^{N,0}\left[\frac{x}{\overline{\gamma_{SR}}}\prod_{t=1}^{N}\frac{m_t}{\Omega_t}\Big|_{m_1,\ldots,m_N}^{-}\right]dx \tag{24}$$

$$\overline{\gamma_{SR}} = KG_{SR}E / N_0 = KG_{SR}\bar{\gamma} \tag{25}$$

To evaluate the integral in (24), the following integral function can be employed[13]

$$\int_0^y x^{a-1} G_{p,q}^{m,n}\left[wx\Big|_{b_1,\ldots,b_q}^{a_1,\ldots,a_p}\right]dx$$
$$= y^a G_{p+1,q+1}^{m,n+1}\left[wy\Big|_{b_1,\ldots,b_m,-a,b_{m+1},\ldots,b_q}^{a_1,\ldots,a_n,1-a,a_n,\ldots,a_p}\right] \tag{26}$$

(24) can be given as

$$P\{\gamma_{SR} > r\} = 1 - \frac{1}{\prod_{t=1}^{N}\Gamma(m_t)} G_{1,N+1}^{N,1}\left[\frac{r}{\overline{\gamma_{SR}}}\prod_{t=1}^{N}\frac{m_t}{\Omega_t}\Big|_{m_1,\ldots,m_N,0}^{1}\right] \tag{27}$$

We follow a procedure similar to (24) to yield as

$$P\{\gamma_{RD} > r\} = 1 - \frac{1}{\prod_{tt=1}^{N}\Gamma(m_{tt})} G_{1,N+1}^{N,1}\left[\frac{r}{\overline{\gamma_{RD}}}\prod_{tt=1}^{N}\frac{m_{tt}}{\Omega_{tt}}\Big|_{m_1,\ldots,m_N,0}^{1}\right] \tag{28}$$

where

$$\overline{\gamma_{RD}} = (1-K)G_{RD}\bar{\gamma} \tag{29}$$

The closed form expression for the tight lower bound on CDF of the γ_{SRD} as

$$F_{\gamma_{upp}}(r) = 1 - \left(1 - \frac{1}{\prod_{t=1}^{N}\Gamma(m_t)} G_{1,N+1}^{N,1}\left[\frac{r}{\overline{\gamma_{SR}}}\prod_{t=1}^{N}\frac{m_t}{\Omega_t}\Big|_{m_1,\ldots,m_N,0}^{1}\right]\right) \times \left(1 - \frac{1}{\prod_{tt=1}^{N}\Gamma(m_{tt})} G_{1,N+1}^{N,1}\left[\frac{r}{\overline{\gamma_{RD}}}\prod_{tt=1}^{N}\frac{m_{tt}}{\Omega_{tt}}\Big|_{m_1,\ldots,m_N,0}^{1}\right]\right) \tag{30}$$

Substituting (14) and (30) in (12), we can obtain a lower bound on the OP for VAF relaying as

$$F_{\gamma_{SC}}(\gamma_{th}) > F_{\gamma_{SD}}(\gamma_{th}) F_{\gamma_{upp}}(\gamma_{th}) \tag{31}$$

where γ_{th} is a given threshold.

4. Numerical Results

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

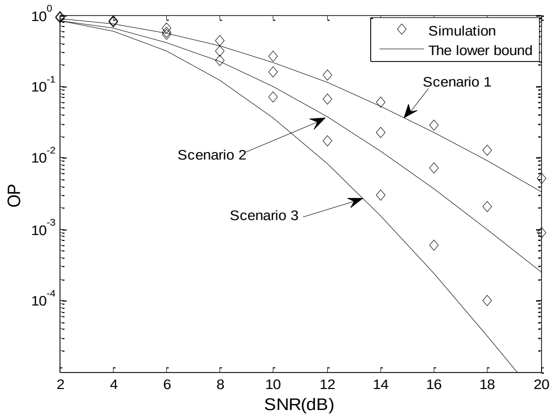

Figure 1. The OP Performance Over N-Nakagami Fading Channels

Figure 1 presents the OP performance of the VAF relaying M2M networks over N-Nakagami fading channels. The relative geometrical gain μ=0dB. The power-allocation parameter K=0.5. The given threshold γ_{th}=4dB. 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_{SD} = 2, m_{SR} = 1, m_{RD} =1 and N_{SD} =N_{SR} = N_{RD} =2.

(2)Scenario 2 : m_{SD} = 2, m_{SR} = 2, m_{RD} =2 and N_{SD} =N_{SR} = N_{RD} =2.

(3)Scenario 3 : m_{SD} = 3, m_{SR} = 3, m_{RD} =3 and N_{SD} =N_{SR} = N_{RD} =2.

From Figure.1,we can obtain that, the simulation results coincide with the theoretical results well， and the accuracy of the analytical results is verified. With the SNR increased, the difference between the analytical results and simulation results is reduced gradually. For VAF relaying, the OP performance is improved with the SNR increased. For example, in scenario 2, when SNR=12dB, the OP is 4×10^{-2}, SNR=14dB, the OP is 1.1×10^{-2}.

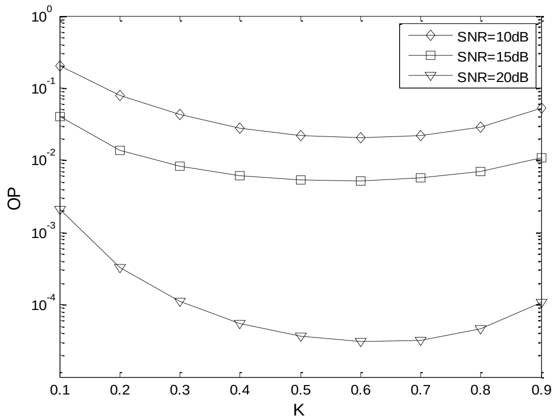

Figure 2. The Effect of the Power-Allocation Parameter K on the OP Performance

Figure 2 presents the effect of the power-allocation parameter K on the OP performance of the VAF relaying M2M 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}=4dB. The OP performance is improved with the SNR increased. For example, when K=0.6, SNR=10dB, the OP is 2×10^{-2}, SNR=15dB, the OP is 5×10^{-3}, SNR=20dB, the OP is 3×10^{-5}. For VAF relaying, when SNR=10dB, the optimum value of K is 0.6 approximately; SNR=15dB, the optimum value of K is 0.5 approximately; SNR=20dB, the optimum value of K is 0.6 approximately.

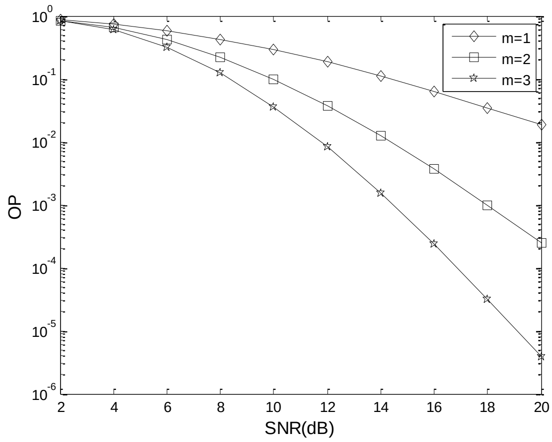

Figure 3. The Effect of the Fading Coefficient m on the OP Performance

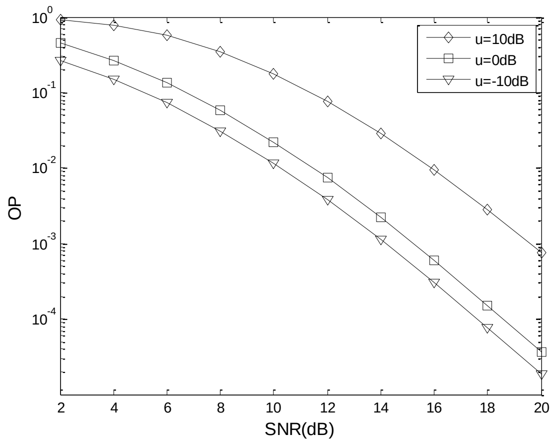

Figure 4. The Effect of the Relative Geometrical Gain μ on the OP Performance

Figure 3 presents the effect of the fading coefficient m on the OP performance of the VAF relaying M2M 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}=4dB.The power-allocation parameter K=0.5.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 1×10^{-1}, m=2, the OP is 2×10^{-2}, m=3, the OP is 1.5×10^{-3}. When the m is fixed, with the increase of SNR, the OP is reduced gradually.

Figure.4 presents the effect of the relative geometrical gain μ on the OP performance of the VAF relaying M2M 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}=4dB.The power-allocation parameter K=0.5. The OP performance is improved as μ reduced. For example, when SNR=12dB, μ=10dB, the OP is 7×10^{-2}, μ=0dB, the OP is 7×10^{-3}, μ=-10dB, the OP is 4×10^{-3}. When the μ is fixed, with the increase of SNR, the OP is reduced gradually.

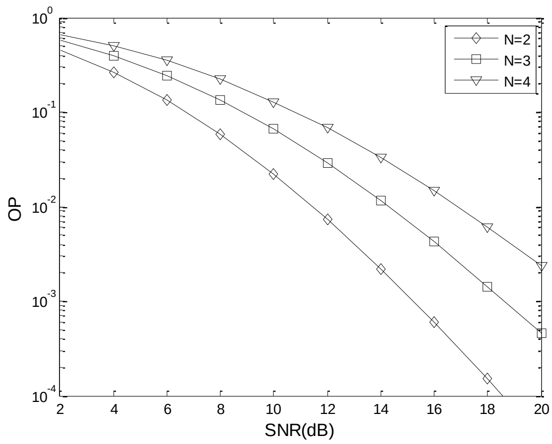

Figure 5. The Effect of the Number of Cascaded Components N on the OP Performance

Figure.5 presents the effect of the number of cascaded components N on the OP performance of the VAF relaying M2M 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}=4dB. The power-allocation parameter K=0.5. The OP performance is degraded as N increased. For example, when SNR=12dB, N=2, the OP is 7×10^{-3}, N=3, the OP is 3×10^{-2}, N=4, the OP is 7×10^{-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 lower bound on OP for the VAF relaying M2M networks over N-Nakagami fading channels is investigated 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 M2M networks.

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