Finite Series Representation of Rician Shadowed Channel with Integral Fading Parameter and the Associated Exact Performance Analysis

JIAN Xin*, ZENG Xiaoping, YU Anning, YE Changrong, YANG Junyi

College of Communication Engineering, Chongqing University, Chongqing 400000, China

Abstract: With the deployment of small cells and device to device communications in future heterogeneous networks, in many situations we would encounter mobile radio channels with partly blocked line of sight component, which are well modeled by the Rician shadowed (RS) fading channel. In this paper, by the usage of Kummer transformation, a simplified representation of the RS fading channel with integral fading parameter is given. It is a finite series representation involving only exponential function and low order polynomials. This allows engineers not only the closed-form expressions for exact performance analysis over RS fading channel, but also the insights on the system design tactics.

Keywords: rician shadowed fading channel; Kummer transformation; outage probability; error probability; channel capacity; co-channel interference

I. INTRODUCTION

The Rician shadowed (RS) fading channel was originally proposed by Loo to describe land mobile satellite (LMS) links with completely or partly blocked line of sight (LOS) component [1, 2]. It is a composite multipath/shadowed fading channel model, in which the amplitude of a Rician distribution is averaged over a log-normal distribution [1]. This enables the model to account for a variety of fading environments besides the scope of LMS links, such as the emerging device to device communications and small cells in the heterogeneous deployment of the next generation mobile networks [3]. The common characteristic of these fading environments is that the direct LOS component is completely or partly blocked by buildings, trees, hills, human bodies or other objects. This gives RS fading channel wide applications in future wireless communication systems. Therefore, it is quite necessary to carry out its full performance analysis and keep pace with the development of newly designed communication systems.

In term of this, several works on the exact analysis of outage probability and co-channel interference in RS fading channel have been proposed [4-7]. However, as the shadowing effect in Loo's model is modeled by a log-normal distribution, the results in [4-7] unanimously involve complicated integrals which cannot be written as known tabulated functions [8]. Assuming that the power of the LOS component follows a Nakagami distribution rather than a log-normal distribution, [8] simplified the expression of Loo's model and provided the closed-form ex-

In this paper, by the usage of Kummer transformation, a simplified representation of the Rician shadowed fading channel with integral fading parameter is given.

pressions for the probability density function (PDF), the moment generation function (MGF) and the moments of the instantaneous power. Thereafter, some simplified results have been given out [9, 10]. However, the inclusion of the confluent hyper-geometric function of the first kind in [8] still makes the analytical manipulation of these expressions usually hard. Therefore, in this paper, with the finite series presentation of the confluent hyper-geometric function of the first kind with positive integral shape parameters, we further simplify the performance analysis of digital communication systems over RS fading channel and provide some closed-form expressions that have not been reported by previous researches.

The remainder of the paper is organized as follows. Section II presents the finite series representation of RS distribution. Section III gives out some useful closed-form expressions to complete the performance analysis over RS fading channel. In Section IV, numerical results are provided to show how to apply the results of Section III. Finally, Section IV concludes the paper.

II. Rician Shadowed Distribution

2.1 PDF of the fading power

The simplified PDF of the fading power of the RS fading channel proposed by [8] is

$$p(s) = \left(\frac{2b_0 m}{2b_0 m + \Omega}\right)^m \frac{1}{2b_0} \exp\left(-\frac{s}{2b_0}\right) {}_1F_1\left(m, 1; \frac{s\Omega}{2b_0(2b_0 m + \Omega)}\right) \quad s > 0 \tag{1}$$

where Ω is the average power of the LOS component; $2b_0$ is the average power of the scattered component; m is fading parameter ranging from 0 to ∞ that describes the severity of shadowing; for m=∞, the LOS component is not obstructed, causing Equation (1) revert to Rician PDF; for m=0 it corresponds to the complete obstruction of the LOS component and reduces to Rayleigh PDF; ${}_1F_1(a,b;u)$ is the confluent hyper-geometric function of first kind with parameters a and b.

2.2 Simplified proof of kummer transformation

Though many functions can be expressed as special cases of ${}_1F_1(\cdot)$, such as exponential function, Bessel function and error function [11], the incursion of ${}_1F_1(\cdot)$ forbids the closed-form expressions for most of performance analysis over RS fading channel. Fortunately, if the shape parameters a and b are positive integers and $a \geq b$, Kummer transformation could give out a finite series representation of ${}_1F_1(\cdot)$ with elementary functions and make the exact analysis possible. The Kummer transformation to present ${}_1F_1(a,b,u)$ as a finite series representation with elementary functions is [11]

$$\begin{aligned} {}_1F_1(a,b,u) &= e^u \sum_{n=0}^{a-b} \frac{(a-b)!}{(a-b-n)!} \frac{1}{n!} \frac{u^n}{b^{(n)}} \\ &= e^u \sum_{n=0}^{a-b} C_{a-b}^n \frac{u^n}{b^{(n)}} \end{aligned} \tag{2}$$

where $b^{(n)} = b(b+1)...(b+n-1)$ is the rising factorial and $1^{(n)} = 1 * 2 * ... * n = n!$.

Here, by the usage of the iterative relation of ${}_1F_1(\cdot)$, we derive Kummer transformation in an alternative way and give out its graphical illustration which is easy of understanding and reveals the inner structure of Kummer transformation. The iterative relation we use is [11, 9.212-2]

$${}_1F_1(a,b,u) = \frac{u}{b} {}_1F_1(a,b+1,u) + {}_1F_1(a-1,b,u) \tag{3}$$

From this equation, it can be seen that to determine ${}_1F_1(a,b,u)$, we only have to know the expressions of the upper-side one ${}_1F_1(a,b+1,u)$ and the left-side one ${}_1F_1(a-1,b,u)$, but the upper-side one must be multiplied by a first-order polynomial u/b in which the constant depends only on the second parameter of ${}_1F_1(a,b,u)$. In Figure 1, following the spirit of signal-flow graph, we draw out Equation (3) in a rectangular lattice in which the inter-section points present ${}_1F_1(a,b,u)$. The decomposition process presented by Equation (3) could be continued until the end-points reach the diagonal line whose expressions can be easily determined as ${}_1F_1(a,a,u)$=e^u. In case of this, from the start point ${}_1F_1(a,b,u)$ to the end points along the diagonal line, we form a Pascal's triangle whose coefficient is equivalent as the binomial coefficient. This coefficient also presents the number of ways to reach the end-points from the start point. Then, multiplying the expressions of the end-points, the number of ways to reach the end-points and the factors along the way and adding them together, we could easily get the expression of ${}_1F_1(a,b,u)$:

$$ {}_1F_1(a,b,u) = e^u \sum_{n=0}^{a-b} C_{a-b}^n \frac{u^n}{b^{(n)}} \tag{4} $$

in which, e^u is the expression of the end-points along the diagonal line, $(a\text{-}b)+1$ is the number of the end-points, C_{a-b}^n is the number of ways to reach the end-points and $x^n/b^{(n)}$ is the factor along the way. Obvious, Equation (4) is the same as that of Kummer transformation, but the explanation here provides us a more direct and intuitive way to understand and use Kummer transformation.

Though Equation (3) is applicable to all ${}_1F_1(a,b,u)$, as only the ${}_1F_1(a,a,u)$ along the diagonal line share the same expression e^u, thus only when $a>b$, Equation (3) can simplify the process of Kummer transformation. When $a<b$, the methodology in [12] should be better. Combing these works together, the expressions of all ${}_1F_1(a,b,u)$ ($a>b$, $a=b$, $a<b$) with positive integers are obtainable. This would greatly simplify the performance analysis involving ${}_1F_1(a,b,u)$.

2.3 Finite series representation

Now, let $a=m$ and $b=1$, ${}_1F_1(m,1,u)$ can be represented as

$$ {}_1F_1(m,1,u) = e^u \sum_{n=0}^{m-1} C_{m-1}^n \frac{u^n}{n!} \tag{5} $$

Equation (1) can be simplified as

$$ p(s) = \left(\frac{2b_0 m}{2b_0 m + \Omega}\right)^m \frac{1}{2b_0} \exp\left(-\frac{ms}{2b_0 m + \Omega}\right) \times \sum_{n=0}^{m-1} C_{m-1}^n \left(\frac{\Omega}{2b_0(2b_0 m + \Omega)}\right)^n \frac{s^n}{n!} \tag{6} $$

The advantages of Equation (6) over Equation (1) rely on two aspects. The first one is that finite series representation achieves more accurate numerical results than the truncated approximation of ${}_1F_1(\cdot)$ with infinite series summation. The second one is that elementary function representation with only exponential function and low-order polynomials is easy to obtain closed-form expressions than that of ${}_1F_1(\cdot)$. In general, with Equation (6), quite some closed-form expressions for the exact performance analysis over RS fading channel could be given out, which are detailed in the next section.

III. Exact Performance Analysis

In this section, we mainly focus on the exact analysis of the CDF and the K-th order moments of the fading power, the error probability related with Gaussian Q-function, the channel capacity related with log-function and the co-channel interference over shadowed Rician/Rician channel. The deduction of other performance metrics would follow the same procedure of these five. The general procedure of the deduction in this section is: 1) substitute the outer exponential function in Equation (6) into the summand and multiply it with s^n, 2) then take the performance metrics to analyze into account and calculate the definite integrals involving exponential function and low-order

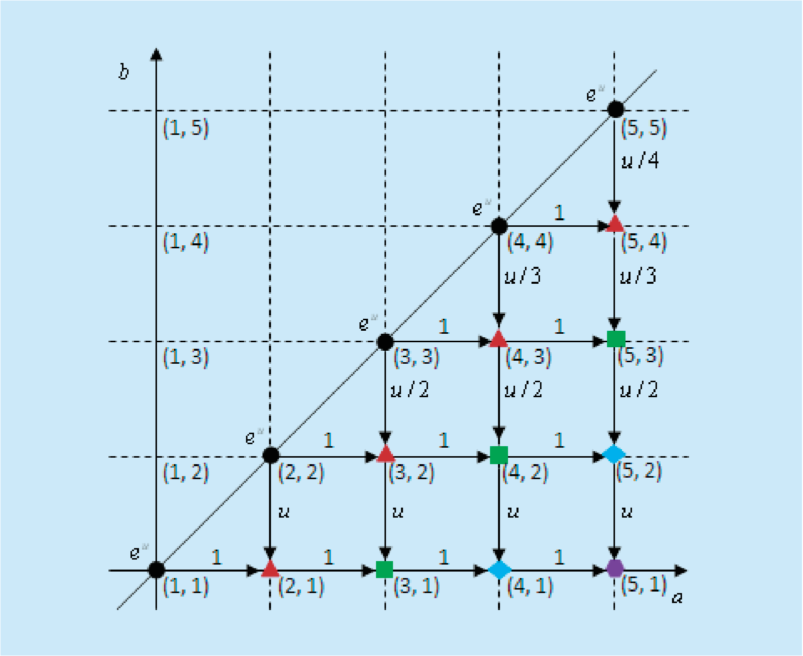

Fig.1 *Iterative relation of ${}_1F_1(a,b,u)$ when $a \geq b$*

polynomials. In most of cases, the closed-form expressions of these definite integrals exist which enables the exact performance analysis over RS fading channel.

3.1 CDF of the fading power

the CDF of the fading power plays a central role in the analysis of outage probability. When the fading parameter m is a positive integer, [10, Eq-4] express the PDF and CDF of the fading power as Laguerre polynomials. Here, with Equation (6), the CDF of the fading power can be simplified as

$$P(A) = \left(\frac{2b_0m}{2b_0m+\Omega}\right)^{m-1}\sum_{n=0}^{m-1}\frac{C_{m-1}^{n}}{n!}\left(\frac{\Omega}{2b_0m}\right)^{n}\gamma\left(n+1,\frac{mA}{2b_0m+\Omega}\right) \tag{7}$$

where $\gamma(\cdot,\cdot)$ is the lower incomplete Gamma function. This is the direct result of the definite integral in [11, 3.351-1]. Obviously, Equation (7) is easier to calculate than that of [10].

3.2 K-th order moments of the fading power

The moments of the fading power could not only be used to make data fitting and parameters estimation, but also can be used to evaluate the amount of fading (AF) which is defined as $AF=\mathrm{var}[s]/(E[s])^2$ [2]. Therefore, it is still necessary to calculate the K-th order moments of the fading power, which is determined as

$$\begin{aligned}E\left(s^K\right) &= \int_0^\infty s^K p(s)ds \\ &= \left(\frac{m}{2b_0m+\Omega}\right)^{m-K-1}(2b_0)^{m-1}\sum_{n=0}^{m-1}\frac{C_{m-1}^{n}(n+K)!}{n!}\left(\frac{\Omega}{2b_0m}\right)^{n}\end{aligned} \tag{8}$$

This is the direct result of the definite integral in [11, 3.351-3]. This finite series representation is simpler and easier for computation than that of [8] which is given as a function of the Gauss hyper-geometric function ${}_2F_1(\cdot)$.

3.3 Integrals involving the gaussian Q-function

The symbol error probability (SEP) of communication systems over AWGN channel always involves Gaussian Q-function. The SEP over fading channel is the conditional average of the SEP of AWGN channel over the received fading power, which is determined as [2]

$$\begin{aligned}P_e &= \int_0^\infty Q\left(g\sqrt{s}\right)p(s)ds \\ &= \frac{1}{\pi}\int_0^{\pi/2}\left[\int_0^\infty \exp\left(-\frac{g^2 s}{2\sin^2(\theta)}\right)p(s)ds\right]d\theta\end{aligned} \tag{9}$$

where g is a constant that depends on the specific modulation/detection combination. Substituting $\exp\left(-\frac{ms}{2b_0m+\Omega}\right)$ and $\exp\left(-\frac{g^2 s}{2\sin^2(\theta)}\right)$ into the summand and multiplying it with s^n in Equation (6), we get

$$\begin{aligned}&\frac{1}{\pi}\int_0^{\pi/2}\left[\int_0^\infty s^n\exp\left(-\left(\frac{g^2}{2\sin^2(\theta)}+\frac{m}{2b_0m+\Omega}\right)s\right)ds\right]d\theta \\ &= \frac{n!}{\pi}\int_0^{\pi/2}\left(\frac{\sin^2(\theta)\,(2b_0m+\Omega)/m}{\sin^2(\theta)+(2b_0m+\Omega)\,g^2/2m}\right)^{n+1}d\theta \\ &= \frac{n!}{\pi}\left(\frac{2b_0m+\Omega}{m}\right)^{n+1}\int_0^{\pi/2}\left(\frac{\sin^2(\theta)}{\sin^2(\theta)+(2b_0m+\Omega)\,g^2/2m}\right)^{n+1}d\theta \\ &= n!\left(\frac{2b_0m+\Omega}{m}\right)^{n+1}J_{n+1}\left(\frac{(2b_0m+\Omega)\,g^2}{2m}\right)\end{aligned} \tag{10}$$

where $J_n(\cdot)$ is the function detailed in Appendix 5A.1 in [2]. Thus, Equation (9) can be simplified as

$$P_e = \left(\frac{2b_0m}{2b_0m+\Omega}\right)^{m-1}\sum_{n=0}^{m-1}C_{m-1}^{n}\left(\frac{\Omega}{2b_0m}\right)^{n}J_{n+1}\left(\frac{(2b_0m+\Omega)\,g^2}{2m}\right) \tag{11}$$

This finite series representation is simpler and easier for computation than that of [13] which is deduced from an infinite power series expansion of the MGF of the fading power. Even when the number of diversity is 1, the result in [13, Eq.31] is still an infinite series.

3.4 Integrals involving the log-function

When characterizing the performance of channel capacity over fading channel, the generic form of the expression always involves the log-function. The channel capacity with optimum rate adaptation to channel fading and constant transmit power is [14]

$$\begin{aligned}C_{ORA} &= B\int_0^\infty \log_2(1+s)p(s)ds \\ &= B\log_2(e)\int_0^\infty \ln(1+s)p(s)ds\end{aligned} \tag{12}$$

Substituting $\exp\left(-\frac{ms}{2b_0m+\Omega}\right)$ and $\ln(1+s)$ into the summand and multiplying it with s^n in Equation (6), we get

$$\int_0^\infty s^n\ln(1+s)\exp\left(-\frac{ms}{2b_0m+\Omega}\right)ds = I_{n+1}\left(\frac{m}{2b_0m+\Omega}\right)$$

(13)

where $I_n(\mu) = (n-1)! e^{\mu} \sum_{k=1}^{n} \frac{\Gamma(-n+k,\mu)}{\mu^k}$ [2, 15 B.7]. Thus, Equation (12) can be determined as

$$C_{ORA} = \left(\frac{2b_0 m}{2b_0 m + \Omega}\right)^m \frac{B\log_2(e)}{2b_0} \times \sum_{n=0}^{m-1} C_{m-1}^n \left(\frac{\Omega}{2b_0(2b_0 m + \Omega)}\right)^n \frac{1}{n!} I_{n+1}\left(\frac{m}{2b_0 m + \Omega}\right) \tag{14}$$

The finite series presentations of Equation (12) share the same advantage as Equation (11). Furthermore, as the channel capacity with optimum power and rate adaptation C_{OPRA} and the channel capacity when the transmitter adapts its power to maintain a constant signal to noise ratio (SNR) at the receiver C_{CIFR} can be obtained in the same way as that of Equation (12), here we omit it deliberately.

3.5 Co-channel interference over shadowed Rician/Rican channel

The CDF of the fading power in III-3.1 could be used to calculate the outage probability over RS channel with no interferes. It is still necessary to consider the case of multiple interferes. Let the instantaneous power in the desired signal and the K interfering signals be denoted as s_0 and $s_k, k=1,...,K$, respectively. For a specified protection ratio λ_{th}, the probability of outage is [15]

$$O_I = P(\lambda < \lambda_{th}) = P\left(s_0 < \lambda_{th} \sum_{k=1}^{K} s_k\right) \tag{15}$$

where $\lambda = s_0/s_I, s_I = \sum_{k=1}^{K} s_k$. With the equation to derive the PDF of the ratio of two random variables [16], Equation (15) is equivalent as

$$O_I = \int_0^{\lambda_{th}} \left[\int_0^{\infty} s_I p_0(\lambda s_I) p_I(s_I) ds_I\right] d\lambda \tag{16}$$

where $p_0(\cdot)$, $p_I(\cdot)$ are the PDF of s_0 and s_I; and since the desired signal and the interfering signals are mutually independent, $p(s_0,s_1)=p_0(\cdot)p_1(\cdot)$. With Equation (6) and substituting only the simplified representation of $p_0(\cdot)$ into Equation (16), the inner integral can be described as

$$\int_0^{\infty} s_I p_0(\lambda s_I) p_I(s_I) ds_I = \left(\frac{2b_0 m_0}{2b_0 m_0 + \Omega_0}\right)^{m_0} \frac{1}{2b_0} \times \sum_{n=0}^{m_0-1} C_{m_0-1}^n \left(\frac{\Omega_0}{2b_0(2b_0 m_0 + \Omega_0)}\right)^n \frac{\lambda^n}{n!} \int_0^{\infty} s_I^{n+1} \exp\left(-\frac{m_0 \lambda s_I}{2b_0 m_0 + \Omega_0}\right) p_I(s_I) ds_I \tag{17}$$

The inner integral of Equation (17) is equal to the $(n+1)$th derivative of the MGF $M_{s_I}(u)$ of $p_I(s_I)$ evaluated at $-\lambda m_0/2b_0 m_0 + \Omega_0$. When the interfering signals are mutually independent, the MGF $M_{s_I}(u)$ of $p_I(s_I)$ could be easily deduced as [8]

$$M_{s_I}(u) = \prod_{k=1}^{K} M_{s_k}(u), M_{s_k}(u) = \frac{(1-2b_k u)^{m_k-1}}{(1-(2b_k + \Omega_k/m_k)u)^{m_k}} \tag{18}$$

Where $M_{s_k}(u)$ is the MGF of Rician shadowed distribution. Though the closed-form expression of the $(n+1)$th derivative of $M_{s_I}(u)$ definitely exists and easy of calculation, it is still hard to write it explicitly with the general undefined parameters. In practice, once the parameters $m_k,\Omega_k,b_k,k=0,..,K$ are determined, the above deduction process could be fully calculated, and then the exact closed-form expression of Equation (16) could be given out.

Reversing the deduction process from Equation (15) to Equation (18), we could give out the work process to deduce the exact analysis of the outage probability of co-channel interference in shadowed Rician/Rician channel with integral fading parameter. That is: 1) Find the MGF $M_{s_I}(u)$ of $p_I(s_I)$ and its $n+1th$ derivative $d^{n+1}M_{s_I}(u)/du^{n+1}$; 2) Evaluate $d^{n+1}M_{s_I}(u)/du^{n+1}$ at $-m_0\lambda/2b_0m_0+\Omega_0$ and find the inner integral of Equation (18); 3) Find the outer integral of Equation (18) and get the outage probability. The advantage of this process is that the multiple operation and differential operation involved are easier to calculate than the complex integrals in [6, 7, 9, 10].

In general, this section provides some useful expressions to carry out exact performance analysis over RS fading channel with integral fading parameter.

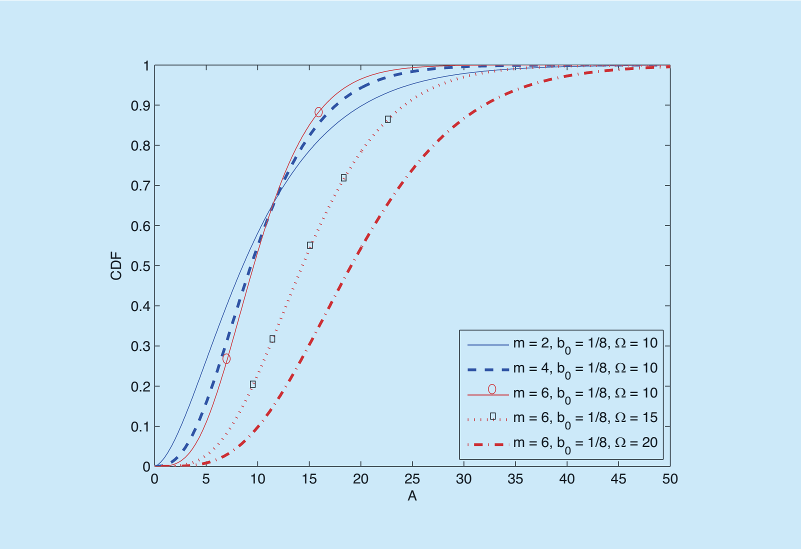

Fig.2 *CDF of the fading power*

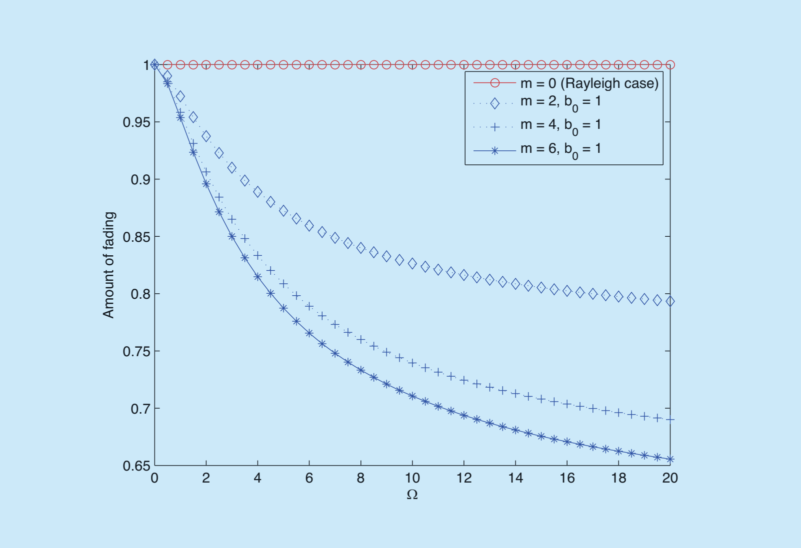

Fig.3 *Amount of the fading*

Table I *Modulation types whose SEP for involves Gaussian Q-function [17]*

Modulation type	SEP
Binary orthogonal signaling	$Q\left(\sqrt{\frac{\varepsilon_b}{N_0}}\right)$
Binary antipodal signaling	$Q\left(\sqrt{\frac{2\varepsilon_b}{N_0}}\right)$
PAM (large M)	$2Q\left(\sqrt{\frac{6\log_2 M}{M^2-1}\frac{\varepsilon_{bavg}}{N_0}}\right)$
PSK (large M)	$2Q\left(\sqrt{\frac{2\pi^2\log_2 M}{M^2}\frac{\varepsilon_{bavg}}{N_0}}\right)$
QAM	$2\left(1-\frac{1}{\sqrt{M}}\right)Q\left(\sqrt{\frac{3\log_2 M}{M-1}\frac{\varepsilon_{bavg}}{N_0}}\right)$

IV. Numerical Results

In this section, numerical results are provided to show how to apply the results of the previous section.

4.1 CDF and amount of fading

Figure 2 shows the CDF of the fading power in Equation (7). It says that the increased power of LOS component Ω would decrease the outage probability of the receiving power. The increase of fading parameter m may not have this direct improvement. At low SNR region (Ω is small), increased m induces decreased outage probability. While at high SNR region (Ω is large), it reverses. This is because that when SNR is low, the un-ignorable scattering component would to some extents compensate the loss of the LOS component. While when SNR is high, partly block would always mean great power loss of LOS component which may not be compensated by the scattering component.

Figure 3 shows the AF of the receiving power. The increase of Ω and m decrease the AF which implies the reduction of the outage probability. This in return supports the conclusions drawn from Figure 2.

4.2 Symbol error probability

Table I shows the modulation types whose SEPs can be represented or approximated as the function of Gaussian Q-function. In Figure 4, we take the binary orthogonal signaling as an example to show the influence of Ω, m and b_0 on SEP. It shows that the increase of Ω and m would decrease the SEP, while the increase of b_0 would increase the decreasing rate of the SEP. These curves unanimously intercross with the SEP curve of AWGN channel. At low SNR region, the SEP of RS channel is lower than that of AWGN channel. With the increase of SNR, it becomes larger than that of AWGN channel. This mainly depends on whether the scattering component can compensate the power loss of the LOS component at high SNR region, which has been seen from Figure 2. The SEP of other modulation types can be analyzed in the same way.

4.3 Ergodic capacity

The channel capacity with optimum rate adaptation to channel fading and a constant transmit power illustrated by Equation (14) is shown in Figure 5. From these curves, similar conclusions as that of Figure 2 and Figure 4 can be drawn.

4.4 Outage probability

Suppose the channel parameters of the K interferes are same and m_i=2, b_i=0.1, Ω_i=1, i=1,...,K, the MGF of K addictive interfering signals can be presented explicitly as

$$M_{s_I}(u) = \left(\frac{1 - 0.2u}{(1 - 0.7u)^2} \right)^K \tag{19}$$

In addition, if we set the channel parameters of the desired signal m_0=2, b_0=0.1, Ω_0=[1,10], with these predefined channel parameters and the work process in III-3.5, the outage probability of co-channel interference can be easily analyzed. In Figure 6, it shows that the number of interferes has more significant influence on the outage probability than that of the power of desired signal.

In general, this section provides some numerical results to show the successful applications of the results of previous section. This allows engineers not only the closed-form expressions for exact performance analysis over RS fading channel, but also the insights on the system design tactics.

V. Conclusions

With the finite series expansion of the RS distribution with elementary functions, we deduce some useful closed-form expressions for exact performance analysis of digital communication systems over RS fading channel. These expressions can be used to deduce the outage probability, amount of fading, error probability and channel capacity of the RS channel. We also present an alternative way to understand the essence of Kummer transformation, which is the core of the finite series expansion of the RS distribution. These works would achieve wide applications with the deployment of the device to device communications and small cells in future heterogeneous networks. The future extensions might concern the multiple input multiple output (MIMO) channel cases, as three dimensional MIMO and massive MIMO [3] have been widely considered in future LTE networks.

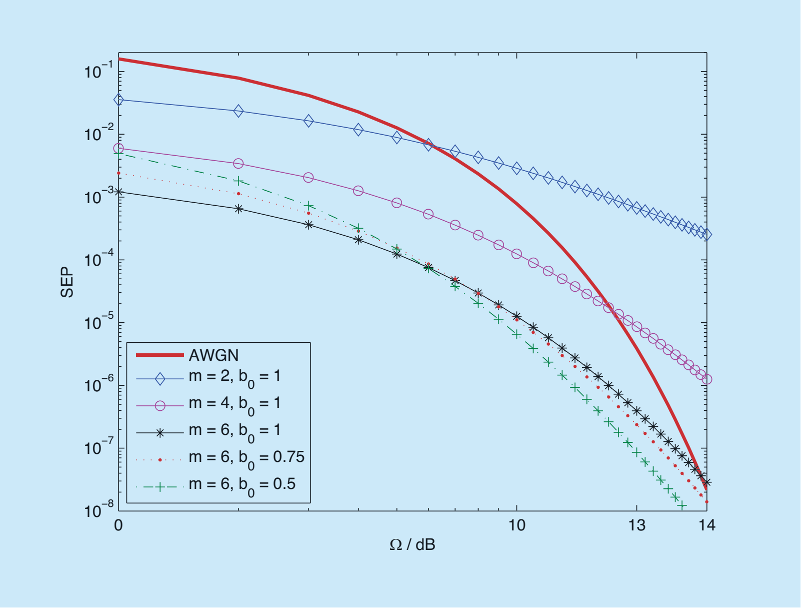

Fig.4 *SEP of binary orthogonal signaling*

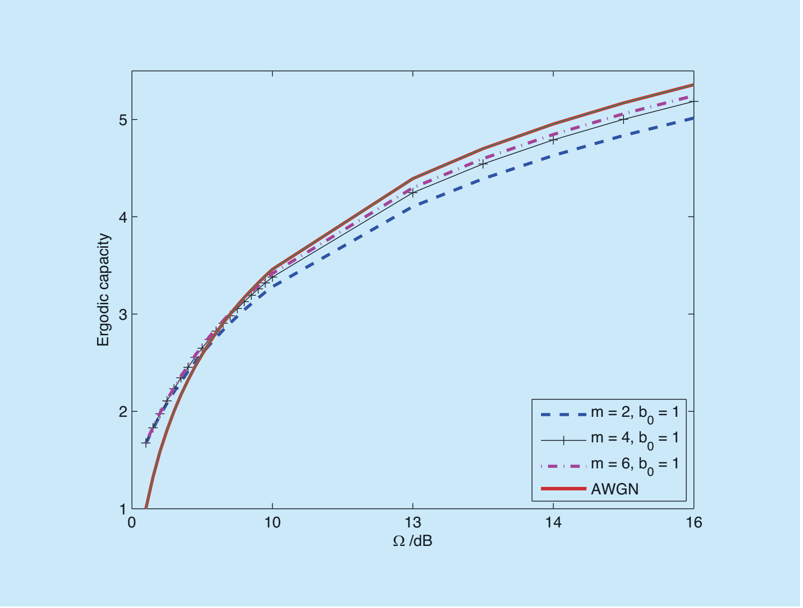

Fig.5 *Ergodic capacity*

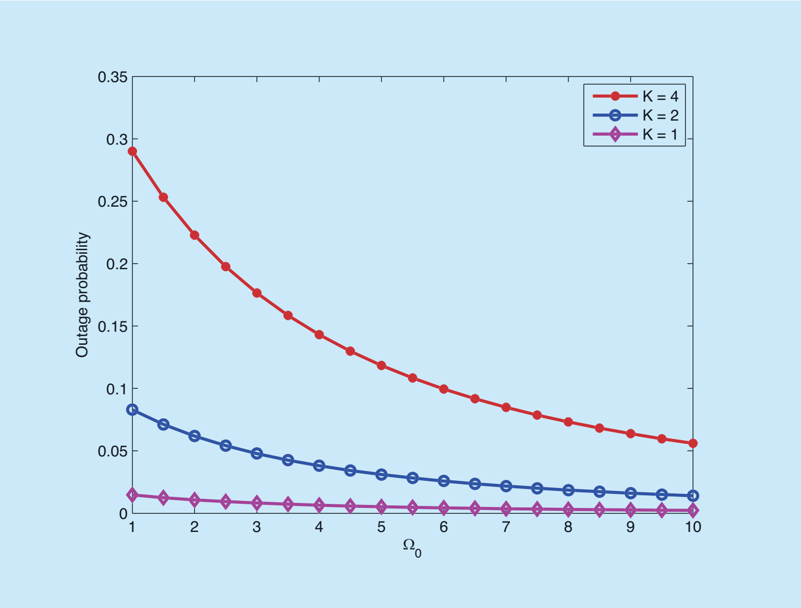

Fig.6 *Outage probability of cochannel interference*

ACKNOWLEDGEMENTS

The authors would like to thank the anonymous referees whose insightful comments helped us to improve the presentation of the paper. This work is sponsored by the National Natural Science Foundation of China under grant No. 61171089 and the Training Program of the Major Research Plan of the National Natural Science Foundation of China under grant No. 91438104.

References

[1] Chun Loo. A statistical model for a land mobile satellite link. IEEE Transactions on Vehicular Technology, vol. VT-34, no. 3, August 1985: 122–127.

[2] Marvin K.Simon and Mohamed-Slim Alouini. Digital Communication over Fading Channels. John Wiley & Sons, Inc., Hoboken, New Jersey, 2005: 36, 123-124, 149-165, 252, 863-869.

[3] Kishiyama, Yoshihisa, et al. Future steps of LTE-A: evolution toward integration of local area and wide area systems. IEEE Wireless Communications. vol.20, no.1, February 2013: 12-18.

[4] Ramjee Prasad and Adriaan Kegel. Effects of Rician and log-normal shadowed signals on spectrum efficiency in microcellular radio. IEEE Transactions on Vehicular Technology, vol. 42, no.3, August 1993: 274–281.

[5] Li-Chun Wang and Chin-Tau Lea. Incoherent estimation on co-channel interference probability for microcellular systems. IEEE Transactions on Vehicular Technology, vol. 45, no.1, February 1996: 164–173.

[6] Tjeng Thiang Tjhung, Chin Choy Chai, and Xiaodai Dong. Outage probability for lognormal-shadowed Rician channels. IEEE Transactions on Vehicular Technology, vol.46 no.2, May 1997: 400–407.

[7] Li-Chun Wang and Chin-Tau Lea. Co-channel interference analysis of shadowed Rician channels. IEEE Communications Letters, vol.2, no. 3, March 1998: 67-69.

[8] Ali Abdi,Wing C. Lau, Mohamed-Slim Alouini, and Mostafa Kaveh. A new simple model for land mobile satellite channels: First and second order statistics. IEEE Transactions on Wireless Communication, vol.2, no.3, May 2003: 519-528.

[9] Giuseppa Alfano and Antonio De Maio. Sum of squared shadowed-Rice random variables and its application to communications systems performance prediction. IEEE Transactions on Wireless Communications, vol.6, no.10, 2007: 3540-3545

[10] J. F. Paris. Closed-form expressions for Rician shadowed cumulative distribution function. Electronics Letters, vol.46, no.13, June 2010: 952-953.

[11] I.S. Gradshteyn and I.M. Ryzhik. Table of integrals, series, and products. Access Online via Elsevier, 2007: 1023, 1221-1222.

[12] Xin Jian, Xiaoping, Zeng. Beta/M/1 Model for Machine Type Communication. IEEE Communications Letters, Vol. 17, No. 3, March 2013: 584-587.

[13] George A. Ropokis, Athanasios A. Rontogiannis Kostas Berberidis and P. Takis Mathiopoulos. Performance analysis of maximal ratio combining over shadowed-Rice fading channels. International Workshop on Satellite and Space Communications. Sienna-Tuscany, Italy, September 2009: 83-87

[14] Andrea J. Goldsmith and Pravin P. Varaiya. Capacity of fading channels with channel side information. IEEE Transcations on Information Theory. vol. 43, no. 11, Nov. 1997: 1896-1992.

[15] Gordon L. Stüber: Principles of mobile communication. Springer, New York, 2011: 165-185

[16] Papoulis, Athanasios and S. Unnikrishna Pillai, Probability, random variables, and stochastic processes. McGraw-Hill Education, New York, 2002: 186-189

[17] John G. Proakis. Digital Communications. McGraw-Hill Education, New York, 2008: 167-203

Biographies

JIAN Xin, received his B.E. and Ph.D. degree from Chongqing University, Chongqing, China in 2009 and 2014, respectively. He is currently a lecture at the College of Communication Engineering, Chongqing University, China. His interests include statistical mathematics, wireless communication theory, traffic engineering and the next generation mobile communication. Email: jianxin_zg@163.com or jianxin@cqu.edu.cn.

ZENG Xiaoping, received the B.E., M.S., and Ph.D. degrees in Electrical Engineering from Chongqing University, Chongqing, China in 1982, 1987, and 1996, respectively. He is now a professor and Ph.D. supervisor at the College of Communication Engineering, Chongqing University, China. His research interests include aeronautical information network, communication signal processing and biomedical signal processing.

YU Anning, a Ph.D. student of five-years-educational system at the College of Communication Engineering, Chongqing University, China. His interests include short-distance communication and electromagnetic propagation.

YE Changrong, a Ph.D. student of five-years-educational system at the College of Communication Engineering, Chongqing University, China. His interests include statistical learning theory and biomedical signal processing.

YANG Junyi, a Master student at the College of Communication Engineering, Chongqing University, China. His interest is the next generation mobile communication.