Relay Selection in the FAF Relaying M2M Cooperative Systems

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Abstract: The approximate average symbol error probability (ASEP) and outage probability (OP) of the multiple-mobile-relay-based mobile-to-mobile (M2M) cooperative systems with fixed-gain amplify-and-forward (FAF) relaying and relay selection over *N*-Nakagami fading channels is investigated in this paper. The cumulative density function (CDF) of the signal-to-noise ratio (SNR) is used to derive the exact ASEP expressions for various modulations. Exact closed-form expressions for OP are also presented. The power allocation problem is formulated for performance optimization. Then the ASEP and OP performance under different conditions is evaluated through numerical simulations to verify the analysis. The simulation results showed that the number of mobile relay nodes, the fading coefficient, the number of cascaded components, the relative geometrical gain, and the power-allocation parameter have an important influence on the ASEP and OP performance.

Key-Words: M2M communications; *N*-Nakagami fading channels; cumulative density function; average symbol error probability; outage probability; relay selection

1 Introduction

Mobile-to-mobile (M2M) communication has attracted wide research interest in recent years. It is widely employed in wireless communication systems, such as mobile ad-hoc and vehicle-to-vehicle networks [1]. The classical Rayleigh, Rician, or Nakagami fading channels have been found not to be applicable in M2M communication. Experimental results and theoretical analysis demonstrate that cascaded fading distributions provide an accurate statistical model for M2M communication [2,3]. Cascaded Rayleigh (also named as *N*-Rayleigh) fading channel is presented in [4]. For $N = 2$, this reduces to double-Rayleigh fading model in [5]. Moreover, this model has been extended to *N*-Nakagami fading model in [6]. For $N = 2$, this reduces to double-Nakagami fading model in [7].

Cooperative diversity has been recently proposed as an efficient solution to many challenging physical-layer problems in M2M communication field. Using amplify-and-forward (AF) relaying scheme, [8] investigated pairwise error probability (PEP) for the cooperative inter-vehicular communication (IVC) system over double-Nakagami fading channels. In [9], by moment generating function (MGF) approach, the authors derived the approximate average symbol error probability (ASEP) expressions for fixed-gain AF (FAF) relaying over double-Nakagami fading channels.

Relay selection has emerged as a powerful technique which can promise significant performance improvement in wireless communications without any power increase. Relay selection has been studied extensively in [10-12].

But, few results are focused on the M2M communication field. Based on decode-and-forward (DF) relaying scheme, [13] investigated the outage probability (OP) performance of a relay selection scheme for cooperative vehicular networks over double-Rayleigh fading channels. However, the direct transmission link between the source and destination was ignored.

To the best knowledge of the author, the ASEP and OP performance of multiple-mobile-relay-based FAF relaying M2M cooperative systems with relay selection over N-Nakagami fading channels has not been investigated in the literature. A single-relay scenario is investigated in [8]. The multiple-mobile-relay-based dual-hop M2M model is investigated in [9], but only the approximate ASEP without relay selection over double-Nakagami fading channels is derived. Most results on the performance employ the MGF method, while the cumulative density function (CDF) of the signal-to-noise ratio (SNR) is largely ignored. Moreover, most of results in above literatures do not consider the power allocation. Motivated by all of the above, we extend our analysis for multiple-mobile-relay-based M2M cooperative model with relay selection over N-Nakagami fading channels. In this paper, the main contributions of this work are as follows:

1. Simple closed-form expressions are provided for the probability density function (PDF) and CDF of SNR over N-Nakagami fading channels. These are used to derive closed-form expressions for ASEP and OP.
2. A power allocation 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 fading coefficient, number of cascaded components, relative geometrical gain, power-allocation parameter, and number of mobile relays have a significant influence on the ASEP and OP performance.

The rest of the paper is organized as follows. The multiple-mobile-relay-based M2M cooperative system model is presented in Section 2. Section 3 provides the exact closed-form expressions for OP, The approximate ASEP for several modulations is presented in Section 4. Section 5 conducts Monte Carlo simulations to verify the analytical results. Concluding remarks are given in Section 6.

2 The System Model

We consider a multiple-mobile-relay-based M2M cooperative model, namely a single mobile source (MS) node, L mobile relay (MR) nodes, and a single mobile destination (MD) node, as depicted in Fig. 1. The nodes operate in half-duplex mode, which are equipped with a single pair of transmitter and receiver antennas.

Using the approach in [8], the relative gain of the MS to MD link is G_{SD}=1, the relative gain of the MS to MR$_l$ link is $G_{SRl}=(d_{SD}/d_{SRl})^v$, and the relative gain of the MR$_l$ to MD link is $G_{RDl}=(d_{SD}/d_{RDl})^v$, where v is the path loss coefficient, and d_{SD}, d_{SRl}, and d_{RDl} represent the distances of the MS to MD, MS to MR$_l$, and MR$_l$ to MD links, respectively [9]. The relative geometrical gain $\mu_l=G_{SRl}/G_{RDl}$ indicates the location of the lth relay with respect to the MS and MD. When the lth relay has the same distance to the MS and MD, μ_l is 1 (0 dB). When the lth relay is closer to the MD, μ_l is negative, and when the lth relay is closer to the MS, μ_l is positive.

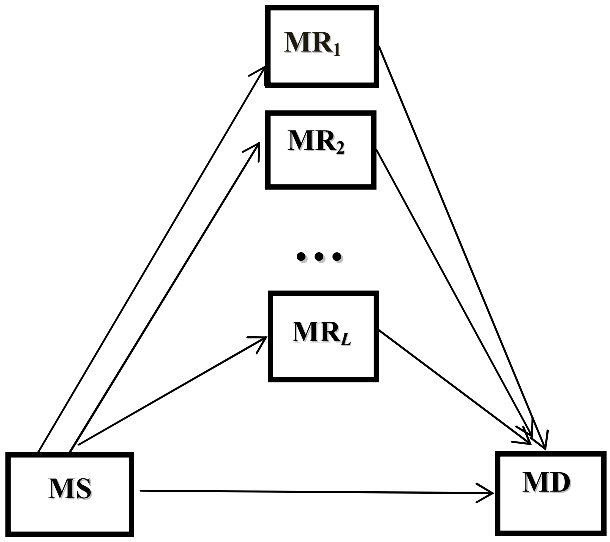

Fig. 1 The system model

Let $h=h_k$, $k\in\{$SD, SRl, RD$l\}$, represent the complex channel coefficients of MS→MD, MS→MR$_l$, and MR$_l$→MD links, respectively, which follow N-Nakagami distribution. h is assumed to be a product of statistically independent, but not necessarily identically distributed, N independent random variables[6]

$$h=\prod_{i=1}^{N} a_i \quad (1)$$

where a_i is a Nakagami distributed random variable with PDF

$$f_a(r)=\frac{2m^m}{\Omega^m\Gamma(m)}r^{2m-1}\exp(-\frac{m}{\Omega}r^2) \quad (2)$$

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[6]

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

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

Let $y=|h_k|^2$, $k\in\{\text{SD, SR}l\text{, RD}l\}$, namely, $y_{SD}=|h_{SD}|^2$, $y_{SRl}=|h_{SRl}|^2$, and $y_{RDl}=|h_{RDl}|^2$. The corresponding CDF of y can be derived as[6]

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

By taking the first derivative of (4) with respect to y, the corresponding PDF can be obtained as [6]

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

Based on the AF cooperation protocol, the received signals r_{SD} and r_{SRl} at the MD and MR_l during the first time slot can be written as[9]

$$r_{SD}=\sqrt{KE}h_{SD}x+n_{SD} \quad (6)$$

$$r_{SRl}=\sqrt{G_{SRl}KE}h_{SRl}x+n_{SRl} \quad (7)$$

where x denotes the transmitted signal, n_{SRl} and n_{SD} are the zero-mean complex Gaussian random variables with variance $N_0/2$ per dimension. During two time slots, the total energy used by the MS and MR_l is E. K is the power-allocation parameter which indicates the fraction of power used by the MS.

During the second time slot, only the best MR amplifies and forwards the signal to the MD. The best MR is selected based on the following criterion

$$\gamma_{R^*}=\max_{1\le l\le L}(\gamma_l) \quad (8)$$

where

$$\gamma_l=\frac{\gamma_{SRl}\gamma_{RDl}}{1+\overline{\gamma_{SRl}}+\gamma_{RDl}} \quad (9)$$

$$\gamma_{SRl}=\frac{KG_{SRl}|h_{SRl}|^2E}{N_0}=KG_{SRl}|h_{SRl}|^2\bar{\gamma} \quad (10)$$

$$\gamma_{RDl}=\frac{(1-K)G_{RDl}|h_{RDl}|^2E}{N_0}=(1-K)G_{RDl}|h_{RDl}|^2\bar{\gamma} \quad (11)$$

$$\overline{\gamma_{SRl}}=KG_{SRl}E/N_0=KG_{SRl}\bar{\gamma} \quad (12)$$

The received signal at the MD is therefore given by

$$r_{R^*D}=\sqrt{cE}h_{SR^*}h_{R^*D}x+n_{DD} \quad (13)$$

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

For FAF relaying, c is given as[9]

$$c=\frac{K(1-K)G_{SR^*}G_{R^*D}E/N_0}{1+KG_{SR^*}E/N_0+(1-K)G_{R^*D}|h_{R^*D}|^2E/N_0} \quad (14)$$

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

$$\gamma_{SC}=\max(\gamma_{SD},\gamma_{SRD}) \quad (15)$$

where

$$\gamma_{SD}=\frac{K|h_{SD}|^2E}{N_0}=K|h_{SD}|^2\bar{\gamma} \quad (16)$$

$$\gamma_{SRD}=\frac{\gamma_{SR^*}\gamma_{R^*D}}{1+\overline{\gamma_{SR^*}}+\gamma_{R^*D}}=\max_{1\le l\le L}(\gamma_l) \quad (17)$$

As far as we know, a convenient mathematical method to obtain the PDF and CDF of γ_{SRD} exactly is still unachievable. Here, we adopt the method in [9] to obtain an approximate γ_{SRD}, which is given as

$$\gamma_{SRDA}=\frac{\gamma_{SR^*}\gamma_{R^*D}}{1+\overline{\gamma_{SR^*}}+\overline{\gamma_{R^*D}}} \quad (18)$$

where

$$\overline{\gamma_{R^*D}}=(1-K)G_{R^*D}\bar{\gamma} \quad (19)$$

3 The Approximate OP

Here, we present new closed-form expressions for the PDF and CDF of γ_{SRDA} as

$$f_{\gamma_{SRDA}}(r)=\prod_{l=1}^{L}\frac{1}{r\prod_{j=1}^{N}\Gamma(m_j)\prod_{jj=1}^{N}\Gamma(m_{jj})}\times G_{0,2N}^{2N,0}\left[\frac{r}{\overline{\chi_l}}\prod_{j=1}^{N}\frac{m_j}{\Omega_j}\prod_{jj=1}^{N}\frac{m_{jj}}{\Omega_{jj}}\Big|_{m_1,\ldots,m_{2N}}^{-}\right] \quad (20)$$

$$F_{\gamma_{SRDA}}(r)=\prod_{l=1}^{L}\frac{1}{\prod_{j=1}^{N}\Gamma(m_j)\prod_{jj=1}^{N}\Gamma(m_{jj})}\times G_{1,2N+1}^{2N,1}\left[\frac{r}{\overline{\chi_l}}\prod_{j=1}^{N}\frac{m_j}{\Omega_j}\prod_{jj=1}^{N}\frac{m_{jj}}{\Omega_{jj}}\Big|_{m_1,\ldots,m_{2N},0}^{1}\right] \quad (21)$$

where

$$\overline{\chi_l}=\frac{\overline{\gamma_{SRl}\gamma_{RDl}}}{1+\overline{\gamma_{SRl}}+\overline{\gamma_{RDl}}} \quad (22)$$

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

The CDF of γ_{SD} can be given as[6]

$$F_{\gamma_{SD}}(r)=\frac{1}{\prod_{i=1}^{N}\Gamma(m_i)}G_{1,N+1}^{N,1}\left[\frac{r}{\overline{\gamma_{SD}}}\prod_{i=1}^{N}\frac{m_i}{\Omega_i}\Big|_{m_1,\ldots,m_N,0}^{1}\right] \quad (24)$$

where

$$\overline{\gamma_{SD}}=K\overline{\gamma} \quad (25)$$

The CDF of γ_{SCA} can be given as

$$F_{\gamma_{SCA}}(r)=F_{\gamma_{SD}}(r)F_{\gamma_{SRDA}}(r) \quad (26)$$

The approximate OP for FAF relaying is given as

$$F_{\gamma_{SCA}}(r_{th})=F_{\gamma_{SD}}(r_{th})F_{\gamma_{SRDA}}(r_{th}) \quad (27)$$

where r_{th} is the threshold for correct detection at MD.

4 The Approximate ASEP

The approximate ASEP is given as[15]

$$P=\frac{a\sqrt{b}}{2\sqrt{\pi}}\int_0^{\infty}\frac{\exp(-br)}{\sqrt{r}}F_{\gamma_{SCA}}(r)dr \quad (28)$$

where a and b are the parameters determined by modulation type. For instance, for q-ary PAM modulation, $a=2(q-1)/q$, $b=3/(q^2-1)$;for q-ary PSK modulation, $a=2$, $b=\sin^2(\pi/q)$.

Substituting (26) into (28), the exact expression for the approximate ASEP is given as

$$P=\frac{a\sqrt{b}}{2\sqrt{\pi}}G \quad (29)$$

where

$$G=\int_0^{\infty}\frac{1}{\sqrt{r}}G_{0,1}^{1,0}\left[br\Big|_{0}^{-}\right]G_{1,N+1}^{N,1}\left[\frac{r}{\overline{\gamma_{SD}}}\prod_{i=1}^{N}\frac{m_i}{\Omega_i}\Big|_{m_1,\ldots,m_N,0}^{1}\right]\times\prod_{l=1}^{L}G_{1,2N+1}^{2N,1}\left[\frac{r}{\overline{\gamma_l}}\prod_{j=1}^{N}\frac{m_j}{\Omega_j}\prod_{jj=1}^{N}\frac{m_{jj}}{\Omega_{jj}}\Big|_{m_1,\ldots,m_{2N},0}^{1}\right]dr \quad (30)$$

5 Numerical Results

In this section, Monte-Carlo simulation is used to confirm the analysis in the previous section. All of the computations were done using MATLAB and some of the integrals were verified using MAPLE. The MS to MD, MS to MR_l, and MR_l to MD links are modeled using the N-Nakagami distribution. The total energy available for transmission is $E=1$. The fading coefficient is $m=1,2,3$, the number of cascaded components is $N=2,3,4$, the number of mobile relays is $L=1,2,3$, and the relative geometrical gain is $\mu=10$ dB, 0 dB, and −10 dB.

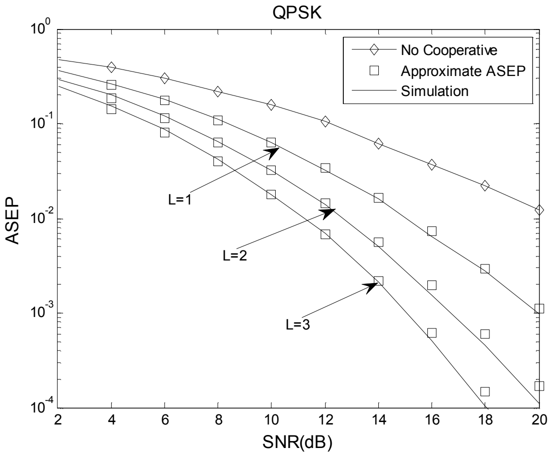

Fig. 2 The ASEP performance over N-Nakagami fading channels with QPSK.

Fig. 2 presents the ASEP performance of the FAF relaying M2M cooperative networks with relay selection over N-Nakagami fading channels. The relative geometrical gain is $\mu=0$dB. The power-allocation parameter is $K=0.5$. The number of cascaded components is $N=2$. The number of mobile relay nodes is $L=1,2,3$. In all cases, the fading coefficients are $m_{SD}=2$, $m_{SR}=2$, $m_{RD}=2$. From Fig.2, it is observed that the numerical simulations results coincide with the theoretical results well, and the accuracy of the analytical approximate ASEP is verified. As expected, there is a direct proportion between the number of the relays L and the ASEP performance. The ASEP performance is improved with the L increased. For example, when SNR=12dB, $L=1$, the ASEP is 3.4×10^{-2}, $L=2$, the ASEP is 1.4×10^{-2}, $L=3$, the ASEP is 6.7×10^{-3}.

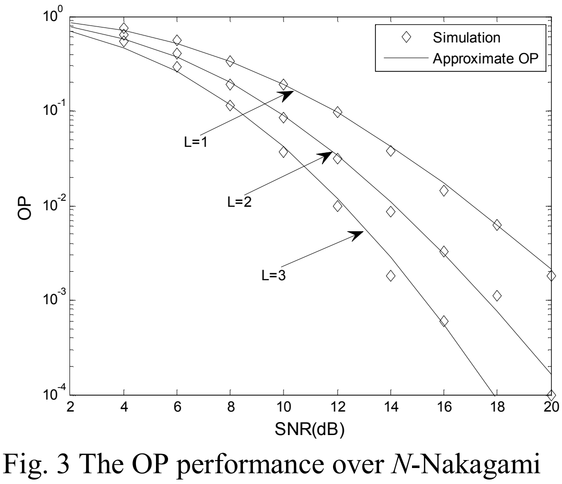

Fig. 3 The OP performance over N-Nakagami fading channels.

Fig. 3 presents the OP performance of the FAF relaying M2M cooperative networks with relay selection over N-Nakagami fading channels. The relative geometrical gain is $\mu=0$dB. The power-allocation parameter is $K=0.5$. The number of cascaded components is $N=2$. The number of mobile relay nodes is L=1,2,3. In all cases, the fading coefficients are m_{SD}=2, m_{SR}=2, m_{RD}=2. From Fig.3, it is observed that the numerical simulations results coincide with the theoretical results well, and the accuracy of the analytical approximate OP is verified. As expected, the OP performance is improved with L increased. For example, when SNR=14dB, L=1, the OP is 4×10^{-2}, L=2, the OP is 1×10^{-2}, L=3, the OP is 3×10^{-3}.

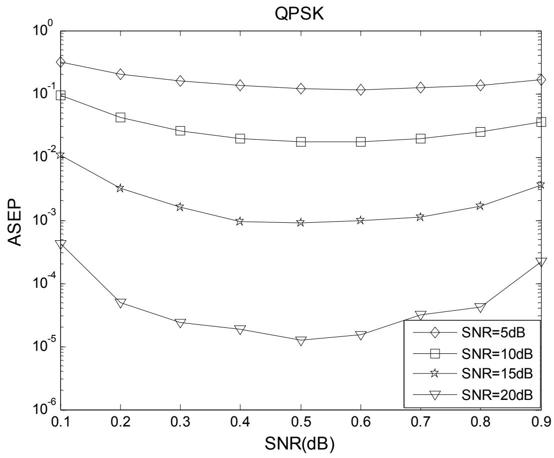

Fig. 4 The effect of the power-allocation parameter K on the ASEP performance.

Fig. 4 presents the effect of the power-allocation parameter K on the ASEP performance with various values of SNR. The number of cascaded components is N=2. The fading coefficient is m=2. The relative geometrical gain is μ=0dB. The number of mobile relay nodes is L=3.Simulation results show that the ASEP performance is improved with the SNR increased. For example, when K=0.8, SNR=5dB, the ASEP is 1.3×10^{-1}, SNR=10dB, the ASEP is 2.4×10^{-2}, SNR=15dB, the ASEP is 1.8×10^{-3}, SNR=20dB, the ASEP is 4.87×10^{-5}. For the different values of SNR, the optimum value of K is different. For example, when SNR=5dB, the optimum value of K is 0.62; SNR=10dB, the optimum value of K is 0.50; SNR=15dB, the optimum value of K is 0.53; SNR=20dB, the optimum value of K is 0.50. This indicates that the equal power allocation (EPA) scheme is not the best scheme.

Fig.5 presents the effect of the fading coefficient m on the ASEP performance. The number of cascaded components is N=2.The fading coefficient is m=1,2,3. The relative geometrical gain is μ=0dB. The number of mobile relay nodes is L=3.The power-allocation parameter is K=0.4.Simulation results show that the ASEP performance is improved with the fading coefficient m increased. For example, when SNR=12dB, m=1, the ASEP is 2.8×10^{-2}, m=2, the ASEP is 6.3×10^{-3}, m=3, the ASEP is 2.8×10^{-3}. This is because the fading severity of the N-Nakagami channels weakens as m is increased. When the m is fixed, with the increase of SNR, the ASEP is reduced gradually.

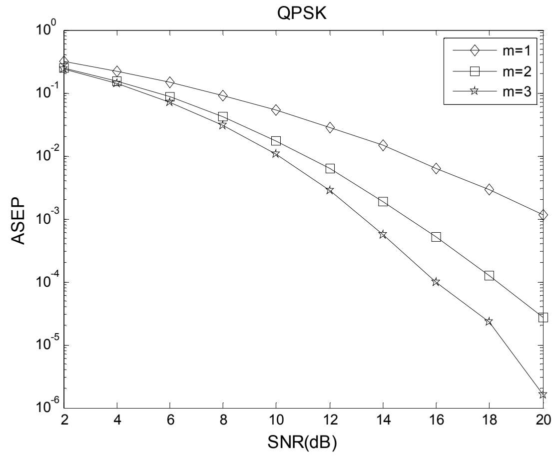

Fig. 5 The effect of the fading coefficient m on the ASEP performance.

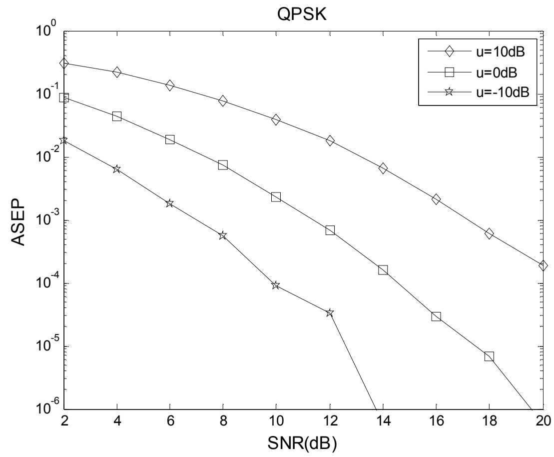

Fig. 6 The effect of the relative geometrical gain μ on the ASEP performance.

Fig.6 presents the effect of the relative geometrical gain μ on the ASEP performance. The number of cascaded components is N=2. The fading coefficient is m=2. The relative geometrical gain is μ=10 dB, 0 dB,−10 dB. The power-allocation parameter is K=0.6. The number of mobile relay nodes is L=3.Simulation results show that the ASEP performance is improved as μ reduced. For example, when SNR=10dB, μ=10dB, the ASEP is 3.8×10^{-2}, μ=0dB, the ASEP is 2.3×10^{-3}, μ=−10dB, the ASEP is 8.9×10^{-5}. This indicates that the best location of the relay should near the destination. When the μ is fixed, with the increase of SNR, the ASEP is reduced gradually.

Fig.7 presents the effect of the number of cascaded components N on the ASEP performance. The number of cascaded components is N=2,3,4.

The fading coefficient is m=2. The relative geometrical gain is μ=−5dB. The power-allocation parameter is K=0.4. The number of mobile relay nodes is L=3.Simulation results show that the ASEP performance is degraded as N increased. For example, when SNR=14dB, N=2, the ASEP is 2×10^{-3}, N=3, the ASEP is 6×10^{-3}, N=4, the ASEP is 1.5×10^{-2}.This is because the fading severity of the cascaded channels increases as N is increased. When the N is fixed, with the increase of SNR, the ASEP is reduced gradually.

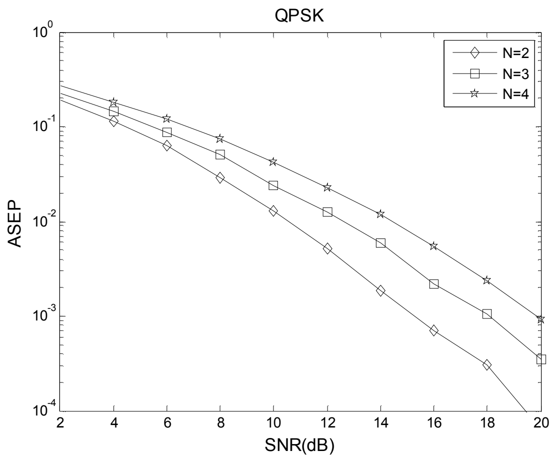

Fig 7. The effect of the number of cascaded components N on the ASEP performance

6 Conclusion

The approximate ASEP and OP of the FAF relaying M2M cooperative systems with relay selection over N-Nakagami fading channels is investigated in this paper. The simulation results showed that the number of mobile relay nodes L, 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 ASEP and OP performance. The expressions derived here can be used to evaluate the performance of vehicular communication systems employed in inter-vehicular, intelligent highway and mobile ad-hoc applications. In the future, we will consider the impact of the correlated channels on the ASEP and OP performance.

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