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Accurate Performance Analysis of Reconfigurable Intelligent Surfaces over Rician Fading Channels

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***Abstract*—We consider in this letter the performance of reconfigurable intelligent surface (RIS)-aided wireless networks over Rician fading channels. We derive new accurate closed-form approximations for several performance measures, including the outage probability, average symbol error probability (ASEP), and the channel capacity. Additionally, to get more insights into the system behavior, we derive asymptotic expression for the outage probability at high signal-to-noise ratio (SNR) values, and provide closed-form expressions for the system diversity order and coding gain. Findings show that the considered RIS scenario can provide a diversity order of $\frac{a+1}{2}$, where a is a function of the Rician channel K-factor, Rician channel scale parameter Ω, and the number of reflecting elements N.**

***Index Terms*—Reconfigurable intelligent surface, Rician fading channel, accurate approximations.**

I. Introduction

Due to their attractive features, the reconfigurable intelligent surfaces (RISs) have recently attracted noticeable attention as a promising candidate for future wireless communication networks. An RIS is an artificial surface, made of electromagnetic material, that is capable of customizing the propagation of the radio waves impinging upon it [1]. The RIS has been proposed as a new low-cost and less complicated solution to realize wireless communication with high energy and spectrum efficiencies.

An overview of the basic characteristics of the large intelligent surface/antenna technology and its potential applications has been provided in [2]. A detailed overview on the state-of-the-art solutions, fundamental differences of RIS with other technologies, and the most important open research issues in this area of research has been provided in [3]. The authors in [4] showed that RIS has better performance than conventional massive multiple-input multiple-output systems as well as better performance than multi-antenna amplify-and-forward relaying networks with smaller number of antennas, while reducing the system complexity and cost.

The performances of relay-assisted and RIS-assisted wireless networks from coverage, probability of signal-to-noise ratio (SNR) gain, and delay outage rate have been compared in [5]. In [6], the authors utilized RIS to improve the quality of a source signal, which is sent to destination through an unmanned aerial vehicle. Recently, analytical expression for the secrecy outage probability of RIS-assisted network in the presence of direct link and eavesdropper has been derived in [7]. To cover the scenario, where a line-of-sight (LOS) component exists between the source and RIS, RIS and destination, the authors in [8]-[11] studied RIS-assisted networks assuming Rician fading models. In [8], the authors formulated an optimization problem in terms of an upper bound of spectral efficiency (SE) for large intelligent surface (LIS) network. Then, they obtained the optimum phase shifts of the RIS, which result in the optimum SE. Another optimization problem has been formulated and solved in [9], where the limited number of phase shifts that optimize the system performance was obtained.

In a performance analysis context, an upper bound for the channel capacity and asymptotic expressions for the outage probability of a RIS-assisted network over Rician fading channels were derived in [10]. Using the central limit theorem (CLT)-based approach, where the non-central chi-square distribution is used to approximate the channel distributions of the RIS, the authors in [11] derived some upper bounds for the bit error rate in both indoor and outdoor applications. As the CLT-based approach is used in derivations, the derived results are expected to diverge from the actual/correct behavior of RIS-assisted networks, especially at low numbers of reflecting elements. Most recently, a paper that studies the outage performance of RIS-assisted networks over generalized fading channels has been proposed by Trigui *et al.* [12]. The Fox's H-transform theory has been used to derive some expressions for the system outage probability in the presence of phase noise.

It is important to mention here that some of the previous works on RIS-assisted networks did the derivations based on the CLT, which makes the results only applicable for large number of reflecting elements. Following other approach and to cover the scenario of any number of reflecting elements, the authors in [13] and [14] have derived accurate approximations for the channel distributions and performance metrics of RIS-assisted networks assuming Raleigh fading channels. Most recently, [15] provided closed-form expressions for the bit error probability of RIS-assisted network over Nakagami-m fading channels. It is important to mention here that the required number of reflecting elements is usually specified by the system requirements. If the system requirements are not high, utilizing low number of reflecting elements could be enough, especially the higher the number of reflecting elements, the higher the channel estimation load, which will need then to be compensated for at the RIS.

Motivated by what is mentioned above and to cover the scenario where a LOS component exists between the source and RIS, RIS and destination and to have valid results for

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