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Research Article

Cache Aided Decode-and-Forward Relaying Networks: From the Spatial View

Junjuan Xia,[1] Fasheng Zhou,[2] Xiazhi Lai,[1] Haochuan Zhang,[3] Hongbin Chen,[4] Qinghai Yang,[5] Xin Liu,[6] and Junhui Zhao[7]

[1]*School of Computer Science and Educational Software, Guangzhou University, Guangzhou, China*
[2]*School of Physics and Electronic Engineering, Guangzhou University, Guangzhou, China*
[3]*Guangdong University of Technology, Guangdong, China*
[4]*Key Laboratory of Cognitive Radio and Information Processing, Guilin University of Electronic Technology, Guilin, China*
[5]*State Key Laboratory on ISN, School of Telecommunications Engineering, Xidian University, Xi'an 710071, China*
[6]*School of Information and Communication Engineering, Dalian University of Technology, Dalian, China*
[7]*School of Information Engineering, East China Jiaotong University, Nanchang, China*

Correspondence should be addressed to Fasheng Zhou; zhoufs@gzhu.edu.cn

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We investigate cache technique from the spatial view and study its impact on the relaying networks. In particular, we consider a dual-hop relaying network, where decode-and-forward (DF) relays can assist the data transmission from the source to the destination. In addition to the traditional dual-hop relaying, we also consider the cache from the spatial view, where the source can prestore the data among the memories of the nodes around the destination. For the DF relaying networks without and with cache, we study the system performance by deriving the analytical expressions of outage probability and symbol error rate (SER). We also derive the asymptotic outage probability and SER in the high regime of transmit power, from which we find the system diversity order can be rapidly increased by using cache and the system performance can be significantly improved. Simulation and numerical results are demonstrated to verify the proposed studies and find that the system power resources can be efficiently saved by using cache technique.

1. Introduction

With the rapid progress in wireless big data, a lot of wireless techniques have been proposed to enhance the transmission quality and reliability [1–10]. Cooperative relaying, such as amplify-and-forward (AF) and decode-and-forward (DF) relaying protocols, is an effective means to enhance network reliability as well as security [11, 12], extend coverage region [13, 14], and reduce the impact of interference [15–17]. Therefore, cooperative relaying is a significant technique in the current and future generations wireless networks, and the research on relaying networks has been active. The outage performance of multirelay networks was studied in [18, 19], and the exact outage probabilities were derived. In [20], the authors turned to investigate the performance of relaying networks in terms of symbol error rate (SER). In [21, 22], the performance of relaying networks in the high signal-to-noise ratio (SNR) regime was analyzed and the diversity order was revealed.

To improve the transmission performance relaying networks, cache technique has been proposed to enhance the user experience quality and reduce the latency. In particular, the authors in [23] studied the fundamental limits of caching and found an information-theoretic formulation of the caching problem by focusing on its basic structure. Then the authors in [24] applied the coding technique into cache and studied the fundamental limits by proposing an improved delivery rate-cache capacity tradeoff. Further, the authors in [25] investigated content-centric sparse multicast beamforming for cache-enabled cloud RAN and revealed

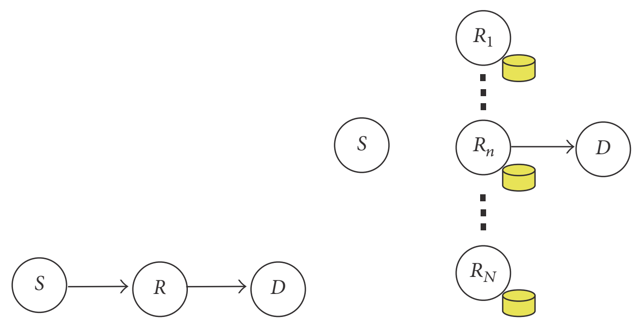

Figure 1: Decode-and-forward relaying networks.

that caching strategy had a significant impact on the system performance. The application of cache into relaying networks has been studied in [26], where optimization of hybrid cache placement for collaborative relaying was investigated. In this paper, the signal transmission cooperation gain and content delivery diversity were achieved to enhance the system transmission performance. There are some other works on the application of cache in network security to ensure the secure information transmission [27–30]. However, to the best of the authors' knowledge, there has been little work on the spatial view of cache on performance improvement of the relaying networks.

In this work, we study the spatial view of cache on the DF relaying networks, where the source communicates with the destination with several DF relays. If the cache is used, the source can prestore the data among the nodes around the destination. In this way, the destination can directly access the data from the nearby nodes, instead of having to communicate with the source. For the traditional dual-hop relaying and the DF relaying assisted by the cache, we study the system transmission performance by deriving the analytical expression of outage probability and SER. We also provide the asymptotic expressions of outage probability and SER in the high region of transmit power, from which we find that the cache can efficiently improve the system performance by increasing the transmission diversity order. Numerical and simulation results are demonstrated to verify the proposed studies in this paper.

Notations 1. We use $\mathscr{CN}(0,\sigma^2)$ to represent a circularly symmetric complex Gaussian random variable (RV) with zero mean and variance σ^2. We use $f_X(\cdot)$ and $F_X(\cdot)$ to represent the probability density function (PDF) and cumulative density function (CDF) of the random variable (RV) X, respectively. In addition, the notation $X \sim \text{Naka}(m,\alpha)$ represents that the random variable X is subject to Nakagami-m distribution, where the PDF of variable of $Y = |X|^2$ is $f_Y(y) = (m^m y^{m-1}/\alpha^m\Gamma(m))e^{-my/\alpha}$. We use $\Pr[\cdot]$ to denote probability.

2. System Model

Figure 1(a) shows the traditional dual-hop relaying networks without cache, where a single decode-and-forward relay node R assists the two-phase data transmission from the source S to the destination D. In contrast, Figure 1(b) demonstrates the cache aided dual-hop relaying networks, where the data can be prestored at N nodes $\{R_n \mid 1 \le n \le N\}$ (the relays can obtain the data from the source during nonpeak time, and these relays can work in either the cooperative or noncooperative ways [31]) around the destination D. Then the data can be directly transmitted from the relays to the destination, instead of through the traditional dual-hop relaying links. Due to the size limitation, each node has a single antenna only [32–35], and we assume that each node operates in a time-division half-duplex mode [36–39]. In the following, we describe the data transmission for the relaying networks without and with cache, respectively.

For the traditional data transmission without cache as shown in Figure 1(a), let $h_{SR} \sim \text{Naka}(m_1,\alpha)$ and $h_{RD} \sim \text{Naka}(m_2,\beta)$ denote the channel parameter of the S-R and R-D links, respectively. In the first phase, the source S sends the normalized signal s to the relay, and then the relay receives

$$y_R = \sqrt{P}h_{SR}s + n_R, \tag{1}$$

where P is the transmit power of the source and $n_R \sim \mathscr{CN}(0,\sigma^2)$ is the additive white noise at the relay. If the relay R can correctly decode the signal from the source, it will forward the signal to the destination in the second phase, and accordingly the destination D receives

$$y_D = \sqrt{P}h_{RD}s + n_D, \tag{2}$$

where $n_D \sim \mathscr{CN}(0,\sigma^2)$ is the additive white noise at the destination. From (1)-(2), we can obtain the received end-to-end SNR at the destination D as

$$\text{SNR}_D = \frac{P}{\sigma^2}\min(u,v), \tag{3}$$

where $u = |h_{SR}|^2$ and $v = |h_{RD}|^2$ denote the channel gains of the first and second hops, respectively.

For the cache aided DF relaying networks demonstrated in Figure 1(b), the source data can be firstly prestored at the N relay nodes around the destination, and then the data transmission can be directly performed from the relays to the destination, instead of through the traditional two-hop relaying links. Specifically, when the nth relay R_n is used for data transmission, the received signal at the destination D is given by

$$y_D = \sqrt{P} h_{R_n,D} s + n_D, \tag{4}$$

where $h_{R_n,D} \sim \text{Naka}(m_2, \beta)$ is the channel parameter of the second-hop relaying links associated with the nth relay. Accordingly, the received end-to-end SNR at the destination D is given by

$$\text{SNR}_D = \frac{P}{\sigma^2} v_n, \tag{5}$$

where $v_n = |h_{R_n,D}|^2$ is the instantaneous channel gain of the R_n-D link. Among these N relays, one best relay R_{n^*} can be selected to assist the data transmission, and the selection criterion is given by

$$n^* = \arg\max_{1 \le n \le N} v_n. \tag{6}$$

3. Performance Evaluation

3.1. Outage Probability. In this part, we investigate the data transmission performance by deriving the analytical expression of outage probability as well as the asymptotic expression with high transmit power. Let $P_{\text{out}}^{\text{wo}}$ and $P_{\text{out}}^{\text{w}}$ denote the outage probability of the DF relaying networks without and with cache assistant, respectively.

3.1.1. Without Cache. For the traditional dual-hop relaying networks without cache, the outage event occurs when the transmission data rate is below a target data rate R_t [40, 41],

$$\frac{1}{2}\log_2\left(1 + \text{SNR}_D\right) < R_t, \tag{7}$$

where the term 1/2 comes from the two-phase data transmission. This equation is equivalent to

$$\text{SNR}_D < \gamma_{1t}, \tag{8}$$

where $\gamma_{1t} = 2^{2R_t} - 1$ is the SNR threshold without cache. Accordingly, we can write the system outage probability $P_{\text{out}}^{\text{wo}}$ as

$$\begin{aligned} P_{\text{out}}^{\text{wo}} &= \Pr\left(\text{SNR}_D < \gamma_{1t}\right) \\ &= \Pr\left(\min(u, v) < \frac{\gamma_{1t}\sigma^2}{P}\right) \\ &= 1 - \Pr\left(\min(u, v) \ge \frac{\gamma_{1t}\sigma^2}{P}\right). \end{aligned} \tag{9}$$

By considering that the variables of u and v are independent of each other, we can rewrite $P_{\text{out}}^{\text{wo}}$ as

$$P_{\text{out}}^{\text{wo}} = 1 - \Pr\left(u \ge \frac{\gamma_{1t}\sigma^2}{P}\right)\Pr\left(v \ge \frac{\gamma_{1t}\sigma^2}{P}\right). \tag{10}$$

By applying the PDFs of $f_u(u) = (m_1^{m_1} u^{m_1-1}/\alpha^{m_1}\Gamma(m_1))e^{-m_1 u/\alpha}$ and $f_v(v) = (m_2^{m_2} v^{m_2-1}/\beta^{m_2}\Gamma(m_2))e^{-m_2 v/\beta}$, we can compute the analytical outage probability of the DF relaying networks without cache as

$$P_{\text{out}}^{\text{wo}} = 1 - \int_{\gamma_{1t}\sigma^2/P}^{\infty} \frac{m_1^{m_1} u^{m_1-1}}{\alpha^{m_1}\Gamma(m_1)} e^{-m_1 u/\alpha} du \times \int_{\gamma_{1t}\sigma^2/P}^{\infty} \frac{m_2^{m_2} v^{m_2-1}}{\beta^{m_2}\Gamma(m_2)} e^{-m_2 v/\beta} dv \tag{11}$$

$$= 1 - e^{-(\gamma_{1t}\sigma^2/P)(m_1/\alpha + m_2/\beta)} \sum_{k_1=0}^{m_1-1}\sum_{k_2=0}^{m_2-1} \frac{1}{k_1! k_2!} \times \left(\frac{m_1\gamma_{1t}\sigma^2}{P\alpha}\right)^{k_1}\left(\frac{m_2\gamma_{1t}\sigma^2}{P\beta}\right)^{k_2}, \tag{12}$$

where [42, eq. (3.351.2)] is applied in the last equality. The analytical outage probability in the above equation contains elementary functions only, and hence it is easy to be evaluated.

To obtain more insights on the system, we propose to derive the asymptotic expression of outage probability for the DF relaying networks without cache, in the high transmit power regime. Since the approximation of $e^x \simeq \sum_{n=0}^{N}(x^n/n!)$ holds for small value of $|x|$ [42], we apply this approximation in (12) and can obtain the asymptotic outage probability of the DF relaying networks without cache as

$$P_{\text{out}}^{\text{wo}} \simeq \frac{m_1^{m_1-1}}{\Gamma(m_1)}\left(\frac{\gamma_{1t}\sigma^2}{P\alpha}\right)^{m_1} + \frac{m_2^{m_2-1}}{\Gamma(m_2)}\left(\frac{\gamma_{1t}\sigma^2}{P\beta}\right)^{m_2}. \tag{13}$$

By considering the relationship between m_1 and m_2, we can further specify the asymptotic outage probability as

$$P_{\text{out}}^{\text{wo}} \simeq \begin{cases} \dfrac{m_1^{m_1-1}}{\Gamma(m_1)}\left(\dfrac{\gamma_{1t}\sigma^2}{P\alpha}\right)^{m_1}, & \text{If } m_1 < m_2 \\ \dfrac{m_1^{m_1-1}}{\Gamma(m_1)}\left(\dfrac{\gamma_{1t}\sigma^2}{P\alpha}\right)^{m_1} + \dfrac{m_2^{m_2-1}}{\Gamma(m_2)}\left(\dfrac{\gamma_{1t}\sigma^2}{P\beta}\right)^{m_2}, & \text{If } m_1 = m_2 \\ \dfrac{m_2^{m_2-1}}{\Gamma(m_2)}\left(\dfrac{\gamma_{1t}\sigma^2}{P\beta}\right)^{m_2}, & \text{If } m_1 > m_2. \end{cases} \tag{14}$$

From this asymptotic expression, we can find that the weaker hop between the dual hops becomes the bottleneck of the system whole transmission, and the system diversity order is equal to $\min(m_1, m_2)$. In particular, if the first hop is weaker with $m_1 < m_2$, the first hop regulates the system transmission performance and the diversity order is m_1; if the second hop is weaker with $m_2 < m_1$, the second hop becomes the bottleneck of the system whole transmission and the diversity order is m_2.

3.1.2. With Cache. For the cache aided DF relaying networks, the destination can directly access the data from the relays, and the outage event occurs when the n^*th relay is selected to assist the data transmission,

$$\log_2(1+\mathrm{SNR}_D) < R_t, \tag{15}$$

which is equivalent to

$$\mathrm{SNR}_D < \gamma_{2t}, \tag{16}$$

where $\gamma_{2t} = 2^{R_t} - 1$ is the SNR threshold with cache. From this expression, we can write the system outage probability as

$$\begin{aligned} P_{\text{out}}^{\text{w}} &= \Pr(\mathrm{SNR}_D < \gamma_{2t}) \\ &= \Pr\left(\nu_1 < \frac{\gamma_{2t}\sigma^2}{P}, \dots, \nu_N < \frac{\gamma_{2t}\sigma^2}{P}\right). \end{aligned} \tag{17}$$

By considering that ν_n values are independent of each other and are identically distributed, we can further write $P_{\text{out}}^{\text{w}}$ as

$$P_{\text{out}}^{\text{w}} = \Bigg[\underbrace{\Pr\left(\nu_1 < \frac{\gamma_{2t}\sigma^2}{P}\right)}_{I}\Bigg]^N. \tag{18}$$

To compute the probability I, we apply the PDF of $f_{\nu_1}(\nu) = (m_2^{m_2}\nu^{m_2-1}/\beta^{m_2}\Gamma(m_2))e^{-m_2\nu/\beta}$ as

$$\begin{aligned} I &= \int_0^{\gamma_{2t}\sigma^2/P} \frac{m_2^{m_2}\nu^{m_2-1}}{\beta^{m_2}\Gamma(m_2)} e^{-m_2\nu/\beta} d\nu \\ &= 1 - e^{-m_2\gamma_{2t}\sigma^2/P\beta} \sum_{k=0}^{m_2-1} \frac{1}{k!}\left(\frac{m_2\gamma_{2t}\sigma^2}{P\beta}\right)^k. \end{aligned} \tag{19}$$

Accordingly, we obtain the analytical expression of outage probability for the cache aided DF relaying networks as

$$P_{\text{out}}^{\text{w}} = \left(1 - e^{-m_2\gamma_{2t}\sigma^2/P\beta} \sum_{k=0}^{m_2-1} \frac{1}{k!}\left(\frac{m_2\gamma_{2t}\sigma^2}{P\beta}\right)^k\right)^N. \tag{20}$$

Note that the above equation includes some elementary functions only and is also easy to be evaluated.

We now derive the asymptotic outage probability for the considered system, to obtain more insights on the system design. By applying the approximation of $e^x \simeq \sum_{n=0}^{N}(x^n/n!)$ into I, we can simplify the expression of I as

$$I \simeq \frac{m_2^{m_2-1}}{\Gamma(m_2)}\left(\frac{\gamma_{2t}\sigma^2}{P\beta}\right)^{m_2}. \tag{21}$$

From the asymptotic I, we can obtain the asymptotic expression of the outage probability for the cache aided DF relaying networks as

$$P_{\text{out}}^{\text{w}} \simeq \left(\frac{m_2^{m_2-1}}{\Gamma(m_2)}\right)^N \left(\frac{\gamma_{2t}\sigma^2}{P\beta}\right)^{m_2 N}. \tag{22}$$

From this equation, we can find that the system diversity order is equal to $m_2 N$, indicating that the system transmission performance can be rapidly improved by increasing the number of cache relays. Moreover, the system performance is not dependent on the first relaying links, as the destination can directly access the data from the relays.

3.2. SER. In this part, we derive the analytical expression of symbol error rate for the DF relaying networks, as well as the asymptotic expression in the high regime of transmit power. We use P_e^{wo} and P_e^{w} to denote the SER of the system without or with cache, respectively. For the linear modulation scheme, the SER can be computed from the expression of outage probability [43]

$$P_e = \frac{1}{\sqrt{2\pi}} \int_0^\infty F_{\mathrm{SNR}_D}\left(\frac{x^2}{\lambda}\right) e^{-x^2/2} dx, \tag{23}$$

where $F_{\mathrm{SNR}_D}(x)$ is the CDF of the received SNR at the destination D, which can be obtained from the analytical expression of outage probability in (12) and (20). And λ is a constant depending on the specific modulation scheme. For example, λ is equal to 2 when the BPSK modulation is used.

3.2.1. Without Cache. For the traditional dual-hop relaying networks without cache, we can write the system SRR as

$$P_e^{\text{wo}} = \frac{1}{\sqrt{2\pi}} \int_0^\infty \left[1 - e^{-(x^2\sigma^2/P\lambda)(m_1/\alpha+m_2/\beta)} \sum_{k_1=0}^{m_1-1}\sum_{k_2=0}^{m_2-1} \frac{1}{k_1!k_2!}\left(\frac{m_1x^2\sigma^2}{P\alpha\lambda}\right)^{k_1}\left(\frac{m_2x^2\sigma^2}{P\beta\lambda}\right)^{k_2}\right] e^{-x^2/2} dx \tag{24}$$

$$\begin{aligned} &= \frac{1}{2} - \sum_{k_1=0}^{m_1-1}\sum_{k_2=0}^{m_2-1} \frac{1}{k_1!k_2!}\left(\frac{m_1\sigma^2}{P\alpha\lambda}\right)^{k_1}\left(\frac{m_2\sigma^2}{P\beta\lambda}\right)^{k_2} \times \frac{1}{\sqrt{2\pi}} \int_0^\infty x^{2(k_1+k_2)} e^{-[1/2+(\sigma^2/P\lambda)(m_1/\alpha+m_2/\beta)]x^2} dx \\ &= \frac{1}{2} - \sum_{k_1=0}^{m_1-1}\sum_{k_2=0}^{m_2-1} \frac{1}{k_1!k_2!}\left(\frac{m_1\sigma^2}{P\alpha\lambda}\right)^{k_1}\left(\frac{m_2\sigma^2}{P\beta\lambda}\right)^{k_2} \times \frac{b_{k_1+k_2}}{[1+(2\sigma^2/P\lambda)(m_1/\alpha+m_2/\beta)]^{k_1+k_2+1/2}}, \end{aligned} \tag{25}$$

where [42, eq. (3.321.3)] and [42, eq. (3.461.2)] are applied and b_n is

$$b_n = \begin{cases} 1, & \text{If } n = 0 \\ (2n-1)!!, & \text{If } n \geq 1. \end{cases} \quad (26)$$

Note that the analytical expression of SER in (25) contains some elementary functions only, and hence we can easily evaluate the system SER for the traditional DF relaying networks without cache aid. The details about the numerical computation can be found in [44–46].

We now propose to derive the asymptotic SER for the traditional DF relaying networks without cache, in the high regime of transmit power P. By combining (13) and (23), we can write the asymptotic SER with high transmit power P as

$$\begin{aligned} P_e^{\text{wo}} &\simeq \frac{1}{\sqrt{2\pi}} \\ &\cdot \int_0^\infty \left[\frac{m_1^{m_1-1}}{\Gamma(m_1)} \left(\frac{x^2\sigma^2}{P\alpha\lambda} \right)^{m_1} + \frac{m_2^{m_2-1}}{\Gamma(m_2)} \left(\frac{x^2\sigma^2}{P\beta\lambda} \right)^{m_2} \right] \\ &\cdot e^{-x^2/2} dx = \frac{m_1^{m_1-1}(2m_1-1)!!}{2\Gamma(m_1)} \frac{1}{(P\alpha\lambda)^{m_1}} \\ &+ \frac{m_2^{m_2-1}(2m_2-1)!!}{2\Gamma(m_2)} \frac{1}{(P\beta\lambda)^{m_2}}, \end{aligned} \quad (27)$$

where [42, eq. (3.461.2)] is used in the last equality. From this asymptotic SER, we can find that the system diversity order is equal to $\min(m_1, m_2)$, indicating that the weaker hop between dual hops becomes the bottleneck of the whole data transmission. In particular, the bottleneck is the first hop link if $m_1 < m_2$ and the second hop otherwise.

3.2.2. With Cache. To compute the analytical expression of SER for the cache aided DF relaying networks, we first re-express the analytical expression in (12) by using the binomial expansion [42],

$$P_{\text{out}}^{\text{w}} = \widetilde{\sum} \frac{c_{1n}}{c_{2n}} e^{-jm_2\gamma_{2t}\sigma^2/P\beta} \left(\frac{m_2\gamma_{2t}\sigma^2}{P\beta} \right)^{c_{3n}}, \quad (28)$$

where

$$\begin{aligned} \widetilde{\sum} &= \sum_{j=0}^{N} \sum_{n_1=0}^{j} \sum_{n_2=0}^{n_1} \cdots \sum_{n_{m_2-1}=0}^{m_2-2}, \\ c_{1n} &= \binom{j}{n_1} \binom{n_1}{n_2} \cdots \binom{n_{m_2-2}}{n_{m_2-1}}, \\ c_{2n} &= (-1)^j (2!)^{n_2-n_3} (3!)^{n_3-n_4} \cdots \\ &\quad \times ((m_2-2)!)^{n_{m_2-2}-n_{m_2-1}} ((m_2-1)!)^{n_{m_2-1}} \\ c_{3n} &= n_1 + n_2 + \cdots + n_{m_2-1}. \end{aligned} \quad (29)$$

From this expression, we write the system SER for the cache aided relaying networks as

$$\begin{aligned} P_e^{\text{w}} &= \widetilde{\sum} \frac{c_{1n}}{\sqrt{2\pi} c_{2n}} \left(\frac{m_2\sigma^2}{P\beta\lambda} \right)^{c_{3n}} \\ &\cdot \int_0^\infty e^{-(1/2 + jm_2\sigma^2/P\beta\lambda)x^2} x^{2c_{3n}} dx \\ &= \widetilde{\sum} \frac{c_{1n}}{2c_{2n}} \left(\frac{m_2\sigma^2}{P\beta\lambda} \right)^{c_{3n}} \frac{b_{c_{3n}}}{(1 + 2jm_2\sigma^2/P\beta\lambda)^{c_{3n}+1/2}}, \end{aligned} \quad (30)$$

where [42, eq. (3.321.3)] and [42, eq. (3.461.2)] are used. From this analytical expression, we can easily evaluate the system SER for the DF relaying networks without cache.

We now propose to derive the asymptotic SER for the cache aided DF relaying networks, where we assume that the transmit power is large. By applying the asymptotic outage probability of (22) in (23), we can obtain the asymptotic SER as

$$\begin{aligned} P_e^{\text{w}} &\simeq \frac{1}{\sqrt{2\pi}} \int_0^\infty \left(\frac{m_2^{m_2-1}}{\Gamma(m_2)} \right)^N \left(\frac{x^2\sigma^2}{P\beta} \lambda \right)^{m_2 N} e^{-x^2/2} dx \\ &= \frac{(2m_2N-1)!!}{2} \left(\frac{m_2^{m_2-1}}{\Gamma(m_2)} \right)^N \frac{1}{(P\beta\lambda)^{m_2N}}. \end{aligned} \quad (31)$$

From this asymptotic SER, we can find that the system diversity order is equal to m_2N, indicating that the system transmission performance can be rapidly improved by increasing the fading parameter m_2 or the number of relays.

4. Simulation and Numerical Results

In this section, we provide some numerical and simulation results to validate the proposed studies. All links in the network experience Nakagami-m fading, and we set $\alpha = \beta = 1$ without loss of generality. The power of the additive white noise at the receiver is set to unity with $\sigma = 1$. The target data rate R_t is set to 1 bps/Hz, so that the two SNR thresholds γ_{1t} and γ_{2t} are associated with 3 and 1, respectively. For the SER computation, the BPSK modulation scheme is used, so that the modulation constant λ is set to 2.

Figure 2 depicts the outage probability of the traditional dual-hop relaying networks versus the transmit power P, where $m_1 = 2$ and m_2 varies from 1 to 3. As observed from this figure, we can find that, for various values of P and m_2, the analytical result matches well with the simulation value and the asymptotic result converges to the exact one in the high regime of transmit power P. This validates the effectiveness of the derived analytical and asymptotic expressions of outage probability for the traditional dual-hop relaying networks without cache. Moreover, the curve slope of the outage probability linearly increases with m_2, when $m_2 \leq m_1$, since the second relaying link becomes the bottleneck of the system data transmission. In further, the curves with $m_2 = 2$ and $m_2 = 3$ have the same slope, indicating that the system diversity order remains unchanged.

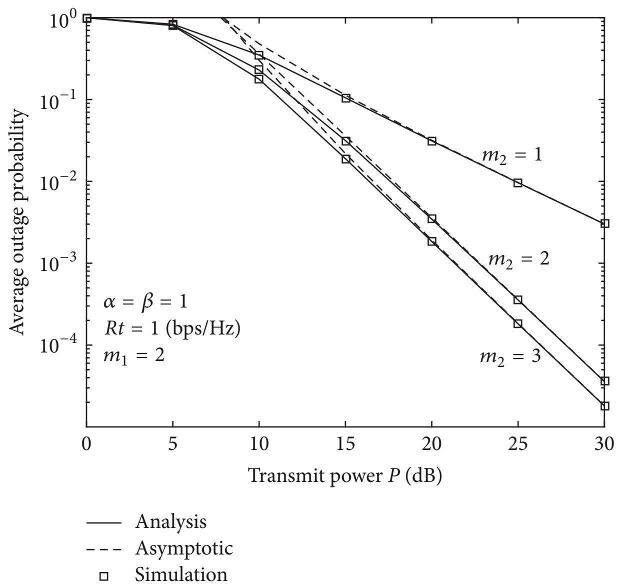

FIGURE 2: Outage probability versus the transmit power P without cache.

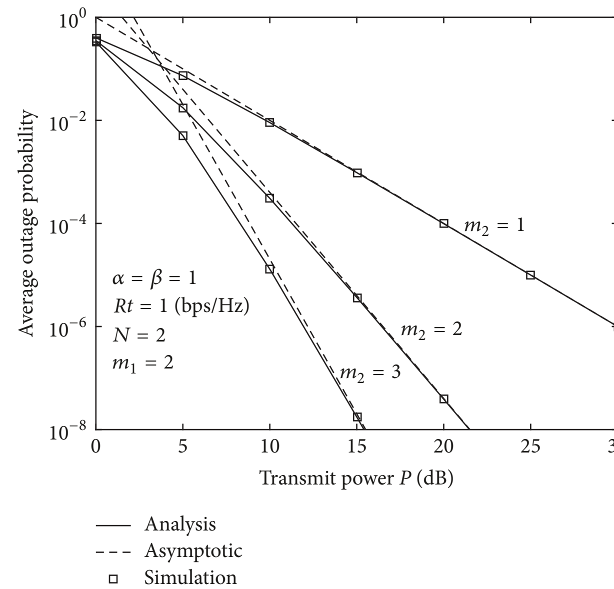

FIGURE 4: Outage probability versus the transmit power P with cache.

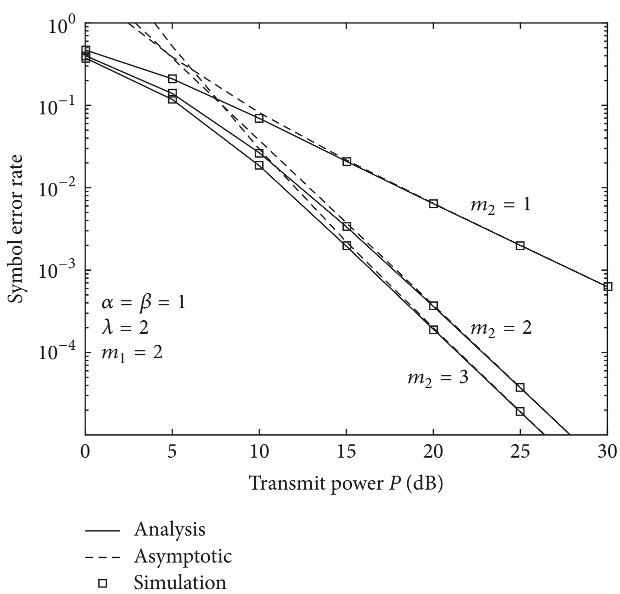

FIGURE 3: Symbol error rate versus the transmit power P without cache.

Figure 3 demonstrates the symbol error rate of the traditional dual-hop relaying networks without cache, where $\lambda = 2$, the transmit power P varies from 0 dB to 30 dB, and m_2 varies from 1 to 3. We can see from this figure that the analytical SER fits well with the simulated SER and the asymptotic SER converges to the exact SER in the high region of transmit power P. This verifies the derived analytical and asymptotic expressions of SER for the traditional dual-hop relaying networks without cache. Moreover, the curve slope increases with m_2 when $m_2 \leq m_1$, since the second relaying link becomes the bottleneck of the system whole data transmission. Furthermore, the curve slope with $m_2 = 2$ is the same as that of $m_2 = 3$, indicating that the system diversity order remains unchanged.

Figure 4 illustrates the outage probability of the cache aided DF relaying networks, where $N = 2$, P varies from 0 dB to 30 dB, and m_2 varies from 1 to 3. As seen in Figure 4, we can find that the analytical outage probability tallies with the simulation probability and the asymptotic outage probability converges to the exact P_{out} with large value of P. This validates the correctness of the derived analytical and asymptotic expressions of outage probability. Moreover, the curve slopes are in parallel with the value of m_2, indicating that the system diversity order increases with the value of m_2. By comparing Figures 2 and 4, we can obtain that, for achieving a target level of outage probability 10^{-4}, the transmit power can be saved by about 17.5 dB when $m_2 = 3$, indicating that the cache technique can save the power resource efficiently.

Figure 5 provides the symbol error rate of the cache aided DF relaying networks versus the transmit power P, where $\lambda = 2$ and $m_1 = 2$ and m_2 varies from 1 to 3. We can see from Figure 5 that the analytical SER is identical to the simulation one, and the asymptotic SER converges to the exact value in the high regime of transmit power P. This verifies the derived analytical and asymptotic expressions of SER for the cache aided DF relaying networks. Moreover, the curve slopes are in parallel with the value of m_2, indicating that the system diversity order increases linearly with m_2. By comparing Figures 3 and 5, we can find that, to achieve a target SER level of 10^{-4}, using cache can save about 10 dB, indicating that cache will be very useful in the scarce power resource scenarios.

Figures 6 and 7 show the impact of number of relays N on the performance of cache aided relaying networks versus the transmit power P, where $m_1 = m_2 = 2$ and N varies from 1 to 3. Specifically, Figures 6 and 7 are associated with

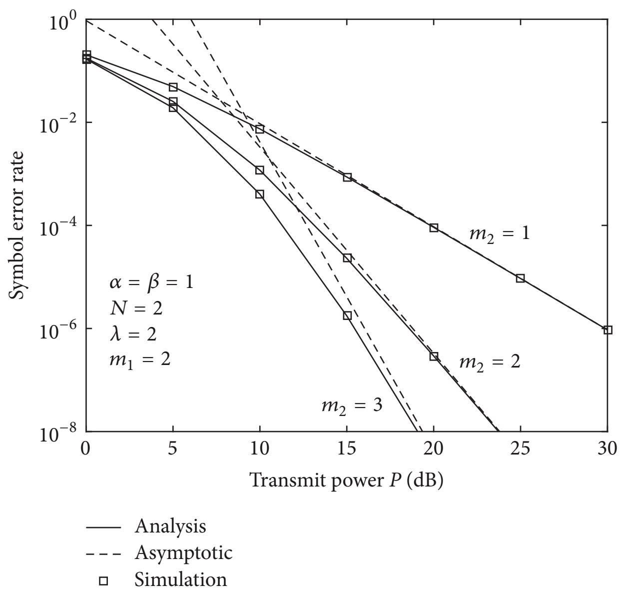

FIGURE 5: Symbol error rate versus the transmit power P with cache.

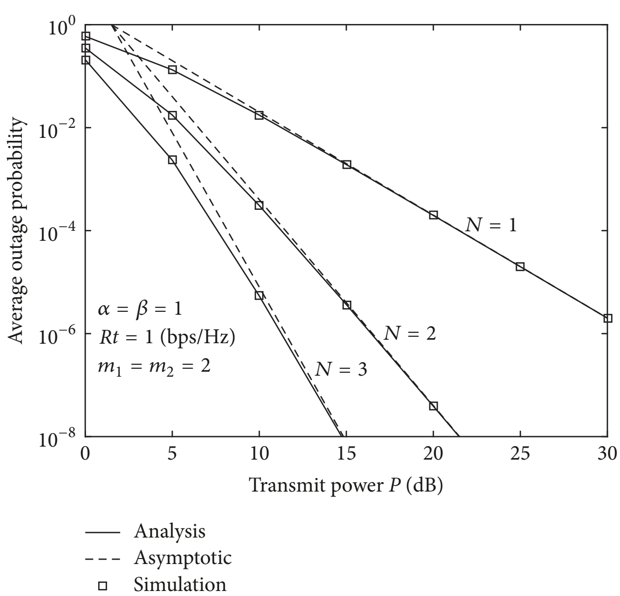

FIGURE 6: Impact of relay number N on the cache aided relaying networks: outage probability.

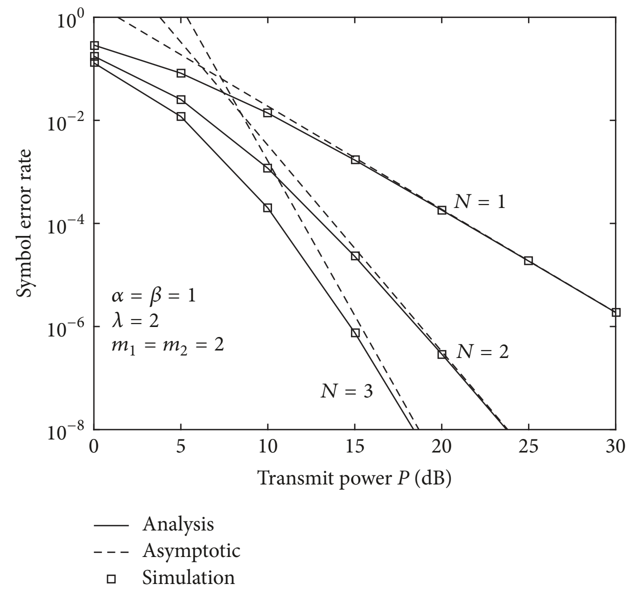

FIGURE 7: Impact of relay number N on the cache aided relaying networks: symbol error rate.

outage probability and SER, respectively. We can find that, for different values of N, the analytical performance is in good agreement with the simulation value and the asymptotic value converges to the exact one when the transmit power is large, which validates the effectiveness of the derived analytical and asymptotic expressions of outage probability and SER. Moreover, the curve slopes are in parallel with N, indicating that the system diversity order increases linearly with the number of relays. For the target outage probability and SER around 10^{-4}, we can find that the cache technique with $N = 3$ can save about 18.5 dB and 11 dB, respectively, indicating that cache can be used to save power resource.

5. Conclusions

This paper studied a two-hop DF relaying network, where cache could be used to prefetch the data from the source to the nodes around the destination. In this way, the destination could directly access the data from the relay nodes, instead of communicating with the source. For the DF relaying networks without and with cache, the system performances were studied by deriving the analytical expressions of outage probability and symbol error rate (SER). The asymptotic outage probability and SER were also provided in the high regime of transmit power, from which we could find the system diversity order is rapidly increased by using cache and the system performance is significantly improved. Simulation and numerical results were demonstrated to verify the proposed studies, and the transmit power could be saved by about 18.5 dB and 11 dB for achieving outage probability and SER level of 10^{-4}.

Conflicts of Interest

The authors declare that they have no conflicts of interest.

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