Effect of Mobile Wireless on Outage and BER Performances Over Rician Fading Channel

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ABSTRACT

Many researchers have analyzed the outage probability of wireless static networks over the Rician fading channel in recent years. However, few researchers consider the mobile wireless network models over the Rician fading channel environment. Due to the dynamic changing topologies of the mobile wireless networks, the methods used in the static wireless networks cannot be directly used in the mobile wireless networks. In this paper, we study the received power and the outage probability over Rician fading channel under the mobile wireless network scenarios. We analyze the Probability Density Function (pdf) of the received power and also give out a calculation formula of the outage probability of the Rician fading channel. Besides, we have considered the Random Way-Point (RWP) model and path loss exponent of one-dimensional (1-D), two-dimensional (2-D) and three-dimensional (3-D) development of nodes. We compare with the influences of the system parameters on the outage probability as well as the influences of the parameters of path loss. We also use the Bit Error Ratio (BER) to evaluate this fading channel. The simulation results indicate that the outage probability is much better when compared with $\eta - \mu$ fading channel for the same signal in this paper. Besides, the performance of the outage probability is different for different dimension modes. Especially, the 1-D model has the best outage probability when compared with 2-D and 3-D situations. The simulation results also indicate that the maximum value of the pdf in a given range for the received power is different under the different dimensions. That is to say, for the 1-D, the range of peak value is from 5 to 10, while for the 2-D and 3D, this range is changed from 10 to 20.

INDEX TERMS

Mobile wireless networks, Rician fading channel, random way-point (RWP), probability density function (pdf), outage probability.

I. INTRODUCTION

With the development of the Fifth Generation (5G) mobile communication technology, 5G-related technologies are widely used in the Intelligent Transportation Systems (ITS) and many other fields. However, due to the complex and changeable mobile communication environments, the research on the performance of the mobile communication system is very complicated. So it becomes very important to design and evaluate the performance of the mobile communication system for its applications. 5G provides enough bandwidth for the Internet of Vehicles (IOV) technology. Currently, several researchers have done much work on the performances of the wireless networks, and most of them focused on static wireless networks. For example, the authors supposed the receiver and transmitter are fixed over the Rician channel, and studied the influences of several factors [1]. Similarly, the authors in [2] have given an outage probability for a finite interference linear Vehicular Ad Hoc Networks (VANETs) with a random multiple access protocol. The authors in [3] have given the Rician Shadowed (RS) fading channel with integral fading parameter. The authors in [4] have analyzed a single input single output Orthogonal Frequency Division Multiplexing (OFDM) system in the combined effect of normalized Carrier Frequency Offset (CFO), phase noise and timing jitter in both Rayleigh and Rician fading channels. The authors in [5] have given the novel simple expressions for the pdf and the Moment Generating Function (MGF) of Rician fading. In all, the above researchers have only considered the static situation that the receiver and transmitter are fixed. In fact, in the current 5G mobile wireless network systems, the receivers and transmitters are moving, and the topologies are changing, especially in the Device to Device (D2D) communications [6], [7] and other mobile wireless networks. Thus, the distance between the receiver and transmitter is not only a constant but...
is a random variable. Even some researchers have considered the mobile cases such as in [8], [9], but they only considered the performances under the Nakagami − m and η − µ fading channel, which was not enough for the current mobile networks.

In the wireless networks, when the receiver and transmitter are far away from each other, the direct signals are very weak due to large diffusion losses. And sometimes there are many reflected signals instead of the direct signals due to the shielding reasons. This phenomenon is mostly happened in the mountains, rural, suburban roads, and so on. The Rician fading channel is more suitable for employing in the above scenarios when compared with the other channels. In a dynamic network, the signal received by the receiver varies with the time. That is, in the dynamic wireless network, the mobility, distance and multipath fading of the receiver and transmitter lead to the received power follows to the non-exponential distribution [10]. When the vehicle is driving on the road, the receiving and sending terminals are relatively mobile, thus this is a dynamic network. Therefore, when studying the IOV related issues, the solution should be built on a dynamic network. A variety of mobile models are used to study the behaviors of wireless mobile network and describe the wireless mobile scenarios. This paper adopts the RWP mobile model. This model has been widely applied in one-dimensional (1-D), two-dimensional (2-D) and three-dimensional (3-D) wireless network topology structures, which is used to describe the behavior of the mobile network [11]. In fact, it is easily to understand that urban roads can be treated as 1-D scenario, and intersections can be treated as 2-D scenario, and the mountain roads can be treated as 3-D scenario. In this RWP model, the mobile user moves along a long zig-zag line segment path. And at each turning point, the moving node can pause for a random period of time, or it can choose a new destination at random, or it can choose a moving speed within a given random velocity distribution.

In fact, the outage probability is a key index to show the performances of the link capacity. When the link capacity fails to meet the required user rate, outage events will occur. This event is probabilistic and depends on the average Signal-to-Noise Ratio (SNR) of the link and its channel fading distribution model. This paper focuses on outage probability, which plays an important role in network planning, designing and evaluations. There were many studies on the outage probability of different channels [12] − [14]. On different transmission problems, different authors come up with different solutions. For example, the authors in [15] have proposed an on-demand caching function virtualization scheme and design a communication scheme between the fog nodes and the future Internet nodes for the forwarding process. The authors in [16] have proposed a Peer-to-Peer (P2P) knowledge market to make knowledge tradable in Edge Artificial Intelligence (edge-AI) enabled Internet of Things (IoT).

In digital transmission, the Bit Error Ratio (BER) is the number of error bits divided by the total number of bits transmitted on a communication channel, which is affected by noise, interference, distortion, or bit-synchronization errors. This paper uses these to evaluate the Rician fading channel. Also, in the process of wireless channel propagation, a statistical model is used to characterize the random attenuation of signals, including the position, size and dielectric properties of obstacles, as well as the variation of reflector and scatterer. The most common model is the abnormal shadow model, which can accurately model the variation of received power in indoor and outdoor infinite propagation.

On the other hand, the Rician fading channel is usually a propagation path consisting of a strong Line of Sight (LOS) component and many random weaker components [17]. It can be seen from [1] that the effect of SNR and distance on the outage probability of Rician fading channel is very obvious, and the value of Rician channel coefficient K also has a very big impact on the outage probability [18]. Rician channel coefficient K can be used for Bessel distribution and is defined as the ratio of energy in LOS path to energy in scattering path. The value range of K is relatively wide, it can be taken from −∞ to +∞, this paper only selected the positive part of a few representative values. The main contributions of this paper are as follows:

- Rician fading channel is considered in this paper, and a centralized access point surrounded by a set of nodes in 802.11 based mobile network is assumed.
- This paper derives the pdf and the Cumulative Distribution Function (cdf) of the received signal power for a mobile user in a Rician fading channel.
- This paper compares the performances under different network topologies, such as 1-D, 2-D and 3-D networks. For a 1-D topology, we consider a line with unit length and an access point at the origin of the line. The 2-D network topology is a circle with unit radius and the 3-D network topology is a sphere with unit radius. In the theoretical analysis, it is assumed that each node is transmitted at an equal unit of power. The performances in these networks are different. Especially the 1-D model is much better when compared with the 2-D and 3-D situations.
- This paper derives a closed-form expression for the outage probability in an interference-limited environment with Rician fading channel. The results reveal that the employed Rician fading channel has better outage probability performances when compared with the η − µ channel.
- This paper derives an average BER formula of the Rician fading channel in mobile wireless environments.

The rest of this paper is shown below. In Section II, we define the system model of pdf, cdf. In Section III, we derive general formulas for outage probability and BER. In Section IV, we analyze the simulation results. Some conclusions are drawn in the last part.
II. SYSTEM MODEL
As shown in Fig. 1, when the car is driving on the road, the speed will change constantly according to the road conditions, so the distance between cars is constantly changing, which does not keep static. The distance between the car and the base station also changes constantly during the driving process.

A. SIGNAL MODEL
We assume the transmitted signal between the access node (one car) to the mobile node (another car) is $\gamma$ in Rician fading channel. The pdf of the received power under Rician fading channel is expressed as [19]

$$
f(\gamma) = \frac{K + 1}{\Omega_s} \times I_0 \left( 2 \sqrt{\frac{K(K + 1)\gamma}{\Omega_s}} \right)$$

$$\times e^{-K} \times \exp \left(-\frac{(K + 1)\gamma}{\Omega_s}\right) \quad (1)$$

where $K$ is the Rician channel parameter, $I_0(.)$ is the modified Bessel Function, $I_0(\gamma) = \sum_{n=0}^{\infty} \frac{1}{n!} (\gamma^n / 2^n)$. The formula (1) is the pdf of received power of in static networks but not in mobile nodes. Where $\Omega_s$ is the average received signal, and the $\Omega_s$ is a constant in the static nodes. However, in a mobile network, the $\Omega_s$ is constantly changing. Thus, the formula (1) is not suitable for the mobile networks. Here, in order to get the pdf of the mobile networks, we set the $\Omega_s$ to have the following relation with the distance $x$ as

$$\Omega_s = P_t x^{-\alpha} \quad (2)$$

where $x$ is the distances between the transmitter and receiver, $P_t$ is the transmit power and $\alpha$ is the path-loss exponent that depends on the propagation environment, according to the reference [9] the value range of $\alpha$ is from 2 to 5. In this paper, a mobile wireless network is considered, and the transmission distance between nodes are randomly changing due to the nodes mobility, but the transmit power is constant.

Assuming that the value range of $x$ for a realistic mobility scenario is $0 \leq x \leq D$. The pdf of the distance $x$ is given as the follow

$$f_x(x) = \frac{K + 1}{P_t x^{-\alpha}} \times I_0 \left( 2 \sqrt{\frac{K(K + 1)\gamma}{P_t x^{-\alpha}}} \right)$$

$$\times e^{-K} \times \exp \left(-\frac{(K + 1)\gamma}{P_t x^{-\alpha}}\right) \quad (3)$$

The conditional pdf of the received signal power at a given distance $x$ is given as

$$f_\gamma(\gamma|X) = \frac{K + 1}{P_t x^{-\alpha}} \times I_0 \left( 2 \sqrt{\frac{K(K + 1)\gamma}{P_t x^{-\alpha}}} \right)$$

$$\times e^{-K} \times \exp \left(-\frac{(K + 1)\gamma}{P_t x^{-\alpha}}\right) \quad (4)$$

B. MOBILITY MODEL
The mobility model is used to describe the distance distribution between the receiver and transmitter in the mobile environment. In the RWP model, the spatial distribution of moving networks node is uneven. The distribution of steady-state spatial nodes can be expressed as a polynomial in the distance $x$ between transmitter and receiver [20]. Here, the RWP model is considered for analyzing the channel performances, and it is easily to understand that the analysis method we proposed is suitable for any rotationally symmetric spatial distribution, as long as it can be approximated as a polynomial function of the receiving distance at any angle at the sending end. In the RWP model, it is usually assumed that the receiving node is at a randomly selected coordinate point within the servant region, depending on the network’s topology. The pdf of the distance $x$ is given by the following [20]

$$f_x(x) = \sum_{i=1}^{n} B_i x^{\beta_i} \quad (5)$$

where parameters $n$, $B_i$, and $\beta_i$ depend on the number of dimensions considered in the topology and are summarized in [17]. For example, ([17], Tab. 1) gives $n = 2$, $B_1 = [6, -6]$, and $\beta_1 = [1, 2]$ for 1-D topology; $n = 3$, $B_1 = (1/73) \times [324, -420, 96]$, and $\beta_1 = [1, 3, 5]$ for 2-D topology; and $n = 3$, $B_1 = (1/72) \times [735, -1190, 455]$, and $\beta_1 = [2, 4, 6]$ for 3-D topology.
In order to arrive at a tractable expression, making use of [21] so that

$$I_0 \left( \frac{K(K + 1)\gamma^2}{P_t x^{-\alpha}} \right) = \sum_{m=0}^{\infty} \frac{1}{m! \Gamma(m + 1)} \times \left( \frac{K(K + 1)\gamma^2}{P_t x^{-\alpha}} \right)^{2m}$$  \hspace{1cm} (6)

According to the formula (3) (4) and (6), we can get the pdf and cdf of the received power

$$f_{Y_{RWP}}(\gamma) = \sum_{m=0}^{\infty} \sum_{i=1}^{n} \frac{B_i e^{-K}}{a m! \Gamma(m + 1)} \left( \frac{P_t}{K(K + 1)\gamma} \right)^{\frac{1+\beta_i}{\alpha}} \times \frac{1}{K\gamma} \times \Gamma \left( m + 1 + \frac{1 + \beta_i}{\alpha}, \frac{(K + 1)\gamma}{P_t} \right)$$  \hspace{1cm} (7)

and

$$F_{Y_{RWP}}(\gamma) = \int_0^\gamma \sum_{m=0}^{\infty} \sum_{i=1}^{n} \frac{B_i e^{-K}}{a m! \Gamma(m + 1)} \left( \frac{P_t}{K(K + 1)\gamma} \right)^{\frac{1+\beta_i}{\alpha}} \times \frac{1}{K\gamma} \times \Gamma \left( m + 1 + \frac{1 + \beta_i}{\alpha}, \frac{(K + 1)\gamma}{P_t} \right) \, d\gamma$$  \hspace{1cm} (8)

where \( \Gamma(.) \) is the lower incomplete gamma function [21].

**Proof.** See Appendix A.

**Remark:** When set \( K = 0 \), the channel can be treated as the Rayleigh fading channel. In this case, the Bessel Function can be approximated as \( I_0 (0) = 1 \). For this special condition, the formula (4) can be reduced to

$$f_{\gamma}(\gamma|X) = \frac{1}{P_t x^{-\alpha}} \times \exp \left( -\frac{\gamma}{P_t x^{-\alpha}} \right)$$  \hspace{1cm} (9)

According (7), the pdf and cdf of the received power is given as

$$f_{Y_{RWP}}(\gamma) = \sum_{i=1}^{n} \frac{B_i}{\alpha 1 + \beta_i}$$  \hspace{1cm} (10)

and

$$F_{Y_{RWP}}(\gamma) = \int_0^\gamma \sum_{i=1}^{n} \frac{B_i}{\alpha 1 + \beta_i} \, d\gamma$$  \hspace{1cm} (11)

**C. RANDOM WAY-POINT (RWP) MODEL**

Fig. 2 shows the signal transmission scenario simulation. In the mobile communication system, the distance between the transmitter and the receiver is constantly changing, and this change is regular and follows a certain random distribution behavior. The received signal changes over time due to node mobility, distance-related path loss, and multipath fadings [20]. The channel model adopted in this paper is the dynamic mobility model, namely the RWP model, in which nodes are randomly located in a given space. Each mobile user (node) selects a location in the network as the destination. Then, the node moves to the destination at a random uniform speed \([0, V_{\text{max}}]\), where \( V_{\text{max}} \) is the maximum speed of each moving node [10]. The direction and speed of each moving node are selected independently. After arriving at the destination, the mobile node stops for a random period of time. After this time, the migration node selects a new random destination and starts moving towards it in the same scenario as in the previous.

Suppose the distance between the moving transmitter and receiver in the RWP model is \( x \), then the pdf of distance \( x \) of a particular node from the access point in 1-D, 2-D and 3-D RWP models over the unit space \([0, 1]\) are given by [22], [23]

$$1 - D : f_i(x) = -6x^3 + 6x, \quad 0 < x < 1$$  \hspace{1cm} (12)

$$2 - D : f_i(x) = \frac{12}{73}(27x - 35x^3 + 8x^5), \quad 0 < x < 1$$  \hspace{1cm} (13)

$$3 - D : f_i(x) = \frac{35}{72}(21 - 34x^2 + 13x^4), \quad 0 < x < 1$$  \hspace{1cm} (14)

**III. SYSTEM PERFORMANCE ANALYSIS**

**A. OUTAGE PROBABILITY**

The outage probability \( P_{\text{out}} \) is one of the important indexes to evaluate and design wireless networks, defined as the area around the access node where the received SNR is greater than a preset threshold. Thus, the \( P_{\text{out}} \) can be expressed as

$$P_{\text{out}} = P (\text{SNR} \geq \mu)$$  \hspace{1cm} (15)

where \( \mu \) represents the preset threshold, and \( \sigma^2 \) represents the noise power. We assume unity noise power \( \sigma^2 = 1 \), in (15). Then, it can be calculated \( P_{\text{out}} \) referred by [9] from the cdf of
the received power as

\[ P_{out} = P \left( \frac{\sigma}{\sqrt{K}} \leq \mu \right) = F_{Y_{RWP}} (\mu) = \int_{0}^{\mu} f_{Y_{RWP}} (\gamma) \, d\gamma \]  

(16)

B. AVERAGE BER

BER is an important indicator to test the transmission performance of the channel. It refers to the number of received bits of a data stream caused by noise, interference, distortion or bit synchronization error in the communication channel. The BER determines the quality of the channel. The exact average BER referred by [8] for binary modulations is given by

\[ F_{y_{RWP}} = \frac{\Gamma(b, a\gamma)}{2\Gamma(b)} \int_{0}^{\infty} F_{Y_{RWP}} (\gamma) \, d\gamma = \frac{a^b}{2\Gamma(b)} \int_{0}^{\infty} \gamma^{(b-1)}e^{(-a\gamma)} F_{Y_{RWP}} \, d\gamma \]  

(17)

where \( \Gamma(z_1, z_2) \) is the upper incomplete gamma function [21], eq.(8.350.2) and \( \Gamma(z) \) is gamma function [21], eq.(8.310.1]. The parameters \( a, b \in (1/2, 1) \) depend on the type of binary modulation/demodulation employed [24].

IV. SIMULATION RESULTS

In this section, simulation results are provided to evaluate our analysis for investigating the effect of Rician fading channel parameters, mobility and propagation parameters on the pdf of received power and outage probability \( (P_{out}) \) for RWP mobility model with 1-D, 2-D and 3-D three different topologies.

Fig. 3 presents three different values of the channel parameter \( K \), i.e., \( K = 3, K = 5 \) and \( K = 10 \). We can see that the channel parameter \( K \) has great effects on the pdf of received power. There are a lot of differences in different dimensions about the pdf of received power. In the 1-D topology, the result curves are parabola, and when the \( \gamma \) is bigger than 7db, the pdf will be increased with the decrease of \( K \). For 2-D and 3-D, when \( K \) reaches 17db, the pdf of received power goes down.

In Fig. 4, the effects of Rician fading channel parameters on the outage probability are studied with different parameters. We can see from these four lines, as the value of \( K \) increases, the outage probability also increases. Besides, it can be found from the Fig. 4 that the spacing between \( K = 3 \) and \( K = 4 \) is very large, and the ordinate (outage probability) difference between them is also very large. However, the spacing between \( K = 4 \) and \( K = 5 \) is very small, indicating that when
the value of $K$ increases from 4 to 5, the outage probability increased fewer than when $K$ increases from 3 to 4 and 5 to 6. Therefore, the outage probability difference between 1-D, 2-D and 3-D is not significant, and the specific differences can be seen in Fig. 5. According to the Fig. 3 and Fig. 4, $K = 6$ is more suitable for 1-D than $K = 3, K = 4$ and $K = 5$, and $K = 3$ is more suitable for 2-D and 3-D than $K = 4, K = 5$ and $K = 6$.

The effects of different topologies on the outage probability of received power are shown in Fig. 5. We can find that the influence of different dimensions on outage probability is very different. It can be clearly seen that the outage probability in 3-D is the highest and in 1-D is the lowest under the same signals. Besides, the probability of receiving less power in 3-D distribution is higher than the 2-D distribution. Similarly, for the 2-D distribution, the received power is less than for 1-D. When $\gamma = 5$, the curve goes up very quickly, and so that the outage probability goes up quickly.

Fig. 6 shows the outage probability of the received power for different propagation environments characterized by path loss exponents $\alpha = 3, 3.5, 4$. In the Fig. 6, the outage probability decreases when the $P_t$ increases until the outage probability reaches to 0. Besides, the outage probability goes down faster when the $\alpha$ is smaller.

Fig. 7 shows the comparison of two different channels on the outage probability. From the Fig. 7, it can be clearly seen that the employed Rician fading channel has much better performances than the $\eta - \mu$ fading channel.

Fig. 8 shows the average BER for BPSK versus $\gamma$ of different channel parameters $K$ for 3-D network. From the Fig. 8, it is evident that for different values of $K$, the average BER is also different. When $K$ is smaller, the average
BER is smaller. The overall trend of the average BER is similar to the outage probability as shown in the Fig. 5, and when $K = 4$, $K = 5$, the spacing between these two lines is smaller, but when $K = 3$, the spacing is much bigger than $K = 4$, $K = 5$, which is also similar with the simulation of the outage probability shown in the Fig. 5.

V. CONCLUSION

This paper analyzes the outage probability of mobile wireless networks in Rician fading channel. We calculate the pdf and cdf of the Rician fading channel in mobile wireless networks. Based on this, the outage probability and average BER of the Rician fading channel in mobile wireless networks are derived. The effect of Rician fading channel parameters, propagation, and the exponential path loss have been studied, as well as average BER. The simulation results prove the accuracy of the theoretical analysis. The proposed method has better outage probability in the same signal when compared with other previous research works, such as $\mu - \mu$ fading channel, and the RWP model is more suitable for mountainous areas and rural areas. In the future, we will focus on the impacts of different channels on the VANETs and do more experiments for some realistic applications within the VANETs by different channels.

APPENDIX

By substituting (6) in (4) and substituting the result and (5) in (3), the unconditional pdf is given as

$$f_{\text{RWP}}(\gamma) = \int_{0}^{\infty} \sum_{m=0}^{\infty} \frac{B_{m} e^{-K \alpha m}}{\Gamma(m+1)} \left(\frac{K + 1}{P_{t} x^{-\alpha}}\right)^{m+1} \times 
\frac{1}{\Gamma} \int_{0}^{\infty} x^{a(m+1)} e^{-x} dx,$$

according to the Gamma Function $\Gamma(z) = \int_{0}^{\infty} t^{z-1} e^{-t} dt$ we can finally get the pdf of the received power.

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