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Secrecy Performance Analysis of SIMO Systems Over Correlated κ–μ Shadowed Fading Channels

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ABSTRACT In this paper, the secrecy performance of single-input–multiple-output systems over correlated κ-μ shadowed fading channels is investigated. In particular, based on the classic Wyner's wiretap model, we derive analytical expressions for secure outage probability (SOP) and the probability of strictly positive secrecy capacity (SPSC) over correlated κ-μ shadowed fading channels. In order to further study the impact of channel parameters on the secrecy performance, novel SOP and the probability of SPSC over independent and identically distributed κ-μ shadowed fading channels are also obtained. In addition, we discuss the asymptotic expressions of the SOP and the SPSC. The match between the analytical results and simulations is excellent for all parameters under considerations. It is interesting to find that the results show that when the signal-to-noise ratio of the main channel is lower than that of the eavesdropping channel, the larger value of correlation coefficient is helpful to improve the secrecy performance and vice versa.

INDEX TERMS Single-input multiple-output, κ-μ shadowed fading, the probability of strictly positive secrecy capacity (SPSC), secure outage probability (SOP).

I. INTRODUCTION

Security is an important measure of wireless communication quality, which represents the resistance of future communication systems to human destructions and threats [1]. Wireless communication systems are particularly subject to more security threats than closed wired communication systems. According to the open system interconnection reference model, the information security technology in the traditional wireless communication system mainly focuses on the network layer and the upper layers, moreover, it is assumed that the physical layer has provided the error free transmission. Unlike traditional cryptographic encryption and decryption methods, physical layer security (PLS) has become an important aspect of providing trustworthiness and reliability for the future wireless communication even without the use of cryptographic protocols in the corresponding literatures [2]–[9]. Based on Shannon's communication principle of secrecy system [2], Wyner put forward the classic wiretap channel model in which confidential information is transmitted from the sender to the legitimate user and the eavesdropper [3]. The definition of secrecy capacity was given in [4], in addition, the SOP, the probability of SPSC and the average secrecy capacity (ASC) were obtained with Rayleigh fading channels. In order to deal with the fluctuation of millimeter wave signals, the authors in [5] put forward a fluctuating two-ray (FTR) model and studied the security performance of the FTR model with arbitrary parameters by analyzing ASC, SOP, and SPSC. Hyadi *et al.* in [6] summarized the influence of the channel state information at the transmitter (CSIT)

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uncertainty on the communication security performance, and analyzed three different sources of CSIT in detail. To better evaluate the security performance of wireless communication systems, three performance metrics which can reflect the eavesdropper's ability to decode the transmitted information and the leakage rate of confidential information were proposed in [7]. Liu in [8] derived the closed-form expression of SPSC over Rician/Rician fading channels. In order to better understand and solve the performance measures of physical layer security, a unified analytical model for the probability of nonzero secrecy capacity, SOP, and the secrecy capacity of multiple-antenna systems was given in [9].

Recently, the secure performance of communication systems over generalized fading channels has attracted a considerable amount of research since the generalized channels are close to the real environment and includes other channels as special cases. For instance, the generalized Gamma distribution can be used to characterize many classical distributions [10], The authors in [11] performed an analysis of PLS over generalized Gamma fading channels. By employing a mixture gamma distribution, the ASC, the probability of SPSC and SOP over generalized-K (G_K) fading channels were derived in [12]. Wu *et al.* [13] analyzed the secrecy performance for amplify-and-forward (AF) relaying networks over G_K fading channels, where analytical expressions for the ASC, SOP and SPSC were derived. The performance of PLS was investigated over κ-μ fading channels by analyzing the SPSC and the lower bound of the SOP in [14]. A closed-form expression for the ASC over α-μ fading channels was presented in [15]. Analytical expressions for the lower bound of the SOP and the SPSC of α-μ/κ-μ and κ-μ/α-μ fading models were obtained to study the secrecy capacity of physical layer [16].

Different from the single antenna transceiver system, multiple-input multiple-output (MIMO) technology can improve the quality of communication by sending and receiving signals through multiple antennas [17], [18]. As a result, many works [19]–[26] on the PLS performance over MIMO fading channels have been carried out. Based on the correlated single-input multiple-output (SIMO) Nakagami-*m* channel, Sun *et al.* in [19] derived the expressions of SPSC and SOP, and presented the influence of the correlation coefficient on the system security capacity in the different signal-to-noise ratio (SNR) conditions. The PLS performance of SIMO underlay cognitive radio networks (CRN) over G_K fading channels were investigated in [20], which provided the statistical characteristics of independent and identically distributed (i.i.d.) G_K distribution and the theoretical expression of SOP. Some benchmarks including achievable sum rate (ASR), symbol error ratio (SER) and outage probability (OP) were derived in [21] over semi-correlated MIMO K fading channels using zero forcing receivers. In order to enhance the performance of PLS between two multi-antenna nodes, a novel solution in view of beamforming with prespecified signal-to-interference-plus-noise ratio (SINR) was provided in [22], which can minimize transmission power. In addition, the work of [12] was extended in [23] to the case of SIMO system where the exact ASC, SOP and SPSC over SIMO G_K fading channels were investigated. For κ-μ fading channels, the authors in [24] presented the derivation of both the ASC and SOP. Pan *et al.* in [25] provided the derivations of ASC in three considered scenarios, namely independent lognormal fading, correlated lognormal fading, or independent composite fading. By means of moment matching, Peppas *et al.* in [26] derived the analytical expressions of secrecy capacity and SOP with generalized selection combining under the considered multi-antenna system over η-μ fading channels.

The κ-μ shadowed fading is a generalized composite distribution which encompasses the κ-μ fading and the Rician shadowed fading and can be equivalent to other fading channels with suitable parameters [27]. This channel model can be applied to different scenarios such as device-to-device communication [28], fifth generation (5G) [29] and satellite communication system [30]. Besides, since many statistical properties of the model can be written as closed-form expressions, κ-μ shadowed distribution is more suitable for performance analysis. In recent years, many researchers have investigated the performance over κ-μ shadowed fading channels. For instance, in [31], performance analysis of PLS over κ-μ shadowed fading channels using the classic Wyner's wiretap model was studied, where the lower bound of the SOP and SPSC were explored by the method of moment matching. The effective rate over single-input single-output (SISO) and multiple-input-single-output (MISO) systems over κ-μ shadowed fading channels were studied in [32] and [33], respectively.

Channel correlation has a great impact on the security performance of the system. Many studies [34]–[38] have been done in this area. the authors in [34] deduced the ASC and SOP based on correlation Rayleigh channel. In the case of high SNR. The approximate SOP was obtained over correlated lognormal fading channels [35]. SOP was derived from a correlated Nakagami-*m*/Gamma composite fading channels which considers both multipath fading and shadow fading [36]. Under the premise of the probability density function (PDF) provided in [37] over i.i.d. and correlated κ-μ shadowed fading channels, Zhang *et al.* in [38] derived high-order capacity statistics of spectrum aggregation systems with maximal ratio combining (MRC) scheme.

Unlike reference [31], this paper extends security performance analysis to multi-antenna scenarios, and studies the effects of correlation and independence between antennas on physical layer security performance. To the best of the authors' knowledge, there is no work in the open literature that investigated the performance of PLS on the correlated κ-μ shadowed fading channels. To compensate for this gap, we dedicate this paper to study the security performance for κ-μ shadowed fading channels based on two scenarios, namely, correlation and i.i.d.. The main contribution of this work resides in deriving closed-form analytical expressions of both SOP and SPSC over correlated and i.i.d. SIMO κ-μ

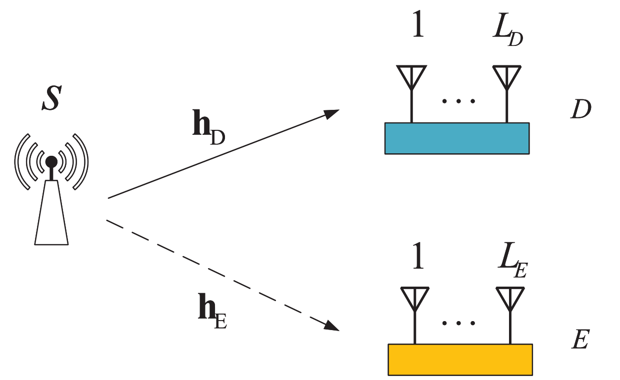

FIGURE 1. System model.

fading channels.[1] The analytical method can be applied to other fading channels when the correlated PDF are given. All derived expressions contain only well-known power series and gamma functions. Moreover, the theoretical results are confirmed via Monte Carlo simulations.

The structure of this paper is as follows. Section II describes the system model as well as PDF and the cumulative density function (CDF) for SIMO systems in correlated and i.i.d. κ-μ shadowed distribution. In Section III, we present the derivation of SOP and the probability of SPSC over the correlated SIMO κ-μ shadowed fading channels. Section IV derives the expressions for the SOP and SPSC over the i.i.d. SIMO κ-μ shadowed fading channels, and in Section V, the results of theoretical analysis and statistical simulations are compared and the influence of channel parameters on the secrecy performance is given. Finally, we summarize the paper in Section VI.

II. SYSTEM MODEL AND STATISTICAL CHARACTERISTICS OF THE SIMO κ-μ SHADOWED DISTRIBUTION

A. SYSTEM MODEL

As illustrated in Fig. 1, the system model considered in this paper is the classical Wyner's wiretap model which involves a sender (S) with single antenna, a legal receiver (D) with L_D antennas and an eavesdropper (E) with L_E antennas. We define the channel from S to D as the main channel and the channel from S to E as the eavesdropper channel. Confidential signals are transmitted through the main channel. However, the eavesdropper can also get the signal through the eavesdropper channel. It is assumed that both channels are correlated or i.i.d. SIMO κ-μ shadowed fading channels. Moreover, in a coherent time block, the receiver has enough time to process the received signal, and the fading coefficients remain unchanged. Thus, the signals at the receivers, D and E, can be written as

$$\mathbf{y}_i = \mathbf{h}_i x + \mathbf{n}, i \in \{D, E\}, \tag{1}$$

[1] In addition, the ASC is also a fundamental secrecy performance metric, which denotes the average maximum achievable secrecy rate, this problem will be as our future work.

where x is the confidential signal transmitted from S, $\mathbf{h}_i \in \mathbb{C}^{N_t\times 1}$ represents the SIMO κ-μ shadowed fading vector between the sender and the multi-antenna receiver, the symbol $\mathbb{C}$ denotes a set of complex numbers, $\mathbf{y}_i \in \mathbb{C}^{N_t\times 1}$ is the received signal vector, $i \in \{D, E\}$ represents the main channel or the eavesdropper channel, and $\mathbf{n} \sim \mathcal{CN}(0, \sigma^2)$ is a complex Gaussian vector with zero mean value and fixed standard deviation σ.

B. STATISTICAL CHARACTERISTICS OF THE SIMO κ-μ SHADOWED FADING

The κ-μ shadowed fading channels is closer to the actual environment because it can reflect the random variation of inhomogeneous fading channels. Furthermore, some statistical properties of the channel, such as the PDF, CDF and the moment generating function (MGF) can be expressed in closed-form, hence, the κ-μ shadowed model has excellent analytical characteristics. In the considered system model, the main and eavesdropper channels both undergo correlated or i.i.d. SIMO k-μ shadowed fading. Referring to [27], we can obtain the PDF of κ-μ shadowed random variable (RV) as

$$\begin{aligned} f_i(\gamma) = & \frac{{\mu_i}^{\mu_i} {m_i}^{m_i}(1+k_i)^{\mu_i}}{\Gamma(\mu_i)(\mu_i k_i + m_i)^{m_i} {\Omega_i}^{\mu_i}} \gamma^{\mu_i - 1} \\ & \times \exp\left(-\frac{\mu_i(1+k_i)}{\Omega_i}\gamma\right) \\ & \times {}_1F_1\left(m_i, \mu_i; \frac{\mu_i^2 k_i(1+k_i)}{(\mu_i k_i + m_i)\Omega_i}\gamma\right), \quad i \in \{D, E\}, \end{aligned} \tag{2}$$

where k_i, μ_i and m_i denote the fading parameters of κ-μ shadowed fading channels, and Ω_i is the average SNR, subscript i indicates the main channel or the eavesdropper channel, $\Gamma(\cdot)$ is the Gamma function as defined in [39, Eq. (8.310.1)] and ${}_1F_1(\cdot)$ is the confluent hypergeometric function [39, Eq. (9.14.1)].

We consider that the combination method used by the receiver is the MRC scheme. Therefore, the instantaneous SNR of the main channel or the eavesdropper channel can be written as

$$\gamma_i = \sum_{j=1}^{L_i} \gamma_{i,j}, i \in \{D, E\}. \tag{3}$$

where $\gamma_{i,j}$ represents received SNR at jth antenna of the main channel or the eavesdropper channel.

1) SUM OF CORRELATED SQUARED κ-μ SHADOWED RVS

With the help of [38], we can obtain the PDF of the sum of L correlated squared κ-μ shadowed RVs as

$$\begin{aligned} f_{cor,i}(\gamma) = & A_i\left(\frac{\eta_i}{\Omega_i}\right)^{U_i} \gamma^{U_i - 1} \exp\left(-\frac{\eta_i}{\Omega_i}\gamma\right) \sum_{k=0}^{\infty} D_k \\ & \times {}_1F_1\left(Lm_i + k_i, U_i; \frac{\eta_i \gamma}{\Omega_i(1+{\lambda_i}^{-1})}\right), \end{aligned} \tag{4}$$

where $i \in \{D, E\}$ represents the main or the eavesdropper channel, $U = \sum_{l=1}^{L}\mu_l$, $\eta = \sum_{l=1}^{L}\mu_l(1+k_l)$,

$A = \prod_{l=1}^{L} (\lambda_1/\lambda_l)^m$, where $\lambda_1 = \min\{\lambda_l\}$ and $\{\lambda_l\}_{l=1}^{L}$ are the eigenvalues of the matrix $\mathbf{DC}$ in which $\mathbf{D} = \mathrm{diag}\{\mu_l k_l/m\}_{l=1}^{L}$ and $\mathbf{C}$ represents the $L \times L$ positive define matrix given by

$$\mathbf{C} = \begin{bmatrix} 1 & \sqrt{\rho_{12}} & \cdots & \sqrt{\rho_{1L}} \\ \sqrt{\rho_{21}} & 1 & \cdots & \sqrt{\rho_{2L}} \\ \vdots & \vdots & \ddots & \vdots \\ \sqrt{\rho_{L1}} & \sqrt{\rho_{L2}} & \cdots & 1 \end{bmatrix}, \qquad (5)$$

where $\rho_{ij} \in [0, 1]$ is the correlation coeffcient of the dominating components of the κ-μ shadowed RVs, the parameter D_k in (4) can be calculated by

$$D_k = \frac{\delta_k}{\lambda_1^{Lm+k}\Gamma(U)}(1+\lambda_1)^{-(Lm+k)}, \quad k = 0, 1, \ldots, \qquad (6)$$

where δ_k can be recursively obtained with $\delta_0 = 1$ using

$$\delta_k = \frac{m}{k+1}\sum_{i=1}^{k+1}\left[\sum_{j=1}^{L}\left(1-\frac{\lambda_1}{\lambda_J}\right)^i\right]\delta_{k+1-i}, \quad k = 0, 1, \ldots. \qquad (7)$$

Utilizing the series representation

$${}_1F_1(a, b; x) = \sum_{q=0}^{\infty}\frac{(a)_q x^q}{(b)_q q!}, \qquad (8)$$

we can rewrite (4) as

$$f_{cor,i}(\gamma) = A_i\left(\frac{\eta_i}{\Omega_i}\right)^{U_i}\gamma^{U_i-1}\exp\left(-\frac{\eta_i}{\Omega_i}\gamma\right)\sum_{k=0}^{\infty}D_k \times \sum_{q=0}^{\infty}\frac{(Lm_i+k_i)_q}{(U_i)_q q!}\left(\frac{\eta_i}{\Omega_i(1+\lambda_i{}^{-1})}\gamma\right)^q, \qquad (9)$$

where $(a)_n = a(a+1)\cdots(a+n-1) = \Gamma(a+n)/\Gamma(a)$ is the pochammer symbol defined in [30].

Based on [39, Eq. (3.326.2)] and [39, Eq. (8.352.6)], the CDF of sum of L correlated squared κ-μ Shadowed RVs is derived as

$$F_{cor,i}(\gamma) = A_i\sum_{k=0}^{\infty}D_{k,i}\sum_{q=0}^{\infty}\frac{(Lm_i+k)_q}{(U_i)_q q!} \times \left(\frac{1}{1+\lambda_{1,i}{}^{-1}}\right)^q(U_i+q-1)! \times \left(1-\exp\left(\frac{\eta_D\gamma}{\Omega_D}\right)\sum_{s=0}^{U_i+q-1}\frac{(\eta_i\gamma)^s}{\Omega_i{}^s s!}\right). \qquad (10)$$

2) SUM OF I.I.D. SQUARED κ-μ SHADOWED RVS

If all the entries of $\mathbf{h}_i$ follow i.i.d. κ-μ shadowed distribution, the PDF of the sum of L i.i.d. squared κ-μ shadowed RVs is given by [38]

$$f_{i.i.d,i}(\gamma) = \left(\frac{L\mu_i(1+k_i)}{\Omega_i}\right)^{L\mu_i}\left(\frac{m_i}{m_i+k_i\mu_i}\right)^{Lm_i} \times \frac{\gamma^{L\mu_i-1}}{\Gamma(L\mu_i)}\exp\left(-\frac{L\mu_i(1+k_i)}{\Omega_i}\gamma\right) \times {}_1F_1\left(Lm_i, L\mu_i; \frac{Lk_i\mu_i{}^2(1+k_i)\gamma}{\Omega_i(m_i+k_i\mu_i)}\right), \qquad (11)$$

where L represents the number of receiving antennas at D or E.

Substituting (8) into (11), we can derive the PDF as

$$f_{i.i.d,i}(\gamma) = (La_i)^{L\mu_i}(b_i)^{-Lm_i}\frac{1}{\Gamma(L\mu_i)}\sum_{q=0}^{\infty}\frac{(Lm_i)_q}{(L\mu_i)_q q!} \times \left(\frac{La_ik_i\mu_i}{b_im_i}\right)^q\gamma^{L\mu_i+q-1}\exp\left(-La_i\gamma\right), \qquad (12)$$

where $a_i = \frac{\mu_i(1+k_i)}{\Omega_i}$, $b_i = \frac{\mu_ik_i+m_i}{m_i}$. Referring to (12) and [39, Eq. (3.326.2)], we can derive the CDF of the sum of L i.i.d. squared κ-μ shadowed RVs as

$$F_{i.i.d,i}(\gamma) = (b_i)^{-Lm_i}\frac{1}{\Gamma(L\mu_i)}\sum_{q=0}^{\infty}\frac{(Lm_i)_q\left(\frac{k_i\mu_i}{b_im_i}\right)^q}{(L\mu_i)_q q!} \times \Upsilon(L\mu_i+q, La_i\gamma), \qquad (13)$$

where $\Upsilon(\alpha, x) = \int_0^x e^{-t}t^{\alpha-1}dt$ is interpreted as the lower incomplete Gamma function [39, Eq. (8.350.1)]. By utilizing [39, Eq. (8.352.6)], (13) can be expressed in an alternative form as

$$F_{i.i.d,i}(\gamma) = (b_i)^{-Lm_i}\frac{1}{\Gamma(L\mu_i)}\sum_{q=0}^{\infty}\frac{(Lm_i)_q\left(\frac{k_i\mu_i}{b_im_i}\right)^q}{(L\mu_i)_q q!} \times (L\mu_i+q-1)! \times \left(1-\sum_{s=0}^{L\mu_i+q-1}\frac{(La_i)^s}{s!}\gamma^s\exp(-La_i\gamma)\right). \qquad (14)$$

III. SECRECY ANALYSIS OF SIMO SYSTEMS OVER CORRELATED κ-μ SHADOWED FADING CHANNELS

In this section, we assume that the RVs of each path at D or E are correlated with correlation coefficient ρ_{ij}, whereas the RVs between the main and the eavesdropper channels are uncorrelated. More specifically, we derive the analytical and asymptotic expressions for SOP and SPSC on correlated SIMO k-μ shadowed fading channels.

A. SOP ANALYSIS

As a significant measure to evaluate the security performance, the SOP denotes the probability that the target rate is greater than the instantaneous secrecy capacity [40]. According to [11], SOP can be expressed as

$$SOP = \int_0^{\infty}F_D(\Theta\gamma_E+\Theta-1)f_E(\gamma_E)d\gamma_E, \qquad (15)$$

where $\Theta = \exp(C_{th}) \geq 0$, and the meaning of C_{th} is target rate.

Theorem 1: For SIMO correlated k-μ shadowed fading channels, the analytical SOP is given as

$$\begin{aligned}
SOP_{cor} &= A_D A_E \sum_{k=0}^{\infty} D_{k,D} \sum_{n=0}^{\infty} D_{n,E} \\
&\times \sum_{q=0}^{\infty}\sum_{p=0}^{\infty} \frac{(L_D m_D+k)_q}{(U_D)_q q!}\left(\frac{1}{1+\lambda_{1,D}{}^{-1}}\right)^q \\
&\times \frac{(L m_E+n)_p}{(U_E)_p p!}\left(\frac{\eta_E}{\Omega_E}\right)^{U_E+p}\left(\frac{1}{1+\lambda_{1,E}{}^{-1}}\right)^p \\
&\times (U_D+q-1)! \left(\frac{\Gamma(U_E+p)}{\left(\frac{\eta_E}{\Omega_E}\right)^{U_E+p}}\right. \\
&- \exp\left(-\frac{\eta_D}{\Omega_D}(\Theta-1)\right)\sum_{s=0}^{U_D+q-1}\frac{\eta_D{}^s}{\Omega_D{}^s s!}\sum_{t=0}^{s}\binom{s}{t} \\
&\left.\times \Theta^t(\Theta-1)^{s-t}\frac{\Gamma(U_E+p+t)}{\left(\frac{\eta_E}{\Omega_E}+\Theta\frac{\eta_D}{\Omega_D}\right)^{U_E+p+t}}\right), \qquad (16)
\end{aligned}$$

where $(\cdot)!$ is the factorial operation, $\binom{s}{t}=\frac{s}{s!(s-t)!}$ denotes the binomial coefficient.

Proof: According to (15), (4) and (10), the SOP can be obtained as

$$\begin{aligned}
SOP_{cor} &= \int_0^{\infty} A_D \sum_{k=0}^{\infty} D_{k,D} \sum_{q=0}^{\infty}\frac{(L_D m_D+k)_q}{(U_D)_q q!} \\
&\times \left(\frac{1}{1+\lambda_{1,D}{}^{-1}}\right)^q (U_D+q-1)! \\
&\times \left(1-\exp\left(-\frac{\eta_D}{\Omega_D}(\Theta\gamma_E+\Theta-1)\right)\right. \\
&\left.\times \sum_{s=0}^{U_D+q-1}\frac{\eta_D{}^s}{\Omega_D{}^s s!}\sum_{t=0}^{s}\binom{s}{t}\Theta^t(\Theta-1)^{s-t}\gamma_E{}^t\right) \\
&\times A_E\left(\frac{\eta_E}{\Omega_E}\right)^{U_E}\sum_{n=0}^{\infty} D_{n,E} \\
&\times \sum_{p=0}^{\infty}\frac{(L m_E+n)_p}{(U_E)_p p!}\left(\frac{\eta_E}{\Omega_E(1+\lambda^{-1})}\right)^p \\
&\times \gamma_E{}^{U_E+p-1}\exp\left(-\frac{\eta_E}{\Omega_E}\gamma_E\right)d\gamma_E \qquad (17)
\end{aligned}$$

In addition to the constant coefficients, the integral term contains a power function and an exponential function in (17). Employing [39, Eq. (3.326.2)], and after some simple manipulations, we can finally derive the SOP as (16).

Corollary 1: In the high-SNR regime ($\Omega_D \to \infty$), the asymptotic SOP on correlated SIMO k-μ shadowed fading channels can be given as

$$\begin{aligned}
SOP_{cor}^{\infty} &= A_D A_E \sum_{k=0}^{\infty} D_{k,D} \sum_{n=0}^{\infty} D_{n,E} \\
&\times \sum_{p=0}^{\infty}\frac{(L m_E+n)_p}{(U_E)_p p!}\left(\frac{\eta_E}{\Omega_E}\right)^{U_E+p} \\
&\times \left(\frac{1}{1+\lambda_{1,E}{}^{-1}}\right)^p \sum_{q=0}^{\infty}\frac{(L m_D+k)_q}{(U_D)_q q!} \\
&\times \left(\frac{1}{1+\lambda_{1,D}{}^{-1}}\right)^q \frac{\left(\frac{\eta_D}{\Omega_D}\right)^{U_D+q}}{U_D+q}\sum_{s=0}^{U_D+q}\binom{U_D+q}{s} \\
&\times \Theta^s(\Theta-1)^{U_D+q-s}\frac{\Gamma(U_E+p+s)}{\left(\frac{\eta_E}{\Omega_E}\right)^{U_D+p+s}}. \qquad (18)
\end{aligned}$$

Proof: According to the known equation provided as $\exp(x)=\sum_{i=0}^{\infty}\frac{x^i}{i!}$, when $\Omega_D \to \infty$, we can derive

$$\sum_{s=0}^{U_D+q-1}\frac{(\eta_D\gamma)^s}{\Omega_D{}^s s!}=\exp\left(\frac{\eta_D\gamma}{\Omega_D}\right)-\frac{\left(\frac{\eta_D\gamma}{\Omega_D}\right)^{U_D+q}}{(U_D+q)!}-o\left(\frac{\eta_D\gamma}{\Omega_D}\right), \qquad (19)$$

where $o(\cdot)$ is items of high order. Therefore, we can transform (10) into

$$\begin{aligned}
&F_{cor,D}^{\infty}(\gamma) \\
&= A_D \sum_{k=0}^{\infty} D_{k,D}\sum_{q=0}^{\infty}\frac{(L_D m_D+k)_q}{(U_D)_q q!} \\
&\times \left(\frac{1}{1+\lambda_{1,D}{}^{-1}}\right)^q \frac{\left(\frac{\eta_D\gamma}{\Omega_D}\right)^{U_D+q}}{U_D+q}\exp\left(-\frac{\eta_D}{\Omega_D}\gamma\right). \qquad (20)
\end{aligned}$$

Using (9) and (20), SOP in the high-SNR regime can be expressed as

$$\begin{aligned}
SOP_{cor}^{\infty} &= \int_0^{\infty} F_{cor,D}^{\infty}(\Theta\gamma_E+\Theta-1)f_{cor,E}(\gamma_E)d\gamma_E \\
&= A_D A_E \sum_{k=0}^{\infty} D_{k,D}\sum_{n=0}^{\infty} D_{n,E}\sum_{p=0}^{\infty}\frac{(L m_E+n)_p}{(U_E)_q p!} \\
&\times \left(\frac{\eta_E}{\Omega_E}\right)^{U_E+p}\left(\frac{1}{1+\lambda_{1,E}{}^{-1}}\right)^p\sum_{q=0}^{\infty}\frac{(L m_D+k)_q}{(U_D)_q q!} \\
&\times \left(\frac{1}{1+\lambda_{1,D}{}^{-1}}\right)^q\frac{\left(\frac{\eta_D}{\Omega_D}\right)^{U_D+q}}{U_D+q}\sum_{s=0}^{U_D+q}\binom{U_D+q}{s} \\
&\times \Theta^s(\Theta-1)^{U_D+q-s}\int_0^{\infty}\gamma_E{}^s\exp\left(-\frac{\eta_D\Theta\gamma_E}{\Omega_D}\right) \\
&\times \gamma_E{}^{U_E-1}\exp\left(-\frac{\eta_E}{\Omega_E}\gamma_E\right)\gamma_E{}^p d\gamma_E. \qquad (21)
\end{aligned}$$

By means of [39, Eq. (3.326.2)], and after some simple integral operations, (18) is obtained.

From (16) and (18), we can see that the expression of SOP contains only elementary functions, moreover, SOP is an decreasing function with regard to Ω_D which is the average SNR of main channel.

B. SPSC ANALYSIS

Another essential benchmark considered is SPSC which means the probability of existence of strictly positive secrecy capacity [40], SOP is the probability that the instantaneous secrecy capacity is less than a certain target value, while SPSC represents the probability that the instantaneous secrecy capacity is greater than zero. SPSC can be obtained by [11] as

$$SPSC = 1 - \int_0^\infty F_D(\gamma_E) f_E(\gamma_E) d\gamma_E. \tag{22}$$

Theorem 2: For SIMO correlated k-μ shadowed fading channels, the analytical SPSC is derived as

$$\begin{aligned} SPSC_{cor} &= 1 - A_D A_E \sum_{k=0}^\infty D_{k,D} \sum_{n=0}^\infty D_{n,E} \\ &\times \sum_{q=0}^\infty \sum_{p=0}^\infty \frac{(L_D m_D + k)_q}{(U_D)_q q!} \left(\frac{1}{1+\lambda_{1,D}{}^{-1}}\right)^q \\ &\times (U_D + q - 1)! \frac{(Lm_E + n)_p}{(U_E)_p p!} \left(\frac{\eta_E}{\Omega_E}\right)^{U_E+p} \\ &\times \left(\frac{1}{1+\lambda_{1,E}{}^{-1}}\right)^p \left(\frac{\Gamma(U_E+p)}{\left(\frac{\eta_E}{\Omega_E}\right)^{U_E+p}} \right. \\ &\left. - \sum_{s=0}^\infty \frac{\eta_D{}^s}{\Omega_D{}^s s!} \frac{\Gamma(U_E+p+s)}{\left(\frac{\eta_E}{\Omega_E}+\frac{\eta_D}{\Omega_D}\right)^{U_E+p+s}} \right). \end{aligned} \tag{23}$$

Proof: Substituting (4) and (10) into (22), SPSC can be presented as

$$\begin{aligned} SPSC_{cor} &= 1 - \int_0^\infty F_{cor,D}(\gamma_E) f_{cor,E}(\gamma_E) d\gamma_E \\ &= 1 - \int_0^\infty A_D \sum_{k=0}^\infty D_{k,D} \sum_{q=0}^\infty \frac{(L_D m_D + k)_q}{(U_D)_q q!} \\ &\times \left(\frac{1}{1+\lambda_{1,D}{}^{-1}}\right)^q (U_D+q-1)! \\ &\times \left(1 - \exp\left(-\frac{\eta_D}{\Omega_D}\gamma_E\right) \sum_{s=0}^{U_D+q-1} \frac{\eta_D{}^s}{\Omega_D{}^s s!} \gamma_E{}^s\right) \\ &\times A_E \left(\frac{\eta_E}{\Omega_E}\right)^{U_E} \sum_{n=0}^\infty D_{n,E} \sum_{p=0}^\infty \frac{(Lm_E+n)_p}{(U_E)_p p!} \\ &\times \left(\frac{\eta_E}{\Omega_E}\right)^p \left(\frac{1}{1+\lambda_{1,E}{}^{-1}}\right)^p \\ &\times \gamma_E{}^{U_E+p-1} \exp\left(-\frac{\eta_E}{\Omega_E}\gamma_E\right) d\gamma_E. \end{aligned} \tag{24}$$

As suggested by [39, Eq. (3.326.2)], we can finally derive the expression of (23) after some algebraic operations.

Corollary 2: In the high-SNR regime ($\Omega_D \to \infty$), the asymptotic SPSC on correlated SIMO k-μ shadowed fading channels can be given as

$$\begin{aligned} SPSC_{cor}^\infty &= 1 - A_D A_E \sum_{k=0}^\infty D_{k,D} \sum_{n=0}^\infty D_{n,E} \\ &\times \sum_{q=0}^\infty \frac{(Lm_D+k)_q}{(U_D)_q q!} \left(\frac{1}{1+\lambda_{1,D}{}^{-1}}\right)^q \frac{\left(\frac{\eta_D}{\Omega_D}\right)^{U_D+q}}{U_D+q} \\ &\times \sum_{p=0}^\infty \frac{(Lm_E+n)_p}{(U_E)_q p!} \left(\frac{\eta_E}{\Omega_E}\right)^{U_E+p} \\ &\times \left(\frac{1}{1+\lambda_E{}^{-1}}\right)^p \frac{\Gamma\left(U_E+p+U_D+q\right)}{\left(\frac{\eta_E}{\Omega_E}\right)^{U_E+p+U_D+q}}. \end{aligned} \tag{25}$$

Proof: Substituting (9) and (20) into (22), when $\Omega_D \to \infty$, the asymptotic SPSC is obtained as

$$\begin{aligned} SPSC_{cor}^\infty &= 1 - \int_0^\infty F_{cor,D}^\infty(\gamma_E) f_{cor,E}(\gamma_E) d\gamma_E \\ &= 1 - \int_0^\infty A_D \sum_{k=0}^\infty D_{k,D} \sum_{q=0}^\infty \frac{(Lm_D+k)_q}{(U_D)_q q!} \\ &\times \left(\frac{1}{1+\lambda_{1,D}{}^{-1}}\right)^q \frac{\left(\frac{\eta_D \gamma_E}{\Omega_D}\right)^{U_D+q}}{U_D+q} \\ &\times A_E \left(\frac{\eta_E}{\Omega_E}\right)^{U_E} \gamma_E^{U_E-1} \exp\left(-\frac{\eta_E}{\Omega_E}\gamma_E\right) \sum_{n=0}^\infty D_{n,E} \\ &\times \sum_{p=0}^\infty \frac{(Lm_E+n)_p}{(U_E)_q p!} \left(\frac{\eta_E}{\Omega_E(1+\lambda_E{}^{-1})}\gamma_E\right)^p d\gamma_E. \end{aligned} \tag{26}$$

Then, making use of [39, Eq. (3.326.2)], we can derive the expression of (26).

It should be noted that the value of SPSC increases with the increase of Ω_D, which means that a larger Ω_D can lead to higher security performance.

In summary, (16) and (23) represent the SOP and SPSC of SIMO systems over correlated κ-μ shadowed fading channels, respectively. Correlation and i.i.d. are the relationship between multiple antennas of the receiver, which can be applicable to different practical scenarios. In addition, i.i.d. channel model is a special case of the correlation ($\rho_{ij} = 0$, $i \neq j$). For the sake of understanding the PLS performance on SIMO κ-μ shadowed fading channels more deeply, it is necessary to explore the security performance of i.i.d. channels. Based on this, we provide the closed-form expressions for SOP and SPSC in the following chapter.

IV. SECRECY ANALYSIS OF SIMO SYSTEMS OVER I.I.D. κ-μ SHADOWED FADING CHANNELS

In this section, we further investigate the secrecy performance of i.i.d. SIMO κ-μ shadowed fading channels in terms of SOP and SPSC.

A. SOP ANALYSIS

Theorem 3: For SIMO i.i.d. k-μ shadowed fading channels, the analytical SOP is given as

$$\begin{aligned} SOP_{i.i.d} &= (La_E)^{L\mu_E}(b_E)^{-Lm_E}(b_D)^{-Lm_D} \\ &\times \frac{1}{\Gamma(L\mu_E)}\sum_{p=0}^{\infty}\sum_{q=0}^{\infty}\frac{(Lm_E)_p}{(L\mu_E)_p p!}\left(\frac{La_E k_E\mu_E}{b_E m_E}\right)^p \\ &\times \frac{(Lm_D)_q}{(L\mu_D)_q q!}\left(\frac{k_D\mu_D}{b_D m_D}\right)^q (L\mu_D+q-1)! \\ &\times \frac{1}{\Gamma(L\mu_D)}\left(\frac{\Gamma(L\mu_E+p)}{(La_E)^{L\mu_E+p}}\right. \\ &- \sum_{s=0}^{L\mu_D+q-1}\exp(-La_D(\Theta-1))\frac{(La_D)^s}{s!} \\ &\times \sum_{t=0}^{s}\binom{s}{t}\Theta^t(\Theta-1)^{s-t} \\ &\times \left.\frac{\Gamma(L\mu_E+p+t)}{\Gamma(L\Theta a_D+La_E)^{L\mu_E+p+t}}\right). \end{aligned} \tag{27}$$

Proof: According to (13) and [39, Eq. (1.111)], we can obtain the CDF of SNR at legal receiver (D) as

$$\begin{aligned} &F_{i.i.d,D}(\Theta\gamma_E+\Theta-1) \\ &= (b_D)^{-Lm_D}\frac{1}{\Gamma(L\mu_D)} \\ &\quad\times\sum_{q=0}^{\infty}\frac{(Lm_D)_q}{(L\mu_D)_q q!}\left(\frac{k_D\mu_D}{b_D m_D}\right)^q (L\mu_D+q-1)! \\ &\quad\times\left(1-\exp(-La_D\Theta\gamma_E-La_D(\Theta-1))\right. \\ &\quad\times\sum_{s=0}^{L\mu_D+q-1}\frac{(La_D)^s}{s!} \\ &\quad\times\left.\sum_{t=0}^{s}\binom{s}{t}\Theta^t{\gamma_E}^t(\Theta-1)^{s-t}\right). \end{aligned} \tag{28}$$

Referring to (12), the PDF of SNR at eavesdropper (E) is expressed as

$$\begin{aligned} f_{i.i.d,E}(\gamma) &= (La_E)^{L\mu_E}(b_E)^{-Lm_E}\frac{1}{\Gamma(L\mu_E)} \\ &\quad\times\sum_{q=0}^{\infty}\frac{(Lm_E)_q\left(\frac{La_E k_E\mu_E}{b_E m_E}\right)^q}{(L\mu_E)_q q!} \\ &\quad\times\gamma^{L\mu_E+q-1}\exp\left(-La_E\gamma\right), \end{aligned} \tag{29}$$

substituting (28) and (29) into (15) and utilizing [39, Eq. (3.326.2)], after some integral and algebraic operations, we can complete the proof of (27).

Corollary 3: In the high-SNR regime ($\Omega_D \to \infty$), the asymptotic SOP on i.i.d. SIMO k-μ shadowed fading channels can be given as

$$\begin{aligned} SOP_{i.i.d}^{\infty} &= (b_D)^{-Lm_D}(b_E)^{-Lm_E}(La_E)^{L\mu_E} \\ &\times\frac{1}{\Gamma(L\mu_D)}\frac{1}{\Gamma(L\mu_E)}\sum_{q=0}^{\infty}\frac{(Lm_D)_q\left(\frac{k_D\mu_D}{b_D m_D}\right)^q}{(L\mu_D)_q q!} \\ &\times\frac{(La_D)^{L\mu_D+q}}{L\mu_D+q}\sum_{p=0}^{\infty}\frac{(Lm_E)_p}{(L\mu_E)_p p!}\left(\frac{La_E k_E\mu_E}{b_E m_E}\right)^p \\ &\times\sum_{s=0}^{L\mu_D+q}\binom{L\mu_D+q}{s}\Theta^s(\Theta-1)^{L\mu_D+q-s} \\ &\times\frac{\Gamma\left(L\mu_E+p+s\right)}{(La_E+La_D\Theta)^{L\mu_E+p+s}}. \end{aligned} \tag{30}$$

Proof: Similar to the proof in section III, the CDF for i.i.d. SIMO k-μ shadowed fading channels at legitimate receiver (D) in the high-SNR system is obtained as

$$\begin{aligned} F_{i.i.d,D}^{\infty}(\gamma) = (b_D)^{-Lm_D}&\frac{1}{\Gamma(L\mu_D)}\sum_{q=0}^{\infty}\frac{(Lm_D)_q}{(L\mu_D)_q q!} \\ &\times\left(\frac{k_D\mu_D}{b_D m_D}\right)^q\frac{(La_D\gamma)^{L\mu_D+q}}{L\mu_D+q}. \end{aligned} \tag{31}$$

Substituting (31) and (12) into (15), we can obtain

$$\begin{aligned} SOP_{i.i.d}^{\infty} &= \int_0^{\infty}F_{i.i.d,D}^{\infty}(\Theta\gamma_E+\Theta-1)f_{i.i.d,E}(\gamma_E)d\gamma_E \\ &= (b_D)^{-Lm_D}(b_E)^{-Lm_E}(La_E)^{L\mu_E}\frac{1}{\Gamma(L\mu_D)}\frac{1}{\Gamma(L\mu_E)} \\ &\quad\times\sum_{s=0}^{L\mu_D+q}\binom{L\mu_D+q}{s}\Theta^s(\Theta-1)^{L\mu_D+q-s} \\ &\quad\times\sum_{p=0}^{\infty}\frac{(Lm_E)_p}{(L\mu_E)_p p!}\left(\frac{La_E k_E\mu_E}{b_E m_E}\right)^p \\ &\quad\times\int_0^{\infty}{\gamma_E}^{L\mu_E+p+s-1}\exp\left(-La_E\gamma_E\right)d\gamma_E. \end{aligned} \tag{32}$$

Then, the derivation of (30) is completed by using [39, Eq. (3.326.2)].

B. SPSC ANALYSIS

Theorem 4: For SIMO i.i.d. k-μ shadowed fading channels, the analytical SPSC is obtained as

$$\begin{aligned} SPSC_{i.i.d} &= 1-(b_D)^{-Lm_D}(b_E)^{-Lm_E}(La_E)^{L\mu_E} \\ &\times\frac{1}{\Gamma(L\mu_D)}\frac{1}{\Gamma(L\mu_E)}\sum_{q=0}^{\infty}\sum_{p=0}^{\infty}\frac{(Lm_E)_p}{(L\mu_E)_p p!} \\ &\times\left(\frac{La_E k_E\mu_E}{b_E m_E}\right)^p\frac{(Lm_D)_q}{(L\mu_D)_q q!}\left(\frac{k_D\mu_D}{b_D m_D}\right)^q \end{aligned}$$

$$\times (L\mu_D + q - 1)! \left(\frac{\Gamma(L\mu_E + p)}{(La_E)^{L\mu_E+p}} - \sum_{s=0}^{L\mu_D+q-1} \frac{(La_D)^s \Gamma(L\mu_E + p + s)}{s!(La_E + La_D)^{L\mu_E+p+s}} \right). \quad (33)$$

Proof: By using (22), SPSC can be expressed as

$$\begin{aligned} SPSC_{i.i.d} &= 1 - \int_0^\infty F_{i.i.d,D}(\gamma_E) f_{i.i.d,E}(\gamma_E) d\gamma_E \\ &= 1 - \frac{1}{\Gamma(L\mu_D)} \int_0^\infty \sum_{q=0}^\infty \frac{(Lm_D)_q}{(L\mu_D)_q q!} \\ &\quad \times (b_D)^{-Lm_D} \left(\frac{k_D\mu_D}{b_D m_D}\right)^q (L\mu_D + q - 1)! \\ &\quad \times \left(1 - \exp(-La_D\gamma_E) \sum_{s=0}^{L\mu_D+q-1} \frac{(La_D\gamma_E)^s}{s!}\right) \\ &\quad \times (La_E)^{L\mu_E} (b_E)^{-Lm_E} \frac{1}{\Gamma(L\mu_E)} \\ &\quad \times \sum_{p=0}^\infty \frac{(Lm_E)_p}{(L\mu_E)_p p!} \left(\frac{La_E k_E \mu_E}{b_E m_E}\right)^p \\ &\quad \times \gamma_E^{L\mu_E+p-1} \exp(-La_E\gamma_E) d\gamma_E. \end{aligned} \quad (34)$$

With the aid of [39, Eq. (3.326.2)], we can get the derivation of SPSC as in (33).

Corollary 4: In the high-SNR regime ($\Omega_D \to \infty$), the asymptotic SPSC on i.i.d. SIMO k-μ shadowed fading channels can be given as

$$\begin{aligned} SPSC^\infty_{i.i.d} &= 1 - (b_D)^{-Lm_D} (b_E)^{-Lm_E} (La_E)^{L\mu_E} \\ &\quad \times \frac{1}{\Gamma(L\mu_D)} \frac{1}{\Gamma(L\mu_E)} \sum_{q=0}^\infty \frac{(Lm_D)_q \left(\frac{k_D\mu_D}{b_D m_D}\right)^q}{(L\mu_D)_q q!} \\ &\quad \times \frac{(La_D)^{L\mu_D+q}}{L\mu_D + q} \sum_{p=0}^\infty \frac{(Lm_E)_p}{(L\mu_E)_p p!} \\ &\quad \times \left(\frac{La_E k_E \mu_E}{b_E m_E}\right)^p \frac{\Gamma(L\mu_E + p + L\mu_D + q)}{(La_E)^{L\mu_E+p+L\mu_D+q}}. \end{aligned} \quad (35)$$

Proof: Similar to the proof in *corollary 3*, we can obtain SPSC In the high-SNR regime as

$$\begin{aligned} SPSC^\infty_{i.i.d} &= 1 - \int_0^\infty F^\infty_{i.i.d,D}(\gamma_E) f_{i.i.d,E}(\gamma_E) d\gamma_E \\ &= 1 - (b_D)^{-Lm_D} (b_E)^{-Lm_E} (La_E)^{L\mu_E} \frac{1}{\Gamma(L\mu_D)} \\ &\quad \times \frac{1}{\Gamma(L\mu_E)} \sum_{q=0}^\infty \frac{(Lm_D)_q \left(\frac{k_D\mu_D}{b_D m_D}\right)^q}{(L\mu_D)_q q!} \frac{(La_D)^{L\mu_D+q}}{L\mu_D + q} \\ &\quad \times \sum_{p=0}^\infty \frac{(Lm_E)_p}{(L\mu_E)_p p!} \left(\frac{La_E k_E \mu_E}{b_E m_E}\right)^p \\ &\quad \times \int_0^\infty \gamma_E^{L\mu_E+p+L\mu_D+q-1} \exp(-La_E\gamma_E) d\gamma_E. \end{aligned} \quad (36)$$

Referring to [39, Eq. (3.326.2)], we obtain (35).

V. NUMERICAL RESULTS

In this section, some numerical results for the analytical derivations of SOP and SPSC are provided. The analytical expressions of both SOP and SPSC over correlated and i.i.d. SIMO k-μ shadowed fading channels contain infinite series, through the simulation results in matlab, we obtain that the infinite series converges to a constant value when all the cycle times are greater than 55. By contrast, we present Monte Carlo simulations to validate our analysis. In all simulations, the parameters shared are as follows: $C_{th} = 1$ dB, $\Omega_D = \lambda\Omega_E$, where λ represents the ratio of the SNR of the main channel to the SNR of the eavesdropper channel. In Monte Carlo simulations, we generate k-μ shadowed RVs based on (2) and (9) by using the acceptance rejection method which can realize random number generator with arbitrary probability distribution. As seen from Figs. 2-13, the results of theoretical simulation and Monte Carlo simulation have very tight error margins. Further, we observe that the secrecy performance becomes excellent as increasing λ, since a higher λ means that the quality of main channel is better than that of the eavesdropper channel.

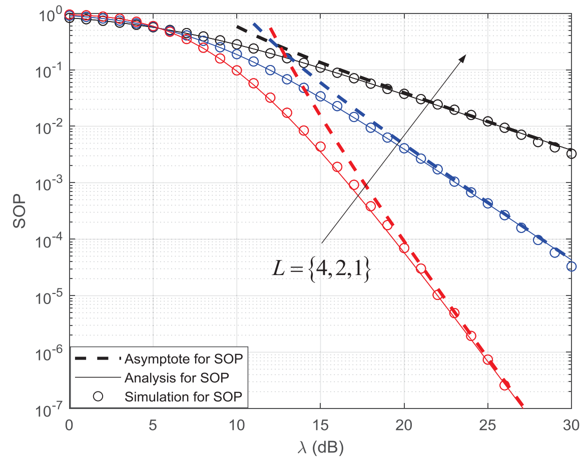

FIGURE 2. **Correlated SOP with changing L versus λ, $L = \{4, 2, 1\}$, $\rho = 0.2$, $k_D = k_E = 1$, $\mu_D = \mu_E = 1$, $m_D = m_E = 1$.**

In Figs. 2-7, simulations and analytical results are compared for SOP and SPSC versus λ over correlated SIMO k-μ shadowed fading channels. From Figs. 2-5, we can find that SPSC increases by increasing L and μ_D with $\lambda > 6$ dB, which means that large L and μ_D can improve secrecy performance. In Fig. 7, we can also find that when $\lambda < -2$ dB, SPSC increases with ρ increasing, where $\rho \in [0 \sim 1]$ is the correlation coefficient of the dominating components of the

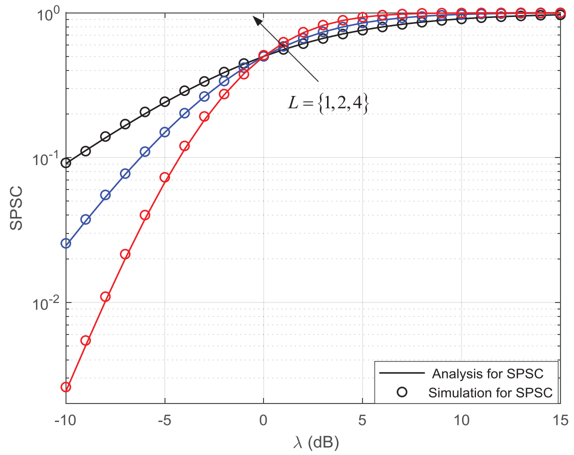

FIGURE 3. Correlated SPSC with changing L versus λ, $L = \{1, 2, 4\}$, $\rho = 0.2$, $k_D = k_E = 1$, $\mu_D = \mu_E = 1$, $m_D = m_E = 1$.

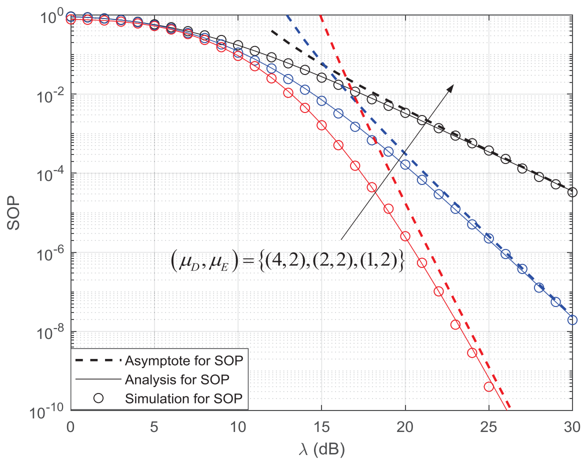

FIGURE 4. Correlated SOP with changing (μ_D, μ_E) versus λ, $(\mu_D, \mu_E) = \{(4, 2), (2, 2), (1, 2)\}$, $\rho = 0.2$, $k_D = k_E = 2$, $m_D = m_E = 1$, $L = 2$.

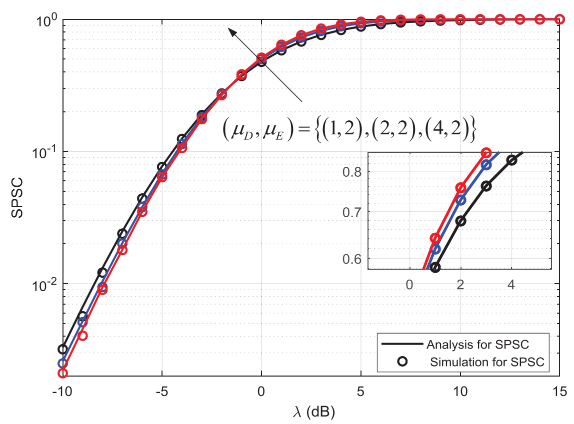

FIGURE 5. Correlated SPSC with changing (μ_D, μ_E) versus λ, $(\mu_D, \mu_E) = \{(1, 2), (2, 2), (4, 2)\}$, $\rho = 0.2$, $k_D = k_E = 2$, $m_D = m_E = 1$, $L = 2$.

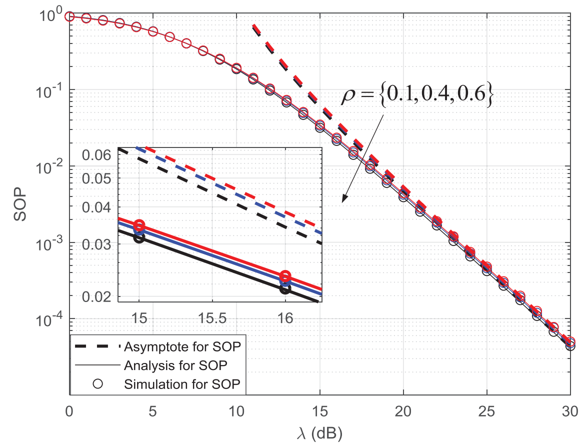

FIGURE 6. Correlated SOP with changing ρ versus λ, $\rho = \{0.1, 0.4, 0.6\}$, $k_D = k_E = 1$, $\mu_D = \mu_E = 1$, $m_D = m_E = 1$, $L = 2$.

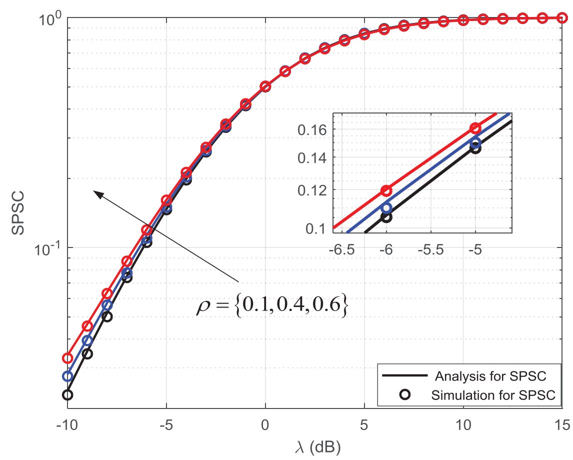

FIGURE 7. Correlated SPSC with changing ρ versus λ, $\rho = \{0.1, 0.4, 0.6\}$, $k_D = k_E = 1$, $\mu_D = \mu_E = 1$, $m_D = m_E = 1$, $L = 2$.

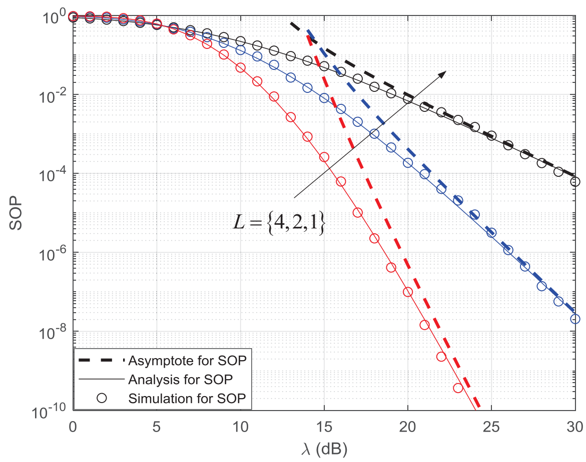

FIGURE 8. I.i.d. SOP with changing L versus λ, $L = \{4, 2, 1\}$, $k_D = k_E = 2$, $\mu_D = \mu_E = 2$, $m_D = m_E = 1$.

κ-μ shadowed RVs. Fig. 7 illustrates that when $\lambda < -2$ dB, large ρ is helpful in improving the performance of PLS. However, when $\lambda > 8$ dB, it can be seen from Fig. 6 that small ρ leads to low secure outage probability. Therefore, small ρ can increase security performance under the premise of $\lambda > 8$ dB, but the degree of improvement is not particularly obvious.

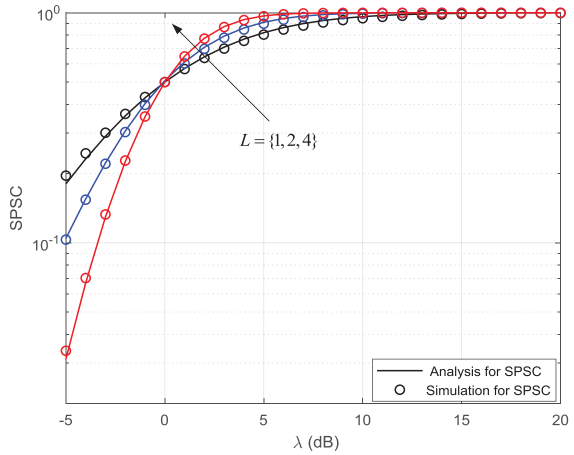

FIGURE 9. I.i.d. SPSC with changing L versus λ, $L = \{1, 2, 4\}$, $k_D = k_E = 2$, $\mu_D = \mu_E = 2$, $m_D = m_E = 1$.

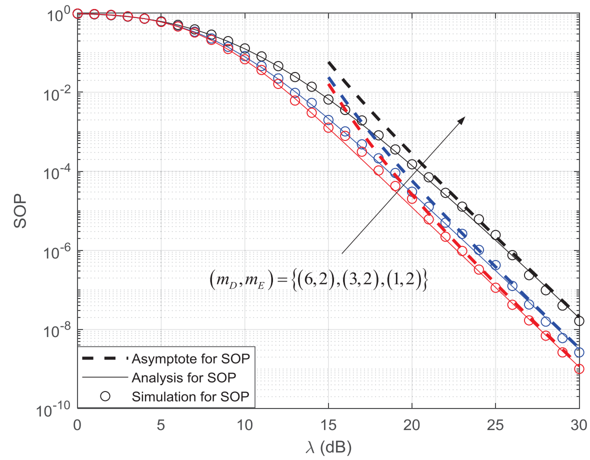

FIGURE 12. I.i.d. SOP with changing (m_D, m_E) versus λ, $(m_D, m_E) = \{(6, 2), (3, 2), (1, 2)\}$, $L = 2$, $k_D = k_E = 2$, $\mu_D = \mu_E = 2$.

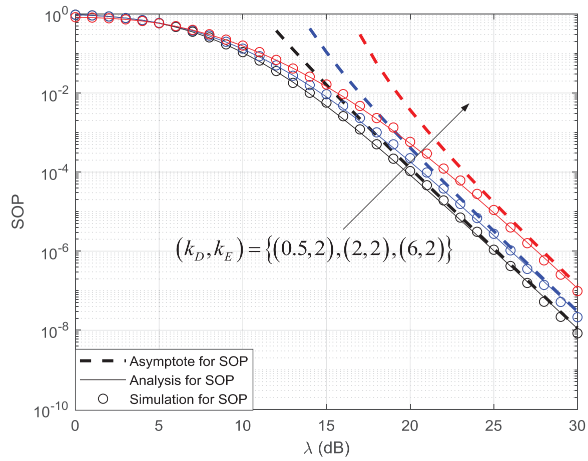

FIGURE 10. I.i.d. SOP with changing (k_D, k_E) versus λ, $(k_D, k_E) = \{(0.5, 2), (2, 2), (6, 2)\}$, $L = 2$, $\mu_D = \mu_E = 2$, $m_D = m_E = 1$.

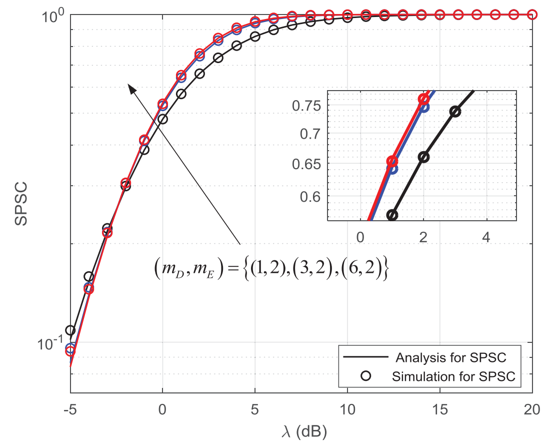

FIGURE 13. I.i.d. SPSC with changing (m_D, m_E) versus λ, $(m_D, m_E) = \{(1, 2), (3, 2), (6, 2)\}$, $L = 2$, $k_D = k_E = 2$, $\mu_D = \mu_E = 2$.

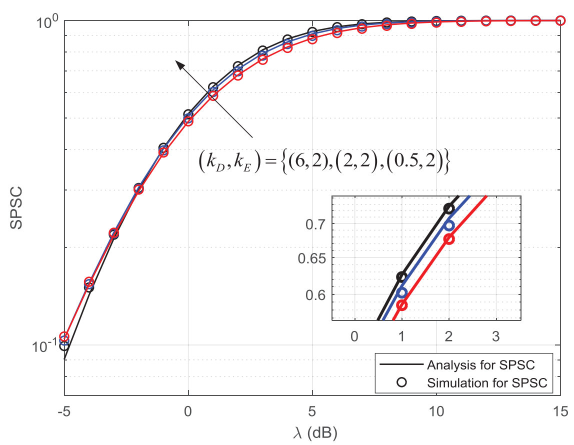

FIGURE 11. I.i.d. SPSC with changing (k_D, k_E) versus λ, $(k_D, k_E) = \{(6, 2), (2, 2), (0.5, 2)\}$, $L = 2$, $\mu_D = \mu_E = 2$, $m_D = m_E = 1$.

In Figs. 8-13, the analytical SOP and SPSC are compared with statistical simulations versus λ over i.i.d. SIMO k-μ shadowed fading channels. From Figs. 8 and 9, it can be seen that when $\lambda > 6$ dB, the curves of SOP decrease and the curves of SPSC increases with the increase of L, which is the number of receiving antennas for D and E. As shown in Fig. 10 and Fig. 11, SOP gradually increases and SPSC gradually decreases as k_D increasing with $\lambda > 2$ dB. Fig. 12 and Fig. 13 reveal that larger m_D leads to lower SOP and higher SPSC when $\lambda > 2$ dB. Consequently, when the channels undergo i.i.d. k-μ shadowed fading, we can get the following results: in the case of high λ, larger L, m_D and smaller k_D are help to enhance the secrecy performance of the considered system. On the contrary, when $\lambda < -2$ dB, smaller L, m_D and larger k_D contribute to the improvement of security performance.

VI. CONCLUSION

In this paper, we analyze the secrecy performance for the classic Wyner's model over SIMO correlated κ-μ shadowed channels. Exact analytical and asymptotic expressions for the SOP and SPSC are derived. Furthermore, as a special case of the correlation, the closed-form SOP and SPSC on SIMO system over i.i.d. κ-μ shadowed channels are presented. Finally, we provide Monte Carlo simulations to verify all the theoretical results and discuss the influences of correlation coefficient, antenna number, and channel parameters on the secrecy performance under different ratios of the SNR between the main channel and the eavesdropper channel.

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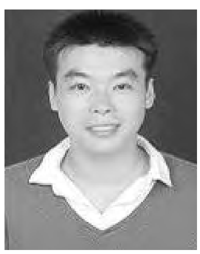

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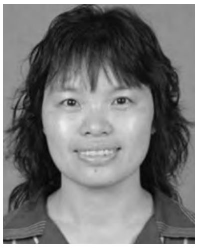

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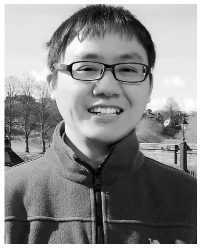

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