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On Physical Layer Security over SIMO κ-μ Shadowed Fading Channels

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Abstract: ***Background*****:** Because of the openness of wireless fading channel, it is easy to be disturbed by other transmission signals and noises. Encryption and decryption can guarantee the security of signals, and physical layer security (PLS) which uses the features of fading channels itself to ensure the security of signal transmission has also been widely concerned. In addition, considering the wide applications of κ-μ shadowed distribution model and the advantages of multiple-input multiple-output (MIMO) technology, we study the confidentiality over single-input multiple-output (SIMO) independent κ-μ shadowed model.

Objective: To introduce the factors affecting the confidentiality on SIMO independent κ-μ shadowed model.

Methods**:** Novel representations of the lower bound on SPSC and SOP are deduced over independent κ-μ shadowed model. we adopt the method of moment matching to deal with infinite series.

Results**:** Through theoretical simulation and statistical simulation, the validity of our analysis is verified. We also get the curves for SOP and SPSC when the parameters of the channel change.

Conclusion**:** Under the condition of larger P, large L, large μ_D, large m_D and small k_D can improve the secrecy performance on independent κ-μ shadowed network.

Keywords: Multi-antenna technology, generalized fading channel, moment matching method, SPSC, SOP, physical layer security.

1. INTRODUCTION

Nowadays, PLS has gained considerable attention as an enabling technology to provide reliability and dependability for the future secure communications without traditional encryption technology. On the basis of Shannon's perfect secrecy theory [1], Wyner defined a classic wiretap channel model to describe the process of information transmission among sender, legitimate user and eavesdropper [2]. Csiszar and Korner in [3] provided a definition of secrecy capacity and derived the SPSC, SOP and ASC over Rayleigh fading channel. In [4], two different environments namely diversity and non-diversity were introduced and analytical expressions for ergodic secrecy rate of wiretap channel were derived, respectively. Qiu *et al.* in [5] proposed a scheme based on a Gaussian Mixture Model and two dimensional characteristics to deal with spoofing attackers. When one or more eavesdroppers appear in the considered systems, three relay schemes: DF, AF and CJ were used to deal with the security of end-to-end communication [6]. The SOP was deduced and analyzed in MISO wireless sensor networks [7], cascaded networks [8] and cognitive DF system [9] when the channels experienced Nakagami-*m* fading.

Compared with SISO network, MIMO technology can achieve higher channel capacity without increasing additional antenna spectrum resources, so many literatures have tended to perform security analysis of different MIMO wireless channel. The authors first deduced the analytical expressions for secrecy capacity probability on Nakagami-*m* channel model under MRC and SC in [10]. To improve the security performance between two receivers equipped with multiple antennas, a transmit power minimization method based on precoding with presupposed SNR was proposed in [11]. Using moment matching method and zero forcing receivers, approximate closed-form expressions of the achievable sum rate, symbol **e**rror rate and outage probability for MIMO semi-correlated *K* distribution model were obtained in [12]. The authors obtained the ASC, SPSC and SOP on SIMO Generalized-*K* distribution model in [13]. The closed-form expressions of the ASC and SOP were used to analyze secre-

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cy performance on SIMO network over κ-μ distribution in [14]. Definite and approximate derivatives were analyzed to study the performance of PLS over SIMO α-μ distribution model in [15]. To address the confidentiality of multiple transmitted signals, a beamforming method was proposed to Improve the security performance of the system under consideration [16].

In a few years of recent, considerable literatures have focused on the performance analysis of generalized fading channels, which can be transformed into other fading channels and can model many application scenarios. According to the AF relay mode, the authors in [17] derived the expressions of ASC, SPSC and SOP on Generalized-*K* fading model. The ASC was provided and analyzed based on Wyner's model, in which the main channel underwent α-μ fading and the eavesdropping channel was κ-μ fading channels [18]. Performance analyses of relay cooperative networks over κ-μ model and α-μ model were studied in [19] and [20], respectively. The ASC and SOP over SISO α-η-κ-μ distribution model were presented in [21]. As a generalized fading channel model, the κ-μ shadowed model appeared for the first time in [22], which is a combination of small-scale fading and shadowed fading and can be converted to other channels such as Rayleigh, Rician shadowed, one-side Gaussian, Nakagami-*m* and κ-μ with the change of parameters. So far there have a few studies related to shadowed fading channels. Sun *et al.* performed an analysis of security over SISO κ-μ shadowed distribution model based on the well-known Wyner's wiretap model. Exact and approximate theoretical results for SPSC and the lower bound on the SOP were derived in [23]. the physical layer security performance of correlated network on κ-μ shadowed channels were studied in [24]. The performance of satellite communication link simulated by κ-μ shadowed channels was studied, and the expressions of average bit error rate, outage probability and ergodic capacity were given in [25]. The effective rate of MISO systems on independent and identically distributed κ-μ shadowed model were derived in [26]. the PDF for the sum of the squared κ-μ shadowed distribution was investigated in [27]. Zhang *et al.* in [28] derived high-order capacity statistics of spectrum aggregation systems under the MRC scheme on independent and correlated systems on κ-μ shadowed model.

As far as the author's knowledge is concerned, there is still not reported in the published literature which investigated the SOP and SPSC on MIMO κ-μ shadowed channel model using the moment matching method. Based on this, we studied the security performance of SIMO independent κ-μ shadowed distribution model by employing a moment matching method. The accurate theoretical equations for SPSC and the lower bound on SOP are derived. However, the infinite series that exists in the exact expressions makes it difficult for performance analysis. To overcome this problem, we further derive concise forms for SPSC and the lower bound on SOP based on an approximate method. The approximate expressions contain only Meijer G-function and Gamma function as we all know.

The paper is organized in the following form. We present the model of the system and channel statistics in Section 2. in Section 3, the derivation of the accurate theoretical expressions for the lower bound on SOP and SPSC over SIMO independent κ-μ shadowed distribution model are derived, respectively. we derive the approximate equations for the lower bound on SOP and SPSC utilizing a moment matching method in Section 4. Statistical simulation is provided to verify the correctness of our analysis in Section 5. The Section 6 is the conclusion of this paper.

The abbreviations used in this paper are shown as Table 1.

Table **1**. List of Abbreviations.

Full name	**Abbreviation**
physical layer security	PLS
multiple-input multiple-output	MIMO
single-input multiple-output	SIMO
multiple-input single-output	MISO
single-input single-output	SISO
signal-to-noise ratio	SNR
secure outage probability	SOP
strictly positive secrecy capacity	SPSC
average secrecy capacity	ASC
decode-and-forward	DF
amplify-and-forward	AF
cooperative jamming	CJ
maximal-ratio combining	MRC
selection combining	SC
cumulative density function	CDF
probability density function	PDF
random variable	RV

2. THE MODEL OF CONSIDERED SYSTEM AND AN OVERVIEW OF THE SIMO INDEPENDENT κ-μ SHADOWED DISTRIBUTION

2.1. The Model of Considered System

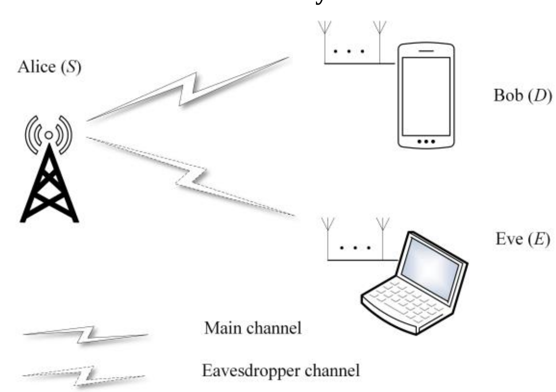

Fig. (1). The model of considered system

The model of considered system contains the legitimate transmitter (*S*) equipped with one antenna, the legitimate receiver (*D*) equipped with L_D antennas, and an eavesdropper (*E*) equipped with L_E antennas, as shown in Fig. (**1**), *S* sends the confidential message to *D*, when *D* receives information, *E* can receive signal from the eavesdropper channel. Assuming that main channel and eavesdropper channel both undergo independent κ-μ shadowed distribution, and the channels are slow fading channels in which the coefficient of determination in a block cycle is basically unchanged. In addition, the block length is long enough to allow the capacity of the codes to be implemented in each block. For the receiver, the acquired signal can be expressed as

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

where $\mathbf{h}_i \in \mathbb{C}^{L\times 1}$ is a vector denotes the independent κ-μ shadowed channel coefficient of the transmitter and the multi-antenna receiver equipped with multiple antennas, $\mathbf{y}_i \in \mathbb{C}^{L\times 1}$ is also a vector, which means the signal acquired by the receiver, $i \in \{D, E\}$ is a subscript indicating whether the vector belongs to the main channel or eavesdropping channel. x is the signal sent from the transmitter, and $\mathbf{n} \sim \mathcal{CN}(0, \sigma^2)$ is a complex additive white Gaussian vector with zero mean and fixed variance.

2.2. Channel Statistics

Because the PDF, the CDF and the moment generating function for κ-μ shadowed RV can be expressed in a closed form, so the channel model is more convenient for performance analysis. In the following, the main channel and eavesdropper channel both undergo independent κ-μ shadowed distribution. According to [22], the PDF for the instantaneous SNR is given as

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

where the parameter k_i can be interpreted as the ratio between the total power of the dominant components and the total power of the scattered waves, μ_i is the number of clusters, m_i denotes the channel parameter of shadowed fading, and $\bar{\gamma}_i$ is the average SNR of the main channel or eavesdropping channel. $\Gamma(\cdot)$ is the Gamma function as defined in [29, Eq. (8.310.1)] and ${}_1F_1(\cdot)$ means the confluent hypergeometric function [29, Eq. (9.14.1)].

MRC is an excellent technology in diversity reception, which can be used to analyze the performance of fading channels [30-32], In the model of considered system, Legal user and eavesdropper use multiple antennas to receive signals. Utilizing MRC, we obtain the instantaneous SNR of D or E as

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

where j is the serial number of each antenna at receiver, γ_i is the SNR at receiver. j represents the order of antennas, According to (2) and (3), we can derive the PDF for the SNR on independent κ-μ shadowed distribution as

$$\begin{aligned} f_i(\gamma) &= \left(\frac{L_i\mu_i(1+k_i)}{\bar{\gamma}_i}\right)^{L_i\mu_i} \left(\frac{m_i}{\mu_i k_i + m_i}\right)^{L_i m_i} \\ &\quad \times \frac{\gamma^{L_i\mu_i - 1}}{\Gamma(L_i\mu_i)} \exp\left(-\frac{L_i\mu_i(1+k_i)}{\bar{\gamma}_i}\gamma\right) \\ &\quad \times {}_1F_1\left(L_i m_i, L_i\mu_i; \frac{L_i k_i \mu_i^2 (1+k_i)}{\bar{\gamma}_i(\mu_i k_i + m_i)}\gamma\right), \end{aligned} \tag{4}$$

Making use of

$${}_1F_1(a, b; x) = \sum_{q=0}^{\infty} \frac{(a)_q x^q}{(b)_q q!}, \tag{5}$$

(4) can be rewritten as

$$\begin{aligned} f_i(\gamma) &= (L_i a_i)^{L\mu_i} (b_i)^{-Lm_i} \frac{1}{\Gamma(L_i\mu_i)} \sum_{q=0}^{\infty} \frac{(L_i m_i)_q}{(L_i\mu_i)_q q!} \\ &\quad \times \gamma^{L_i\mu_i + q - 1} \left(\frac{L_i a_i k_i \mu_i}{b_i m_i}\right)^q \exp(-L_i a_i \gamma), \end{aligned} \tag{6}$$

where $a_i = \frac{\mu_i(1+k_i)}{\bar{\gamma}_i}, b_i = \frac{\mu_i k_i + m_i}{m_i}$.

According to the theory of probability and [29, Eq. (3.326.2)], the CDF for the SNR on independent κ-μ shadowed distribution is derived as

$$\begin{aligned} F_i(\gamma) &= (b_i)^{-L_i m_i} \frac{1}{\Gamma(L_i\mu_i)} \sum_{q=0}^{\infty} \frac{(L_i m_i)_q \left(\frac{k_i\mu_i}{b_i m_i}\right)^q}{(L_i\mu_i)_q q!} \\ &\quad \times \Upsilon(L_i\mu_i + q, La_i\gamma), \end{aligned} \tag{7}$$

where $\Upsilon(\alpha, x) = \int_0^{\infty} e^{-t} t^{\alpha-1} dt$ is the lower incomplete Gamma function defined in [29, Eq. (8.350.1)]. Then, employing [29, Eq. (8.352.6)], (7) can be rewritten in another form as

$$\begin{aligned} F_i(\gamma) &= (b_i)^{-L_i m_i} \frac{1}{\Gamma(L_i\mu_i)} \sum_{q=0}^{\infty} \frac{(L_i m_i)_q \left(\frac{k_i\mu_i}{b_i m_i}\right)^q}{(L_i\mu_i)_q q!} \\ &\quad \times G_{1,2}^{1,1}\left[L_i a_i \gamma \middle| \begin{matrix} 1 \\ L_i\mu_i + q, 0 \end{matrix}\right], \end{aligned} \tag{8}$$

where $G(\cdot)$ denotes the Meijer G-function [29, Eq. (9.301)], $(\cdot)!$ represents the integral of the content in parenthese.

3. SECRECY PERFORMANCE ANALYSIS

In the following theorems, we give the derivation of the accurate theoretical representations for the SOP and SPSC over SIMO independent κ-μ shadowed distribution model, respectively.

3.1. Secure Outage Probability

The SOP is a significant criterion for evaluating the security performance, which represents the probability that the secrecy capacity is lower than a fixed threshold value [4], SOP is provided as [10]

$$P_{out} = P\left(\gamma_D < \Theta\gamma_E + \Theta - 1\right) = \int_0^\infty F_D(\Theta\gamma_E + \Theta - 1) f_E(\gamma_E) d\gamma_E, \tag{9}$$

where $\Theta = \exp(C_{th})$, C_{th} is a fixed threshold value.

Theorem 1: For SIMO independent κ-μ shadowed distribution model, the exact analytical representations for the lower bound on SOP is presented as

$$Sop^L = (b_E)^{-Lm_E} (b_D)^{-Lm_D} \frac{1}{\Gamma(L_D\mu_D)} \frac{1}{\Gamma(L_E\mu_E)} \times \sum_{p=0}^{\infty} \frac{(L_E m_E)_p}{(L_E\mu_E)_p\, p!} \left(\frac{k_E\mu_E}{b_E m_E}\right)^p \sum_{q=0}^{\infty} \frac{(L_D m_D)_q}{(L_D\mu_D)_q\, q!} \left(\frac{k_D\mu_D}{b_D m_D}\right)^q \times G_{2,2}^{1,2}\left[\frac{a_D\Theta}{a_E}\middle| \begin{matrix} 1, 1 - L_E\mu_E - p \\ L_D\mu_D + q, 0 \end{matrix}\right]. \tag{10}$$

Proof: By substituting formulas (6) and (8) into (9), we can obtain

$$\begin{aligned} Sop &= \int_0^\infty F_D(\Theta\gamma_E + \Theta - 1) f_E(\gamma_E) d\gamma_E \\ &= \int_0^\infty (b_D)^{-Lm_D} (b_E)^{-Lm_E} \frac{1}{\Gamma(L_D\mu_D)} \frac{1}{\Gamma(L_E\mu_E)} \\ &\times \sum_{q=0}^{\infty} \frac{(L_D m_D)_q}{(L_D\mu_D)_q\, q!} \left(\frac{k_D\mu_D}{b_D m_D}\right)^q \sum_{p=0}^{\infty} \frac{(L_E m_E)_p \left(\frac{L_E a_E k_E \mu_E}{b_E m_E}\right)^p}{(L_E\mu_E)_p\, p!} \\ &\times (L_E a_E)^{L\mu_E} \gamma_E^{L\mu_E + p - 1} \exp(-L_E a_E \gamma_E) \\ &\times G_{1,2}^{1,1}\left[L_D a_D(\Theta\gamma_E + \Theta - 1)\middle| \begin{matrix} 1 \\ L_D\mu_D + q, 0 \end{matrix}\right] d\gamma_E. \end{aligned}$$

(11)

With the aid of [23, Eq. (29)], [33, Eq. (11)] and [23, Eq. (33)], and after some algebraic operations, (10) can be deduced at last.

3.2. Strictly Positive Secrecy Capacity

This section introduces the SPSC, which is one more essential criterion that means the probability for the SNR of main channel is larger than that of eavesdropping channel. [4], the SPSC can be given by [10]

$$P_{out} = P\left(\gamma_D > \gamma_E\right) = 1 - \int_0^\infty F_D(\gamma_E) f_E(\gamma_E) d\gamma_E. \tag{12}$$

Theorem 2: For SIMO system over independent κ-μ shadowed distribution model, the accurate theoretical expression of SPSC is represented as

$$Spsc = 1 - (b_E)^{-Lm_E} (b_D)^{-Lm_D} \frac{1}{\Gamma(L_D\mu_D)} \frac{1}{\Gamma(L_E\mu_E)} \times \sum_{q=0}^{\infty} \frac{(L_D m_D)_q}{(L_D\mu_D)_q\, q!} \left(\frac{k_D\mu_D}{b_D m_D}\right)^q \sum_{p=0}^{\infty} \frac{(L_E m_E)_p}{(L_E\mu_E)_p\, p!} \left(\frac{k_E\mu_E}{b_E m_E}\right)^p \times G_{2,2}^{1,2}\left[\frac{a_D}{a_E}\middle| \begin{matrix} 1, 1 - L_E\mu_E - p \\ L_D\mu_D + q, 0 \end{matrix}\right]. \tag{13}$$

Proof: According to (12), SPSC can be can be written in the following form,

$$\begin{aligned} Spsc &= 1 - \int_0^\infty F_D(\gamma_E) f_E(\gamma_E) d\gamma_E \\ &= 1 - \int_0^\infty (b_D)^{-Lm_D} (b_E)^{-Lm_E} \frac{1}{\Gamma(L_D\mu_D)} \frac{1}{\Gamma(L\mu_E)} \\ &\times \sum_{q=0}^{\infty} \frac{(L_D m_D)_q}{(L_D\mu_D)_q\, q!} \left(\frac{k_D\mu_D}{b_D m_D}\right)^q \sum_{p=0}^{\infty} \frac{(L_E m_E)_p}{(L_E\mu_E)_p\, p!} \\ &\times \left(\frac{L_E a_E k_E \mu_E}{b_E m_E}\right)^p (L_E a_E)^{L\mu_E} \gamma_E^{L\mu_E + p - 1} \\ &\times \exp(-L_E a_E \gamma_E) G_{1,2}^{1,1}\left[L_D a_D \gamma_E \middle| \begin{matrix} 1 \\ L_D\mu_D + q, 0 \end{matrix}\right] d\gamma_E. \end{aligned} \tag{14}$$

Utilizing [23, Eq. (33)], the SPSC can be derived as (13)

Since (10) and (13) both contain infinite series that is not conducive to performance analysis. To deal with this problem, we adopt a moment matching to derive another concise representation of the criterions in section 4.

4. CONCISE REPRESENTATIONS FOR SECURE OUTAGE PROBABILITY AND STRICTLY POSITIVE SECRECY CAPACITY

Based on a moment matching method [14], the PDF for the SNR on independent κ-μ shadowed distribution can be represented as

$$f_i(\gamma) = \frac{1}{\Gamma(\Delta_i)} \left(\frac{\Omega_i L_i}{\Delta_i}\right)^{-\Delta_i} \gamma^{\Delta_i - 1} \exp\left(-\frac{\Delta_i}{\Omega_i L_i}\gamma\right), \tag{15}$$

where $\Delta_i = \dfrac{m_i \mu_i L_i (1 + k_i)^2}{m_i + \mu_i k_i^2 + 2 m_i k_i}$.

According to (15), we can derive the CDF of for the SNR as

$$F_i(\gamma) = \frac{1}{\Gamma(\Delta_i)} \Upsilon\left(\Delta_i, \frac{\Delta_i}{\Omega_i L_i}\gamma\right) \tag{16}$$

Theorem 3: For SIMO independent κ-μ shadowed distribution model, the approximate equation of the lower bound on SOP is described as

$$Sop^L = \frac{1}{\Gamma(\Delta_D)\Gamma(\Delta_E)} G_{2,2}^{1,2}\left[\frac{\Omega_E\Delta_D}{\Omega_D\Delta_E}\Theta\middle|_{\Delta_E, 0}^{1, 1-\Delta_E}\right]. \tag{17}$$

Proof: Substituting (15) and (16) into (9), We can get the following equation,

$$\begin{aligned} Sop &= \int_0^\infty F_D(\Theta\gamma_E + \Theta - 1) f_E(\gamma_E) d\gamma_E \\ &= \frac{(L_E\Omega_E)^{-\Delta_E}}{\Gamma(\Delta_D)\Gamma(\Delta_E)\Delta_E^{-\Delta_E}} \int_0^\infty \gamma_E^{\Delta_E - 1} \\ &\times \exp\left(-\frac{\Delta_E\gamma_E}{L_E\Omega_E}\right) \Upsilon\left(\Delta_D, \frac{\Delta_D(\Theta\gamma_E + \Theta - 1)}{L_D\Omega_D}\right) d\gamma_E. \end{aligned} \tag{18}$$

Using [23, Eq. (29)], (18) can be transformed into the following form,

$$
\begin{aligned}
Sop^{L} &= \int_0^{\infty} F_D(\Theta\gamma_E) f_E(\gamma_E) d\gamma_E \\
&= \frac{\left(L_E\Omega_E\right)^{-\Delta_E}}{\Gamma(\Delta_D)\Gamma(\Delta_E)\Delta_E^{-\Delta_E}} \int_0^{\infty} \gamma_E^{\Delta_E - 1} \\
&\quad \times \exp\left(-\frac{\Delta_E\gamma_E}{L_E\Omega_E}\right) \Upsilon\left(\Delta_D, \frac{\Delta_D\Theta\gamma_E}{L_D\Omega_D}\right) d\gamma_E .
\end{aligned} \tag{19}
$$

Referring to [33, Eq. (11)] and [23, Eq. (33)], we can get the derivation of (17).

Theorem 4: For SIMO independent κ-μ shadowed distribution model, the SPSC is expressed as

$$
Spsc = \frac{1}{\Gamma(\Delta_D)\Gamma(\Delta_E)} G_{2,2}^{1,2}\left[\frac{\Omega_E\Delta_D}{\Omega_D\Delta_E}\Theta\middle|_{\Delta_E,0}^{1,1-\Delta_E}\right]. \tag{20}
$$

Proof: According to (11), the SPSC can be obtained as

$$
\begin{aligned}
Spsc &= 1 - \int_0^{\infty} F_D(\gamma_E) f_E(\gamma_E) d\gamma_E \\
&= 1 - \frac{\left(L_E\Omega_E\right)^{-\Delta_E}}{\Gamma(\Delta_D)\Gamma(\Delta_E)\Delta_E^{-\Delta_E}} \int_0^{\infty} \gamma_E^{\Delta_E - 1} \\
&\quad \times \exp\left(-\frac{\Delta_E\gamma_E}{L_E\Omega_E}\right) \Upsilon\left(\Delta_D, \frac{\Delta_D\gamma_E}{L_D\Omega_D}\right) d\gamma_E .
\end{aligned} \tag{21}
$$

As suggested by [23, Eq. (33)], we can obtain the derivation of the expression of (20).

5. NUMERICAL RESULTS

In this section, some numerical results for the proposed analytical derivations are presented. In contrast, Monte Carlo simulation is used to verify our analysis. Apart from some parameters can be changed, we have the following assumptions: C_{th} =1 dB, $\overline{\gamma}_D = \mathrm{P}\overline{\gamma}_E$, $L_D = L_E = L$, SOP simulation: $\overline{\gamma}_E$ = 20 dB, SPSC simulation: $\overline{\gamma}_E$ = 1 dB, where P is the ratio that represents the SNR ratio of the main channel to the eavesdropping channel. According to (2), we randomly get 10^6 κ-μ shadowed RVs which are used for Monte Carlo simulations. From Figs. (**2-9**), we can find that the simulation results

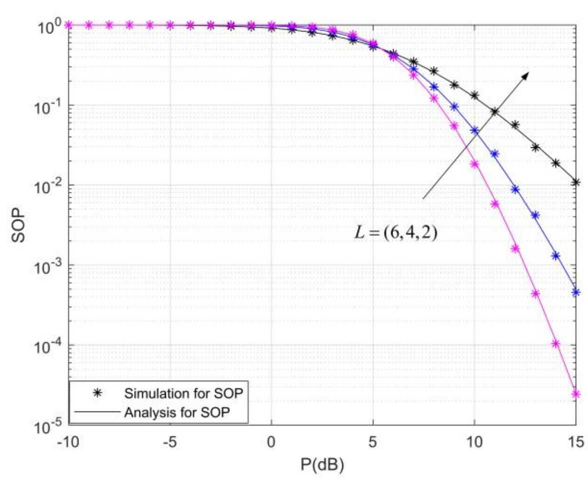

Fig. (2). SOP versus P for various L when $k_D = k_E$ =2, $\mu_D = \mu_E$ =2, $m_D = m_E$ =1.

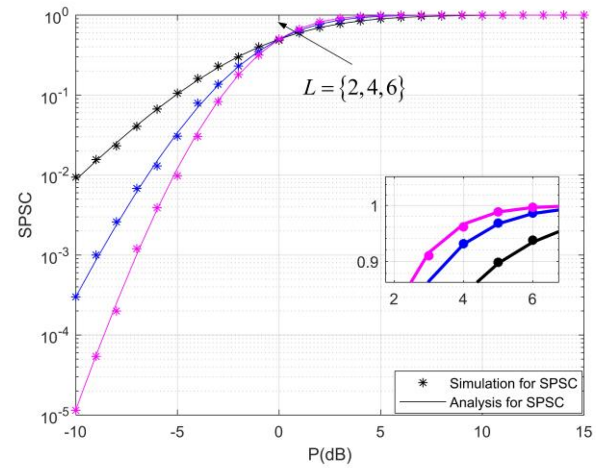

Fig. (3). SPSC versus P for various L when $k_D = k_E$ =2, $\mu_D = \mu_E$ =2, $m_D = m_E$ =1.

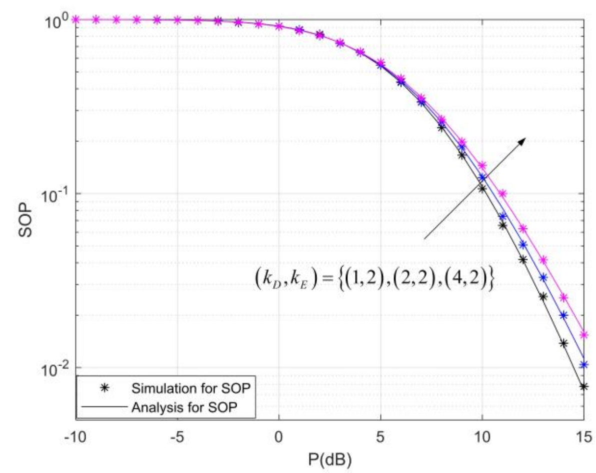

Fig. (4). SOP versus P for various (k_D, k_E) when L =2, $\mu_D = \mu_E$ =2, $m_D = m_E$ =1.

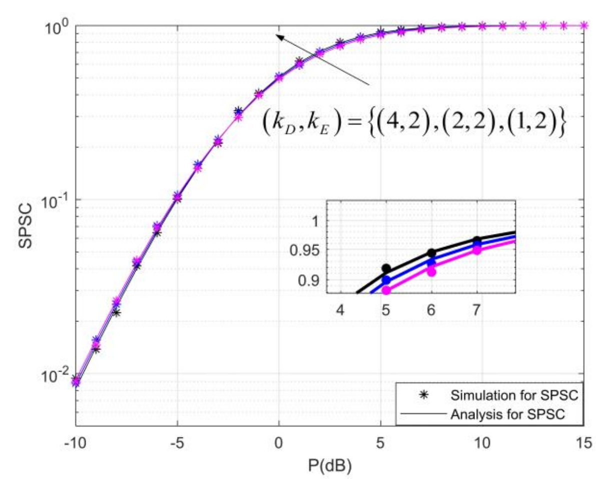

Fig. (5). SPSC versus P for various (k_D, k_E) when L =2, $\mu_D = \mu_E$ =2, $m_D = m_E$ =1.

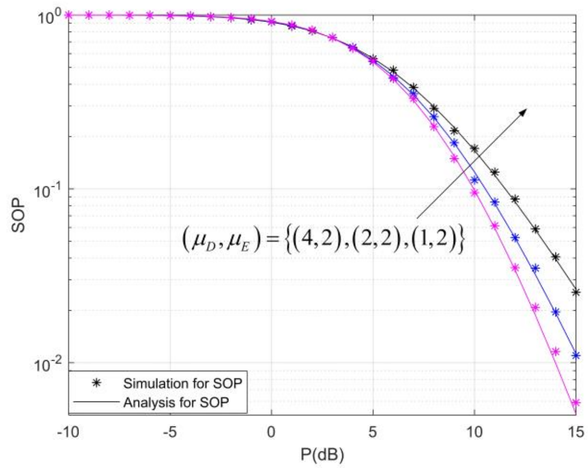

Fig. (6). SOP versus P for various (μ_D, μ_E) when L =2, $k_D = k_E$ =2, $m_D = m_E$ =1.

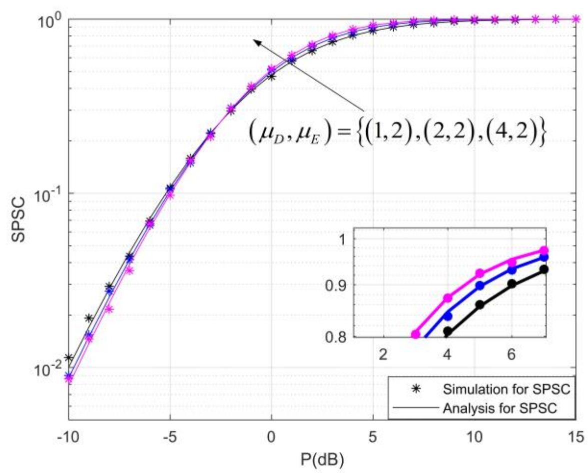

Fig. (7). SPSC versus P for various (μ_D, μ_E) when L =2, $k_D = k_E$ =2, $m_D = m_E$ =1.

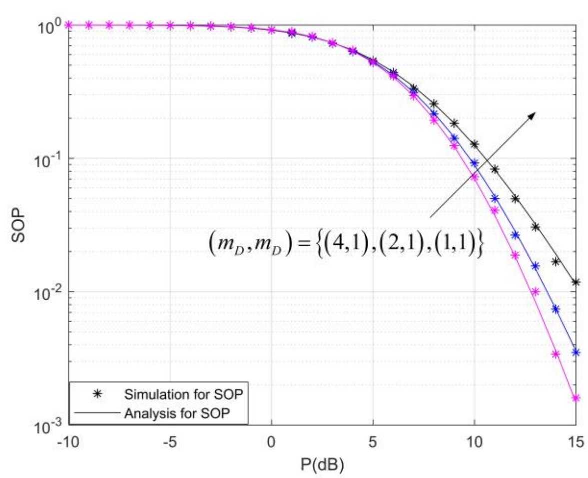

Fig. (8). SOP versus P for various (m_D, m_E) when L =2, $k_D = k_E$ =2, $\mu_D = \mu_E$ =2.

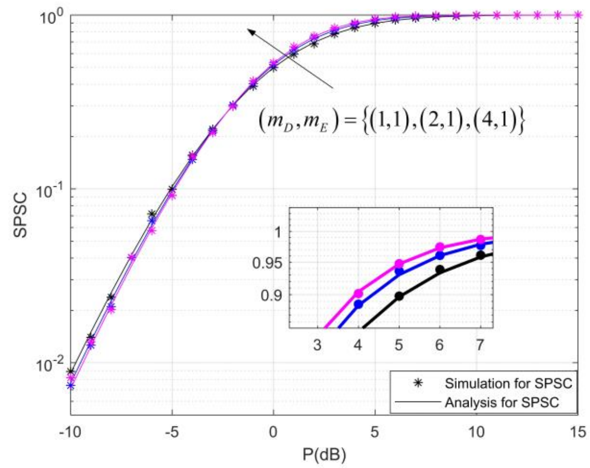

Fig. (9). SPSC versus P for various (m_D, m_E) when L =2, $k_D = k_E$ =2, $\mu_D = \mu_E$ =2.

sufficiently match with corresponding results of the analysis. Furthermore, we can see that the security performance improves while increasing P.

In Fig. (**2**) and Fig. (**3**), it can be discovered that when P > 5 dB, SOP decreases and SPSC increases as L increasing. Fig. (**4**) and Fig. (**5**) illustrate that SOP increases and SPSC decreases while k_D increasing while P > 3 dB. Similarly, by analyzing the diagrams of theory and Monte Carlo simulation from Figs. (**6-9**), we can find that large value of μ_D and m_D yield lower SOP and higher SPSC with P > 3 dB.

6. CONCLUSION

Lower SOP and higher SPSC mean that the system has better security performance, and vice versa. By that standard, when P takes a higher value, large L , large μ_D , large m_D and small k_D are help to enhance confidentiality of the SIMO network over independent κ-μ shadowed distribution model.

ETHICS APPROVAL AND CONSENT TO PARTICIPATE

Not applicable.

HUMAN AND ANIMAL RIGHTS

Not applicable.

CONSENT FOR PUBLICATION

Not applicable.

AVAILABILITY OF DATA AND MATERIALS

Not applicable.

CONFLICT OF INTEREST

The authors declare no conflict of interest, financial or otherwise.

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