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Research Article

Relay Selections for Security and Reliability in Mobile Communication Networks over Nakagami-m Fading Channels

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This paper studies the relay selection schemes in mobile communication system over Nakagami-m channel. To make efficient use of licensed spectrum, both single relay selection (SRS) scheme and multirelays selection (MRS) scheme over the Nakagami-m channel are proposed. Also, the intercept probability (IP) and outage probability (OP) of the proposed SRS and MRS for the communication links depending on realistic spectrum sensing are derived. Furthermore, this paper assesses the manifestation of conventional direct transmission scheme to compare with the proposed SRS and MRS ones based on the Nakagami-m channel, and the security-reliability trade-off (SRT) performance of the proposed schemes and the conventional schemes is well investigated. Additionally, the SRT of the proposed SRS and MRS schemes is demonstrated better than that of direct transmission scheme over the Nakagami-m channel, which can protect the communication transmissions against eavesdropping attacks. Additionally, simulation results show that our proposed relay selection schemes achieve better SRT performance than that of conventional direct transmission over the Nakagami-m channel.

1. Introduction

Cognitive radio (CR) [1] is considered as one of the most promising technologies to significantly improve spectrum utilization [2]. According to obtained information in different environments, transmission parameters, such as frequency, transmission power, modulation, and bandwidth, can be adaptively changed in CR networks [3]. Based on the highly dynamic nature existing in architecture of CR networks, however, legitimate CR devices expose themselves to both internal and external attackers. The security problem is urgent to solve in order to devise dependable CR networks. Hence, the security problems of CR network [4–6] have attracted great attention in both academia and industry. Security and reliability are two vital indexes of communication systems, but they fail to have good performance simultaneously in many cases. Therefore, it is of great significance to enhance the security-reliability trade-off (SRT) [7] performance based on the CR network.

Physical-layer security is regarded as one of effective approaches to improve the security of the wireless communications. On the one hand, point-to-point (P2P) transmission techniques, such as MIMO diversity [8], jamming [9], and beamforming [10], have been developed in order to improve dependable wireless links. Also, since localization provides fundamental support for many location-aware protocols and applications in the communication networks, it is one of the key technologies in wireless sensor networks (WSNs) [11]. For the purpose of improving localization accuracy and energy consumption aspects which are essential factors of designing mobile communication network, a novel algorithm considering the aftermath of disasters based on wireless sensor networks (WSNs) was provided by Han and his colleagues [12]. As observed, in many literatures about physical-layer security, some scholars employ signal processing techniques such as the precoding and beaming to settle relevant issues aiming at obtaining better performance. Recently, an agile confidential transmission strategy combining big data driven cluster and opportunistic beamforming was well investigated [13]. On the other hand, the author in [14] explored a scenario where an eavesdropper appears to tap the transmissions of the source and the relays. Also, node cooperation is employed to overcome eavesdropping without upper layer data encryption

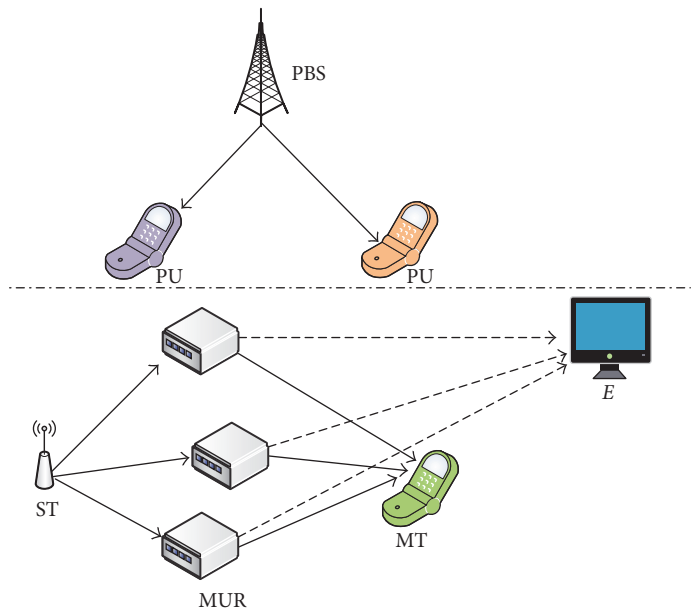

Figure 1: Model of a mobile communication network.

and improve the performance of secure wireless communications in the physical-layer security aspect [15]. In addition, relays selection schemes over the Rayleigh fading channel were proposed to improve the SRT performance of the CR networks [16]. However, the Rayleigh channel fails to be corresponding to the characteristics of many actual channels.

The *Nakagami-m* channel is more accordant with channel characteristics in realistic communication systems compared with that of Rayleigh fading channel and Ricean channel. In addition, it is widely used for modeling wireless fading channels, including Rayleigh and the one-sided Gaussian distribution as special cases [17–19]. However, few scholars have employed this kind of channels in SRT analysis. This causes the failure of previous SRT analysis to meet the performance in realistic mobile communication system in general. Motivated by the above considerations, a mobile communication network based on the *Nakagami-m* channel is conducted as a branch of CR networks. This network comprises one primary base station (PBS), eavesdropper (E), some primary users (PUs), multiple mobile terminals (MT), multiple relays (MUR), and a secondary transmitter (ST). Different from [16], we propose a scenario that investigates the SRT performance over the *Nakagami-m* channel, which can better capture the characteristics of the physical channel [20–23]. Specifically, relay selection schemes in mobile communication systems over the *Nakagami-m* channel are well investigated, and mathematical SRT analysis of the proposed SRS and MRS schemes over the *Nakagami-m* channel is first provided. Furthermore, simulation results show limpidly that the proposed SRS and MRS schemes over the *Nakagami-m* channel generally outperform the direct transmission scheme in their SRT.

The remainder of this paper is organized as below. Section 2 develops the system model. And the relay selection schemes over the *Nakagami-m* channel and mathematical analysis are provided in Section 3. In Section 4, simulation results and analysis are presented, which is followed by the conclusions in Section 5.

2. System Model

A typical mobile communication system is considered in Figure 1. As we know, the ST should detect by spectrum sensing whether the PBS occupies the licensed spectrum. In case of this situation, the ST cannot transmit randomly to avoid interference within the PUs. On the contrary, the licensed spectrum is not occupied. Meanwhile, E tries to intercept the secondary transmission process. For convenience, we define H_0 and H_1, respectively, as the cases in which the licensed spectrum is unoccupied and occupied by the PBS in a special time slot. Additionally, $\widehat{H}$ represents the status that the licensed spectrum is detected by spectrum sensing. Hence, the status of the spectrum is given as

$$\widehat{H} = \begin{cases} H_0, & \text{unoccupied} \\ H_1, & \text{occupied,} \end{cases} \tag{1}$$

where the probability P_d of the correct detection of the presence of PBS and the associated false alarm probability P_f are noted as $P_d = P(\widehat{H} = H_1 \mid H_1)$ and $P_f = P(\widehat{H} = H_1 \mid H_0)$, respectively. To ensure that the interference exerted on the PUs is below a tolerable level, we set $P_d = 0.99$ and $P_f = 0.01$ according to the IEEE 802.22 standard [14].

3. SRT Analysis over *Nakagami-m* Channel

In this section, we present the SRT analysis about the direct transmission and the SRS and MRS schemes over the *Nakagami-m* channel. As is analyzed in [14], IP and OP,

respectively, represent the security and reliability which are experienced by the eavesdropper and destination. Hence, the channel capacities at the destination and eavesdropper are assumed as C_D and C_E and the OP and IP can be expressed as

$$P_{\text{out}} = P\left(C_D < R \mid \widehat{H} = H_0\right) \tag{2}$$

$$P_{\text{int}} = P\left(C_E > R \mid \widehat{H} = H_0\right). \tag{3}$$

3.1. Direct Transmission Scheme. In this section, we consider a conventional direct transmission scheme over the *Nakagami-m* channel. Let P_s and P_R denote the transmit powers of the ST and PBS, respectively. For the licensed spectrum is considered to be unoccupied by the ST (i.e., $\widehat{H} = H_0$), the signal received at the PBS can be expressed as

$$y_{\text{ST}} = h_{\text{MUR}}\sqrt{P_s}x_s + h_{\text{PBS}}\sqrt{\alpha P_R}x_R + n_0. \tag{4}$$

Here, x_s and x_R represent the random symbols transmitted by the ST and the PBS at a special time instance. Also, without loss of generality, assume that $E[|x_s|^2] = E[|x_R|^2] = 1$, where $E[\cdot]$ is the expected value operator. At the same time, h_{MUR} and h_{PBS} are noted as the fading coefficients of the channel spanning from ST to MT and from PBS to MT, respectively. Furthermore, n_0 is the additive white Gaussian noise (AWGN). Then, the random variable α can be given by

$$\alpha = \begin{cases} 0, & H_0 \\ 1, & H_1. \end{cases} \tag{5}$$

However, for that the wireless medium has a broadcast nature, the signal of the ST which will be overheard by E can be written by

$$y_{\text{SE}} = h_{\text{MT}}\sqrt{P_s}x_s + h_E\sqrt{\alpha P_R}x_R + n_0. \tag{6}$$

Supposing that a spectrum hole has been detected, from (5), we obtain

$$\begin{aligned} P_{\text{out}}^{\text{direct}} &= P\left(C_{\text{ST}} < R, H_0 \mid \widehat{H} = H_0\right) \\ &\quad + P\left(C_{\text{ST}} < R, H_1 \mid \widehat{H} = H_0\right) \\ &= \lambda_0 P\left(\left|h_{\text{ST}}\right|^2 < \Delta\right) \\ &\quad + \lambda_1 P\left(\left|h_{\text{ST}}\right|^2 - \left|h_{\text{PBS}}\right|^2 \gamma_p \Delta < \Delta\right), \end{aligned} \tag{7}$$

where $\Delta = (2^R - 1)/\gamma_s$, $\gamma_s = P_s/N_0$, and $\gamma_p = P_R/N_0$. In (7), $P(|h_{\text{ST}}|^2 < \Delta)$ and $P(|h_{\text{ST}}|^2 - |h_{\text{PBS}}|^2\gamma_p\Delta < \Delta)$ can be obtained as

$$\begin{aligned} &P\left(\left|h_{\text{ST}}\right|^2 < \Delta\right) \\ &\quad = 1 - \sum_{k=1}^{m_1-1} \frac{m_1^{m_1-k}\exp\left(-m_1\Delta\right)}{\Gamma\left(m_1 - k + 1\right)} \\ &\qquad - \exp\left(-m_1\Delta\right) P\left(\left|h_{\text{ST}}\right|^2 - \left|h_{\text{PBS}}\right|^2 \gamma_p\Delta < \Delta\right) \\ &\quad = 1 + \sum_{k=1}^{m_2-1} \frac{m_2^{m_2-k}\exp\left(m_2/\gamma_p\right)}{\Gamma\left(m_2\right)} \\ &\qquad - \frac{m_2^{m_2}}{\Gamma\left(m_2\right)}\exp\left(-m_1\Delta\right) \\ &\qquad \times \left(m_1\Delta\gamma_p + m_2\right)^{-m_2}\Gamma\left(m_2, \frac{m_1\Delta\gamma_p + m_2}{\gamma_p}\right) \\ &\qquad \times \left(\sum_{k=1}^{m_1-1}\frac{m_1^{m_1-k}}{\Gamma\left(m_1\right)} + 1\right). \end{aligned} \tag{8}$$

Furthermore, we can observe from (3) that when the capacity of the ST-E channel exceeds the data rate, an intercept event will occur. Hence, the corresponding IP is given by

$$\begin{aligned} P_{\text{int}}^{\text{direct}} &= \lambda_0 P\left(\left|h_{\text{MT}}\right|^2 > \Delta\right) \\ &\quad + \lambda_1 P\left(\left|h_{\text{MT}}\right|^2 - \left|h_{\text{PBS}}\right|^2 \gamma_p\Delta > \Delta\right). \end{aligned} \tag{9}$$

To be specific, $P(|h_{\text{MT}}|^2 > \Delta)$ and $P(|h_{\text{MT}}|^2 - |h_{\text{PBS}}|^2\gamma_p\Delta > \Delta)$ are written as

$$\begin{aligned} &P\left(\left|h_{\text{MT}}\right|^2 > \Delta\right) \\ &\quad = \sum_{k=1}^{m_1-1} \frac{m_1^{m_1-k}\exp\left(-m_1\Delta\right)}{\Gamma\left(m_1 - k + 1\right)} \\ &\qquad + \exp\left(-m_1\Delta\right) P\left(\left|h_{\text{MT}}\right|^2 - \left|h_{\text{PBS}}\right|^2 \gamma_p\Delta > \Delta\right) \\ &\quad = -\sum_{k=1}^{m_2-1} \frac{m_2^{m_2-k}\exp\left(m_2/\gamma_p\right)}{\Gamma\left(m_2\right)} \\ &\qquad + \frac{m_2^{m_2}}{\Gamma\left(m_2\right)}\exp\left(-m_1\Delta\right) \\ &\qquad \times \left(m_1\Delta\gamma_p + m_2\right)^{-m_2}\Gamma\left(m_2, \frac{m_1\Delta\gamma_p + m_2}{\gamma_p}\right) \\ &\qquad \times \left(\sum_{k=1}^{m_1-1}\frac{m_1^{m_1-k}}{\Gamma\left(m_1\right)} + 1\right). \end{aligned} \tag{10}$$

3.2. Single Relay Selection. The SRS scheme over the *Nakagami-m* channel is investigated in this section. Specifically, once the licensed spectrum is deemed to be unoccupied, the ST first broadcasts its signal to the N MUR, which attempts to decode x_s from their received signals. For convenience, Θ is denoted as the set of MUR that succeed in decoding x_s. N MUR are assumed in this network, which

consist of 2^N possible subsets Θ, and the sample space of Θ can be formulated as

$$\Theta = \{0, \theta_1, \theta_2, \ldots, \theta_i, \ldots, \theta_{2^N-1}\}, \tag{11}$$

where 0 and θ_i represent the empty set and the ith nonempty subset of the N relays. If the set Θ is empty, no MUR successfully decodes x_s. By contrast, a specific MUR is selected from Θ to decode the signal and transmit it to the MT. Hence, given that $\widehat{H} = H_0$, we can work out the signal received at a specific MUR-i

$$y_i = h_{Ri}\sqrt{\alpha P_s}x_s + h_{Pi}\sqrt{P_R}x_R + n_0. \tag{12}$$

To make SRT analysis, noting that $\widehat{H} = H_0$, the OP of the cognitive transmission depending on SRS can be denoted as

$$\begin{aligned}
P_{\text{out}}^{\text{single}} &= P\left(C_{\text{ST}} < R, \theta = 0 \mid \widehat{H} = H_0\right) + \sum_{n=1}^{2^N-1} P\left(C_{\text{ST}}\right. \\
&\left. < R, \theta = \theta_n \mid \widehat{H} = H_0\right) = \lambda_0 \prod_{i=1}^{N} P\left(\left|h_{Si}\right|^2 < \Lambda\right) \\
&+ \lambda_1 \prod_{i=1}^{N} P\left(\left|h_{Si}\right|^2 < \left|h_{Ri}\right|^2 \gamma_p \Lambda + \Lambda\right) \\
&+ \lambda_0 \sum_{n=1}^{2^N-1} \prod_{i\in\Theta} P\left(\left|h_{Si}\right|^2 > \Lambda\right) \\
&\cdot \prod_{j\in\overline{\Theta}} P\left(\left|h_{Sj}\right|^2 < \Lambda\right) P\left(\max_{i\in\Theta}\left|h_{Ri}\right|^2 < \Lambda\right) \\
&+ \lambda_1 \sum_{n=1}^{2^N-1} \prod_{i\in\Theta} P\left(\left|h_{Si}\right|^2 > \left|h_{Ri}\right|^2 \gamma_p \Lambda + \Lambda\right) \\
&\cdot \prod_{j\in\overline{\Theta}} P\left(\left|h_{Sj}\right|^2 < \left|h_{Ri}\right|^2 \gamma_p \Lambda + \Lambda\right) \times P\left(\max_{i\in\Theta}\left|h_{Ri}\right|^2\right. \\
&\left. < \left|h_{\text{PBS}}\right|^2 \gamma_p \Lambda + \Lambda\right),
\end{aligned} \tag{13}$$

where $\Lambda = (2^{2R}-1)/\gamma_s$. Specifically, (13) consists of the following parts:

$$\begin{aligned}
&P\left(\left|h_{Si}\right|^2 < \Lambda\right) \\
&= 1 - \sum_{k=1}^{m_3-1} \frac{{m_3}^{m_3-k} \exp\left(-m_3\Lambda\right)}{\Gamma\left(m_3 - k + 1\right)} \\
&\quad - \exp\left(-m_3\Lambda\right) P\left(\left|h_{Si}\right|^2 - \left|h_{Ri}\right|^2 \gamma_p \Lambda < \Lambda\right) \\
&= 1 + \sum_{k=1}^{m_4-1} \frac{{m_4}^{m_2-k} \exp\left(m_4/\gamma_p\right)}{\Gamma\left(m_4\right)} \\
&\quad - \frac{{m_4}^{m_4}}{\Gamma\left(m_4\right)} \exp\left(-m_3\Lambda\right)\left(m_3\Lambda\gamma_p + m_4\right)^{-m_4} \\
&\quad \times \Gamma\left(m_4, \frac{m_3\Lambda\gamma_p + m_4}{\gamma_p}\right) \\
&\quad \times \left(\sum_{k=1}^{m_3-1} \frac{{m_3}^{m_3-k}}{\Gamma\left(m_3\right)} + 1\right) P\left(\max_{i\in\Theta}\left|h_{Ri}\right|^2 < \Lambda\right) \\
&= \prod_{i\in\Theta}\left[1 - \sum_{k=1}^{m_i-1} \frac{{m_i}^{m_i-k} \exp\left(-m_i\Lambda\right)}{\Gamma\left(m_i - k + 1\right)} - \exp\left(-m_i\Lambda\right)\right].
\end{aligned} \tag{14}$$

Also, we discuss the IP of the SRS scheme. From (6), the IP can be given by

$$\begin{aligned}
P_{\text{int}}^{\text{single}} &= \lambda_0 \sum_{n=1}^{2^N-1} \prod_{i\in\Theta} P\left(\left|h_{Si}\right|^2 > \Lambda\right) \\
&\cdot \prod_{j\in\overline{\Theta}} P\left(\left|h_{Sj}\right|^2 < \Lambda\right) P\left(\max_{i\in\Theta}\left|h_{\text{best}}\right|^2 > \Lambda\right) \\
&+ \lambda_1 \sum_{n=1}^{2^N-1} \prod_{i\in\Theta} P\left(\left|h_{Si}\right|^2 > \left|h_{Ri}\right|^2 \gamma_p \Lambda + \Lambda\right) \\
&\times \prod_{j\in\overline{\Theta}} P\left(\left|h_{Sj}\right|^2 < \left|h_{Ri}\right|^2 \gamma_p \Lambda + \Lambda\right) \times P\left(\left|h_{\text{best}}\right|^2\right. \\
&\left. > \left|h_E\right|^2 \gamma_p \Lambda + \Lambda\right).
\end{aligned} \tag{15}$$

Here, with the aids of functional analysis theory and multivariate integral theory, we express $P(\max_{i\in\Theta}|h_{Ri}|^2 < |h_{\text{PBS}}|^2\gamma_p\Lambda + \Lambda)$, $P(\max_{i\in\Theta}|h_{\text{best}}|^2 > \Lambda)$, and $P(\max_{i\in\Theta}|h_{\text{best}}|^2 > |h_{\text{PBS}}|^2\gamma_p\Lambda + \Lambda)$ as below.

$$\begin{aligned}
&P\left(\max_{i\in\Theta}\left|h_{Ri}\right|^2 < \left|h_{\text{PBS}}\right|^2 \gamma_p \Lambda + \Lambda\right) \\
&= \prod_{i\in\Theta}\prod_{j\in\Theta}\left\{\left[1 + \sum_{k=1}^{m_j-1} \frac{{m_j}^{m_j-k} \exp\left(m_j/\gamma_p\right)}{\Gamma\left(m_j\right)}\right]\right. \\
&\quad - \frac{{m_i}^{m_j}}{\Gamma\left(m_j\right)} \exp\left(-m_i\Lambda\right) \times \left(m_i\Lambda\gamma_p + m_j\right)^{-m_j} \\
&\quad \left. \cdot \Gamma\left(m_j, \frac{m_i\Lambda\gamma_p + m_j}{\gamma_p}\right) \times \left(\sum_{k=1}^{m_i-1} \frac{{m_1}^{m_i-k}}{\Gamma\left(m_i\right)} + 1\right)\right\}
\end{aligned}$$

$$P\left(\max_{i\in\Theta}|h_{\text{best}}|^2>\Lambda\right)=\prod_{i\in\Theta}\left\{1-\left[1-\sum_{k=1}^{m_i-1}\frac{m_i^{m_i-k}\exp\left(-m_i\Lambda\right)}{\Gamma\left(m_i-k+1\right)}-\exp\left(-m_i\Lambda\right)\right]\right\}$$

$$P\left(\max_{i\in\Theta}|h_{\text{best}}|^2>|h_{\text{PBS}}|^2\gamma_p\Lambda+\Lambda\right)$$
$$=\prod_{i\in\Theta}\prod_{j\in\Theta}\left\{\left[-1-\sum_{k=1}^{m_j-1}\frac{m_j^{m_j-k}\exp\left(m_j/\gamma_p\right)}{\Gamma\left(m_j\right)}\right]+\frac{m_i^{m_j}}{\Gamma\left(m_j\right)}\exp\left(-m_i\Lambda\right)\times\left(m_i\Lambda\gamma_p+m_j\right)^{-m_j}\cdot\Gamma\left(m_j,\frac{m_i\Lambda\gamma_p+m_j}{\gamma_p}\right)\left(\sum_{k=1}^{m_i-1}\frac{m_1^{m_i-k}}{\Gamma\left(m_j\right)}+1\right)\right\}. \tag{16}$$

3.3. Multirelays Selection Scheme. We provide the SRT analysis which is based on the MRS scheme over the *Nakagami-m* channel in this subsection. Specifically, x_s is first transmitted to N MUR over a detected spectrum hole. As is mentioned in Section 3.2, we denote Θ by the set of SRS with successful decoding. If it is empty, all MUR fail to decode x_s and will not pass the source signal forward, leading to the difficulty in decoding of MT and E. If it is not empty, all MUR within Θ will be utilized for simultaneously transmitting x_s to MT. This is different from the SRS scheme. When it comes to power consumption, a fair comparison with the SRS scheme can be made under the conditions that the overall transmit power across all MUR is constrained to P_s. For the sake of making good use of MRS, we define the weight vector as

$$w=\left[w_1,w_2,\ldots,w_{|\Theta|}\right]^T,\quad \|w\|=1. \tag{17}$$

And the signals received at MT and E are expressed as

$$\begin{aligned}y_D^{\text{multi}}&=\sqrt{P_s}w^TH_Dx_s+\sqrt{\alpha P_R}h_{\text{PBS}}x_R+n_0\\ y_E^{\text{multi}}&=\sqrt{P_s}w^TH_{\text{MT}}x_s+\sqrt{\alpha P_R}h_Ex_R+n_0,\end{aligned} \tag{18}$$

where $H_D=[h_{1D},h_{2D},\ldots,h_{\Theta D}]$. Then based on the *Nakagami-m* channel, we study the SRT performance of the MRS scheme. Similar to (7), the OP analysis is obtained as

$$\begin{aligned}P_{\text{out}}^{\text{multi}}&=P\left(\theta=0\mid\widehat{H}=H_0\right)\\&\quad+\sum_{n=1}^{2^N-1}P\left(C_D^{\text{multi}}<R,\theta=\theta_n\mid\widehat{H}=H_0\right)\\&=\lambda_0\prod_{i=1}^{N}P\left(|h_{Si}|^2<\Lambda\right)\\&\quad+\lambda_1\prod_{i=1}^{N}P\left(|h_{Si}|^2<|h_{Ri}|^2\gamma_p\Lambda+\Lambda\right)\\&\quad+\lambda_0\sum_{n=1}^{2^N-1}\prod_{i\in\Theta}P\left(|h_{Si}|^2>\Lambda\right)\prod_{j\in\overline{\Theta}}P\left(|h_{Sj}|^2<\Lambda\right)\\&\quad\cdot P\left(\sum_{i\in\Theta}|h_{Ri}|^2<\Lambda\right)\\&\quad+\lambda_1\sum_{n=1}^{2^N-1}\prod_{i\in\Theta}P\left(|h_{Si}|^2>|h_{Ri}|^2\gamma_p\Lambda+\Lambda\right)\\&\quad\cdot\prod_{j\in\overline{\Theta}}P\left(|h_{Sj}|^2<|h_{Ri}|^2\gamma_p\Lambda+\Lambda\right)\times P\left(\sum_{i\in\Theta}|h_{Ri}|^2<|h_{\text{PBS}}|^2\gamma_p\Lambda+\Lambda\right).\end{aligned} \tag{19}$$

The IP analysis of the MRS scheme can be given as follows:

$$\begin{aligned}P_{\text{int}}^{\text{multi}}&=\lambda_0\sum_{n=1}^{2^N-1}\prod_{i\in\Theta}P\left(|h_{Si}|^2>\Lambda\right)\prod_{j\in\overline{\Theta}}P\left(|h_{Sj}|^2<\Lambda\right)\\&\quad\times P\left(\frac{|H_{\text{MT}}H_d^H|^2}{|H_D|^2}>\Lambda\right)\\&\quad+\lambda_1\sum_{n=1}^{2^N-1}\prod_{i\in\Theta}P\left(|h_{Si}|^2>|h_{Ri}|^2\gamma_p\Lambda+\Lambda\right)\\&\quad\times\prod_{j\in\overline{\Theta}}P\left(|h_{Sj}|^2<|h_{Ri}|^2\gamma_p\Lambda+\Lambda\right)\\&\quad\cdot P\left(\frac{|H_{\text{MT}}H_d^H|^2}{|H_D|^2}>|h_E|^2\gamma_p\Lambda+\Lambda\right).\end{aligned} \tag{20}$$

To find a general closed-form OP and IP expression for the MRS scheme is quite a challenge, and thus we use computer simulations to get the numerical SRT performance of the MRS scheme. Clearly, when h_{Ri} is given as the fading coefficients of the channel spanning from MUR-i to PBS, we have $\sum|h_{Ri}|^2>\max|h_{Ri}|^2$, $i\in\Theta$. This leads to a performance gain for the MRS over that of SRS in terms of maximizing the legitimate transmission capacity. Furthermore, for a fixed outage requirement, the MRS scheme can, in comparison with the SRS scheme, realize a better intercept performance over the *Nakagami-m* channel. This is due to the fact that an outage reduction achieved by the capacity enhancement of the legitimate transmission relaying on MRS would be converted into an intercept improvement. Meanwhile, in the

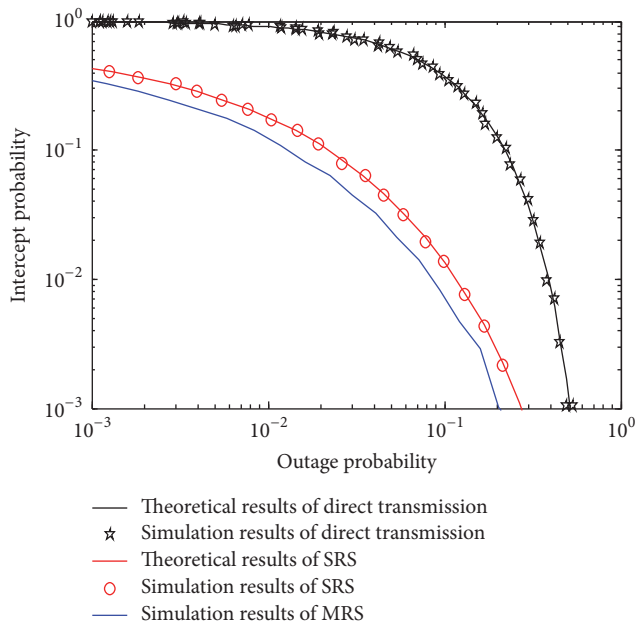

FIGURE 2: OP versus IP when $m = 2$ and $N = 5$ when $P_d = 0.99$ and $P_f = 0.01$.

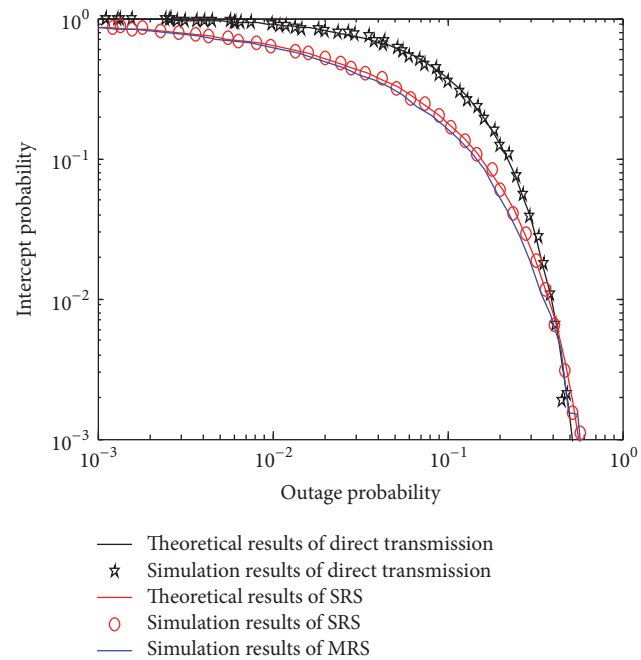

FIGURE 3: OP versus IP when $m = 2$ and $N = 2$ when $P_d = 0.99$ and $P_f = 0.01$.

MRS scheme, when simultaneously transmitting to MT, it will require a high-complexity symbol-level synchronization for multiple distributed relays, whereas the SRS does not require such a complex synchronization process. Therefore, we can achieve a better performance of MRS over SRS at the expense of a higher implementation.

4. Numerical Results and Discussion

We give a numerical analysis of our expressions using different types of parameters in this section. Specifically, the OP and the IP in the direct transmission schemes, SRS schemes, and MRS schemes are investigated. Theoretical results and the simulation results are presented in the case under different conditions in the *Nakagami-m* channel model. Initially, P_d is set to $P_d = 0.99$, while P_f is 0.01. Also, we set the initial signal-to-noise ratio (SNR) γ_p as 10 dB and data rate is employed as $R = 1$ bit/s/Hz in this simulation.

Figure 2 shows the simulation results when $m = 2$ and $N = 5$, the IP and OP of the direct transmission, along with the SRS and MRS schemes. Here the solid lines and discrete marker symbols each represent the theoretical and simulated results. As is shown in the figure, the proposed SRS and MRS schemes both attain lower OP (reliability) and IP (security) than the direct transmission scheme over the *Nakagami-m* channel. Also, the OP and IP of the MRS are lower than those of SRS scheme. Hence, we can conclude that the SRS and MRS schemes have better SRT performance than the direct transmission scheme. However, considering that the MRS scheme needs to work with very complex and high-cost symbol-level synchronization system, it is inappropriate for us to assert that the MRS scheme outweighs the SRS scheme.

Figure 3 illustrates the simulation results in the case of $m = 2$ and $N = 2$. Compared with the simulation results shown in Figure 2, we can observe that, with the increasing number of the relays, the OP and IP are decreasing. Meanwhile, the performance of the SRS and MRS schemes significantly improves when the number of relays increases. Furthermore, similar to the analysis given in Figure 2, the superiority of the MRS over the SRS shows when elaborate symbol-level synchronization is required among the multiple relays for simultaneously transmitting to the relays or base stations.

In Figure 4, the simulation results under different fading exponents m are presented, in which case $m = 3$ is considered. Figure 4 shows that the proposed SRS and MRS schemes generally outstrip the conventional direct transmission in terms of IP and OP, in the case that $m = 3$. Moreover, compared with the results depicted in Figure 2, the SRT of the SRS and MRS schemes rises as the fading exponent m increases from 2 to 3. Additionally, the MRS schemes outperform the SRS approach in the IP and OP analysis, which further confirms the strength of the MRS for protecting the MUR-PBS links against eavesdropping attacks.

In Figure 5, P_d and P_f are set 0.9 and 0.1, respectively. From Figures 2 and 5, we observe the proposed SRS and MRS schemes perform better than the direct transmission in terms of OP and IP aspect, and the SRT performance improves when $P_d = 0.99$. It illustrates that the SRT performance of the SRS and MRS schemes improves when the correct detection probability increases. Additionally, the MRS schemes outperform the SRS approach in the SRT analysis, which implies the strength of the MRS for protecting the MUR-PBS links against eavesdropping attacks although it needs complex synchronization system.

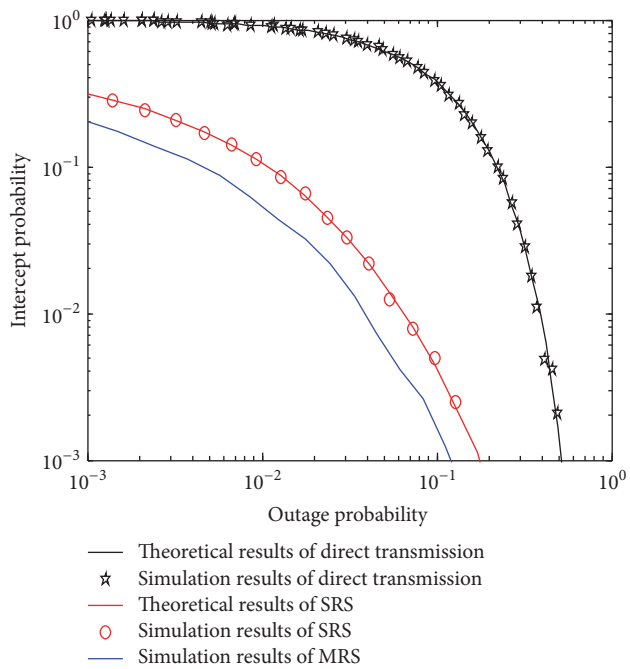

Figure 4: OP versus IP when $m = 3$ and $N = 5$ when $P_d = 0.99$ and $P_f = 0.01$.

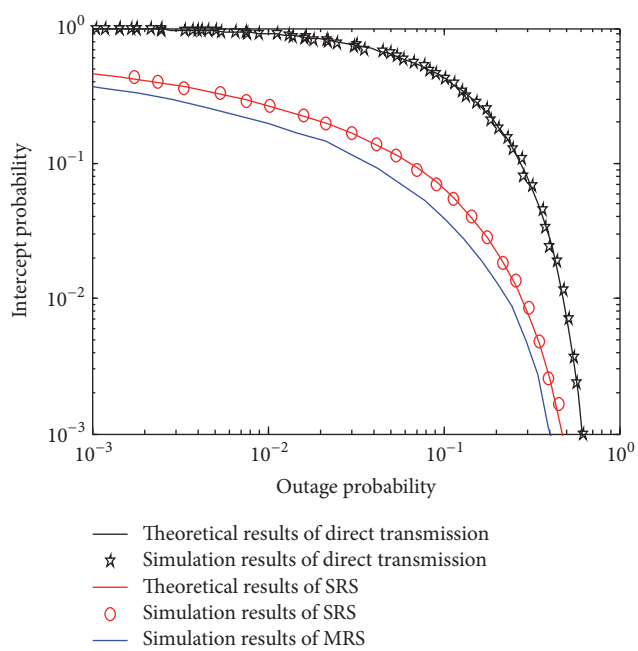

Figure 5: OP versus IP when $m = 2$ and $N = 5$ when $P_d = 0.9$ and $P_f = 0.1$.

5. Conclusion

We propose new relay selection schemes over the Nakagami-m channel in the mobile communication system in this paper. SRS and MRS schemes are presented to assess the security and reliability of the communication links. Meanwhile, simulation results indicate a better performance of the SRS and MRS schemes than the direct transmission scheme over the *Nakagami-m* channel. Additionally, with the increasing number of the relays, the SRT performance of both the SRS and the MRS schemes improves remarkably, which demonstrates their benefits in enhancing both the security and reliability of the mobile communication system.

Conflicts of Interest

The authors declare no conflicts of interest.

Authors' Contributions

Hongji Huang and Wanyou Sun derived the performance bound and designed the experiments; Hongji Huang and Guan Gui performed the experiments; Hongji Huang and Jie Yang analyzed the data; Hongji Huang and Guan Gui wrote the paper.

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