Outage Performance for IDF Relaying Mobile Cooperative Networks

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Abstract. Cooperative communication has emerged as a key technique in fifth generation (5G) mobile wireless networks. In this paper, with incremental decode-and-forward (IDF) relaying and transmit antenna selection (TAS), we investigate the outage probability (OP) performance of mobile cooperative networks. Exact closed-form expressions for OP with optimal TAS are derived. These expressions are used to evaluate the impact of power allocation on OP performance. Then we verify the mathematical derivations using Monte Carlo simulations. The OP performance is influenced by power-allocation parameter.

Keywords: Mobile cooperative communication
Incremental decode-and-forward · Outage probability
Transmit antenna selection · Power allocation

1 Introduction

The tremendous growth in mobile data traffic has created significant interest in the development of fifth-generation (5G) wireless communication systems [1, 2]. Many new technologies are being proposed for 5G mobile communications to satisfy the demands, such as device-to-device (D2D), heterogeneous networks, ultra-dense networks, and massive multiple-input-multiple-output (MIMO) systems [3–5]. For example, in cognitive small cells, the authors used cooperative Nash bargaining game theory to investigate the power allocation problem in [5].

In 5G mobile wireless networks, cooperative communication is considered to be a key technology. The authors investigated average bit error probability (BEP) performance of threshold digital relaying, and incremental-selective decode-and-forward (DF) relaying in [6, 7]. In [8], the authors investigated the outage probability (OP) performance of incremental amplify-and-forward (AF) relaying.

The hardware complexity of MIMO systems increases with the number of antennas. Transmit antenna selection (TAS) has been proposed to reduce this complexity.

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Using TAS, the authors investigated the OP performance of MIMO systems over Nakagami-m fading channels in [9]. The authors investigated symbol error rate (SER) performance of MIMO systems using TAS over η-μ fading channels in [10]. Further, using TAS and AF relaying, [11] provided new analysis results for OP and SER of MIMO systems over Rayleigh fading channels.

Although there are many results in the literature on TAS, the performance has been evaluated without considering the actual characteristics of a mobile communications channel. For example, the performance of TAS has only been investigated over Rayleigh, η-μ and Nakagami-*m* fading channels [9–11]. Recently, the *N*-Nakagami fading channel has been proposed to more accurately characterize mobile communications channels. Thus in this paper, TAS is considered for incremental delay-and-forward (IDF) relaying mobile cooperative networks over *N*-Nakagami fading channels. We investigate OP performance of optimal TAS, and the impact of the power allocation on OP performance is examined. In addition, these expressions are evaluated using Monte Carlo simulation, to verify the mathematical derivations.

The rest of the paper is organized as follows. Section 2 describes the mobile cooperative network model. We investigate the OP performance of the optimal TAS scheme in Sect. 3. Monte Carlo simulations are used to verify the mathematical derivations in Sect. 4. We give some conclusions in Sect. 5.

2 The System Model

The mobile cooperative model is shown in Fig. 1. With the help of L single-antenna mobile relay (MR) nodes, the mobile source (MS) node can communicate with the mobile destination (MD) node. MS has N_t antennas, while MD has N_r antennas.

$h = h_k, k \in \{h_{\mathrm{SD}ij}, h_{\mathrm{SR}il}, h_{\mathrm{RD}lj}\}$ represents the complex channel coefficients. h follows N-Nakagami distribution. The relative gain of the $\mathrm{MS}_i \rightarrow \mathrm{MD}_j$ link is $G_{\mathrm{SD}ij} = 1$, the relative gain of $\mathrm{MS}_i \rightarrow \mathrm{MR}_l$ is $G_{\mathrm{SR}il}$, the relative gain of $\mathrm{MR}_l \rightarrow \mathrm{MD}_j$ is $G_{\mathrm{RD}lj}$. MS and MR_l use the total energy E in the two time slots.

MS_i transmits the signal x in the first time slot. MD_j and MR_l receive the signals $r_{\mathrm{SD}ij}$ and $r_{\mathrm{SR}il}$ as

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

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

where K is the power allocation parameter, the mean and variance of $n_{\mathrm{SR}il}$ and $n_{\mathrm{SD}ij}$ are 0 and $N_0/2$ [12].

The best MR compares $\gamma_{\mathrm{SD}ij}$ to a threshold γ_T, and determines whether or not to use DF cooperation in the second time slot. The best MR is selected as follows

$$\gamma_{\mathrm{RD}ij} = \max_{1 \le l \le L} (\gamma_{\mathrm{RD}lj}) \tag{3}$$

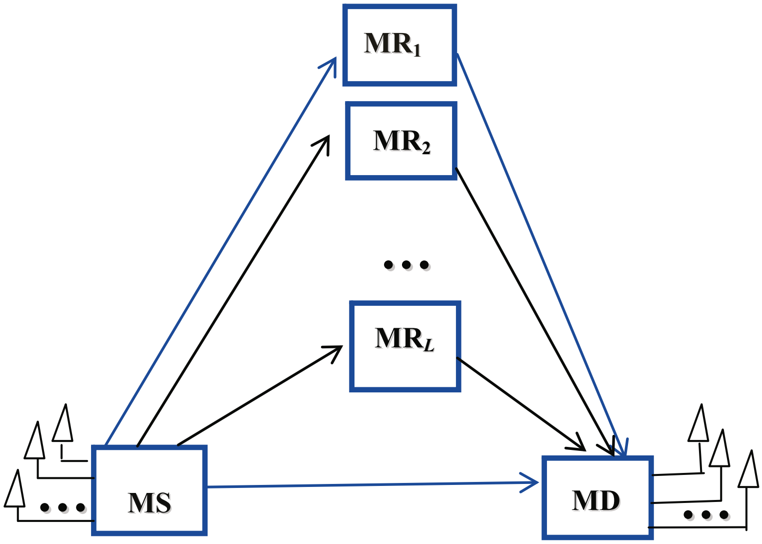

Fig. 1. The system model

where $\gamma_{\mathrm{RD}lj}$ represents the SNR of $\mathrm{MR}_l \to \mathrm{MD}_j$ link, and

$$\gamma_{\mathrm{RD}lj} = \frac{(1-K)G_{\mathrm{RD}lj}\left|h_{\mathrm{RD}lj}\right|^2 E}{N_0} = (1-K)G_{\mathrm{RD}lj}\left|h_{\mathrm{RD}lj}\right|^2 \bar{\gamma} \tag{4}$$

If $\gamma_{\mathrm{SD}ij} > \gamma_{\mathrm{T}}$, the best MR will not participate in cooperation. MD_j receives the SNR as

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

where

$$\gamma_{\mathrm{SD}ij} = \frac{K\left|h_{\mathrm{SD}ij}\right|^2 E}{N_0} = K\left|h_{\mathrm{SD}ij}\right|^2 \bar{\gamma} \tag{6}$$

If $\gamma_{\mathrm{SD}ij} < \gamma_{\mathrm{T}}$, the best MR uses DF cooperation protocol. MD_j receives the signal as

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

where the mean and variance of $n_{\mathrm{RD}j}$ are 0 and $N_0/2$.

MD_j uses the selection combining (SC) scheme, and receives the SNR as

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

MD receives the SNR as

$$\gamma_{SC_i} = \max_{1 \le j \le N_r}(\gamma_{ij}) \tag{9}$$

where

$$\gamma_{ij} = \begin{cases} \gamma_{0ij}, & \gamma_{SDij} > \gamma_T \\ \gamma_{SCij}, & \gamma_{SDij} < \gamma_T \end{cases} \tag{10}$$

The transmit antenna w is selected as follows

$$w = \max_{1 \le i \le N_t}(\gamma_{SC_i}) = \max_{1 \le i \le N_t, 1 \le j \le N_r}(\gamma_{ij}) \tag{11}$$

3 The Optimal TAS OP

3.1 $\gamma_{th} > \gamma_T$

We obtain the OP as

$$\begin{aligned} F_{optimal} &= \Pr(\max_{1 \le i \le N_t, 1 \le j \le N_r}(\gamma_{ij}) < \gamma_{th}) = \\ &= (\Pr(\gamma_T < \gamma_{SD}, \gamma_0 < \gamma_{th}) + \Pr(\gamma_{SD} < \gamma_T, \gamma_{SC} < \gamma_{th}))^{N_t \times N_r} \\ &= (G_1 + G_2)^{N_t \times N_r} \end{aligned} \tag{12}$$

where γ_{th} is the threshold.

The G_1 is given as

$$\begin{aligned} G_1 = &\frac{1}{\prod_{d=1}^{N}\Gamma(m_d)} G_{1,N+1}^{N,1}\left[\frac{\gamma_{th}}{\overline{\gamma_{SD}}}\prod_{d=1}^{N}\frac{m_d}{\Omega_d}\Big|_{m_1,\ldots,m_N,0}^{1}\right] - \\ &\frac{1}{\prod_{d=1}^{N}\Gamma(m_d)} G_{1,N+1}^{N,1}\left[\frac{\gamma_T}{\overline{\gamma_{SD}}}\prod_{d=1}^{N}\frac{m_d}{\Omega_d}\Big|_{m_1,\ldots,m_N,0}^{1}\right] \end{aligned} \tag{13}$$

$$\overline{\gamma_{SD}} = K\overline{\gamma} \tag{14}$$

where $G[\cdot]$ is the well-known Meijer's G-function, the fading coefficient is defined as m, and the scaling factor is defined as Ω [13].

The G_2 is given as

$$G_2 = \frac{1}{\prod_{d=1}^{N} \Gamma(m_d)} G_{1,N+1}^{N,1}\left[\frac{\gamma_T}{\overline{\gamma_{SD}}} \prod_{d=1}^{N} \frac{m_d}{\Omega_d}\Big|_{m_1,\ldots,m_N,0}^{1}\right] \times \left(\frac{1}{\prod_{t=1}^{N} \Gamma(m_t)} G_{1,N+1}^{N,1}\left[\frac{\gamma_{th}}{\overline{\gamma_{RD}}} \prod_{t=1}^{N} \frac{m_t}{\Omega_t}\Big|_{m_1,\ldots,m_N,0}^{1}\right]\right)^L \tag{15}$$

$$\overline{\gamma_{RD}} = (1-K)G_{RD}\overline{\gamma} \tag{16}$$

3.2 $\gamma_{th} < \gamma_T$

We obtain the OP as

$$\begin{aligned} F_{\text{optimal}} &= (\Pr(\gamma_{SD} < \gamma_T, \gamma_{SC} < \gamma_{th}))^{N_t \times N_r} \\ &= (\Pr(\gamma_{SD} < \gamma_{th}) \Pr(\gamma_{RD} < \gamma_{th}))^{N_t \times N_r} \\ &= (G_{11} G_{22})^{N_t \times N_r} \end{aligned} \tag{17}$$

The G_{11} is given as

$$\begin{aligned} G_{11} &= \Pr(\gamma_{SD} < \gamma_{th}) \\ &= \frac{1}{\prod_{d=1}^{N} \Gamma(m_d)} G_{1,N+1}^{N,1}\left[\frac{\gamma_{th}}{\overline{\gamma_{SD}}} \prod_{d=1}^{N} \frac{m_d}{\Omega_d}\Big|_{m_1,\ldots,m_N,0}^{1}\right] \end{aligned} \tag{18}$$

The G_{22} is given as

$$\begin{aligned} G_{22} &= \Pr(\gamma_{RD} < \gamma_{th}) \\ &= \left(\frac{1}{\prod_{t=1}^{N} \Gamma(m_t)} G_{1,N+1}^{N,1}\left[\frac{\gamma_{th}}{\overline{\gamma_{RD}}} \prod_{t=1}^{N} \frac{m_t}{\Omega_t}\Big|_{m_1,\ldots,m_N,0}^{1}\right]\right)^L \end{aligned} \tag{19}$$

4 Numerical Results

In this section, Monte Carlo simulations are used to verify the mathematical derivations. $E = 1$. We define $\mu = G_{SR}/G_{RD}$ (in decibels) as the relative geometrical gain.

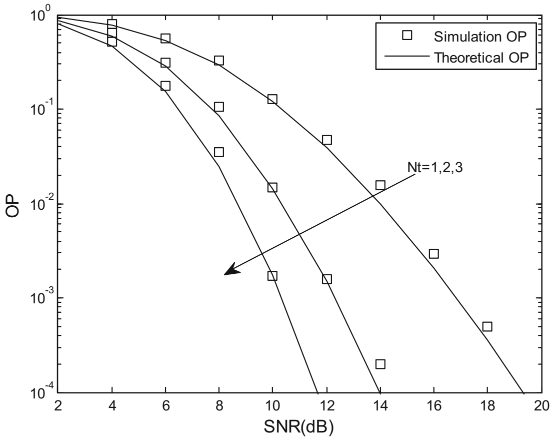

Fig. 2. The optimal TAS OP performance with $\gamma_{th} < \gamma_T$

Figure 2 presents the OP performance with $\gamma_{th} = 5$ dB, $\gamma_T = 6$ dB. Figure 3 presents the OP performance with $\gamma_{th} = 5$ dB, $\gamma_T = 2$ dB. The simulation parameters used are as follows: $N = 2$, $m = 2$, $K = 0.5$, $N_t = 1, 2, 3$, $L = 2$, $N_r = 1$, $\mu = 0$ dB. From Figs. 2 and 3, it is clear that Monte-Carlo simulation results and the analysis results match. Further, increasing N_t improves the OP performance. For example, when $\gamma_{th} = 5$ dB, $\gamma_T = 2$ dB, SNR = 10 dB, the OP is 2.9×10^{-1} with $N_t = 1$, 8.3×10^{-2} with $N_t = 2$, 2.4×10^{-2} with $N_t = 3$. With N_t fixed, increasing SNR decreases the OP.

The effect of K on OP performance is evaluated in Fig. 4. The simulation parameters used are as follows: $N = 2$, $m = 2$, $\mu = 0$ dB, $N_t = 2$, $L = 2$, $N_r = 2$, $\gamma_{th} = 5$ dB, $\gamma_T = 3$ dB. Simulation results show that increasing SNR improves the OP performance. For example, when $K = 0.7$, the OP is 2.8×10^{-1} with SNR = 5 dB,

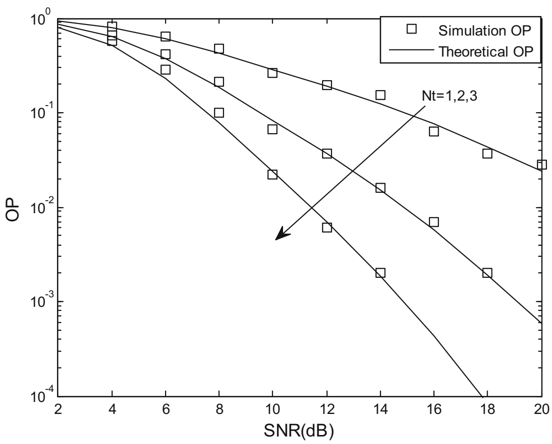

Fig. 3. The optimal TAS OP performance with $\gamma_{th} > \gamma_T$

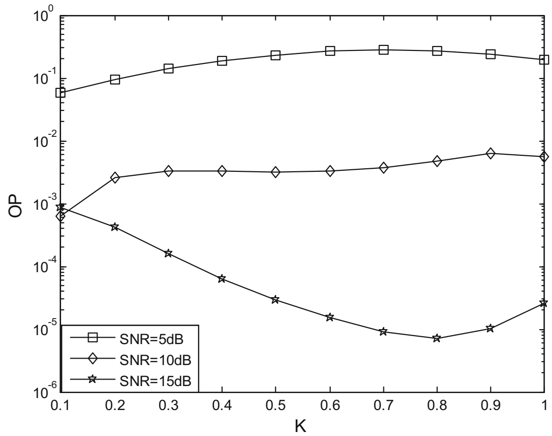

Fig. 4. The OP performance versus K

3.7×10^{-3} with SNR = 10 dB, 9.1×10^{-6} with SNR = 15 dB. When SNR = 5 dB, $K = 0.10$; SNR = 10 dB, $K = 0.10$; SNR = 15 dB, $K = 0.81$. We obtain that $K = 0.5$ is not the best choice. For most applications, we can store the optimum power allocation (OPA) values in a lookup table.

5 Conclusions

In this paper, with TAS, we investigate the OP performance of IDF relaying mobile cooperative networks. Monte Carlo simulation was used to verify these expressions, and to examine the effect of the power allocation on the OP performance. Future research will consider the impact of correlated channels on the performance.

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