Spectral and Energy Efficiency Analysis of RIS-Assisted LEO Satellite Communications under Satellite Mobility

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Abstract

This paper studies the spectral efficiency (SE) and energy efficiency (EE) of a downlink passive reconfigurable intelligent surface (RIS)-assisted low Earth orbit (LEO) satellite communication system under satellite mobility. Satellite movement is modeled using the elevation angle to capture variations in link geometry. The impact of satellite mobility and RIS size on system performance is evaluated through numerical analysis. Results show that both SE and EE improve with increasing elevation angle and larger RIS sizes, highlighting the potential of passive RIS deployment in LEO satellite systems.

Keywords: Energy efficiency, LEO satellite communications, reconfigurable intelligent surface, satellite mobility, spectral efficiency.

Ⅰ. Introduction

Low Earth orbit (LEO) satellite systems offer low latency and wide-area coverage but suffer from rapidly changing channel conditions due to satellite mobility. Reconfigurable intelligent surfaces (RIS) have been proposed to enhance LEO satellite communications by intelligently shaping the wireless propagation environment with low power consumption [1]. Existing studies have explored RIS-assisted LEO satellite systems using a multi-user transmission scheme [2], active RIS architecture [3], and advanced RIS deployments [4]. However, the fundamental performance behavior of passive RIS-assisted LEO satellite systems under satellite mobility has not been sufficiently examined. In this paper, we investigate the spectral efficiency (SE) and energy efficiency (EE) of a downlink passive RIS-assisted LEO satellite system, where satellite movement is characterized by the elevation angle.

Ⅱ. Method

We consider a downlink LEO satellite communication system assisted by a passive RIS, where a single satellite communicates with a ground user. The direct satellite-user link is assumed to be negligible, and communication relies on the RIS-assisted reflected link, which is a common assumption in RIS-assisted satellite systems [2], [3]. Satellite mobility is modeled using the elevation angle θ, which determines the satellite-RIS distance as $d_{SR} = H/sin(\theta)$, where H is the satellite altitude [1]. The satellite-RIS channel is modeled as Rician fading, while the RIS-user channel follows Rayleigh fading, and free-space path loss is assumed [2], [4].

To evaluate the impact of satellite mobility and RIS configuration on system performance, we analyze SE and EE across varying elevation angles (20°–90°) and RIS sizes (N=32, 64, 128 elements).

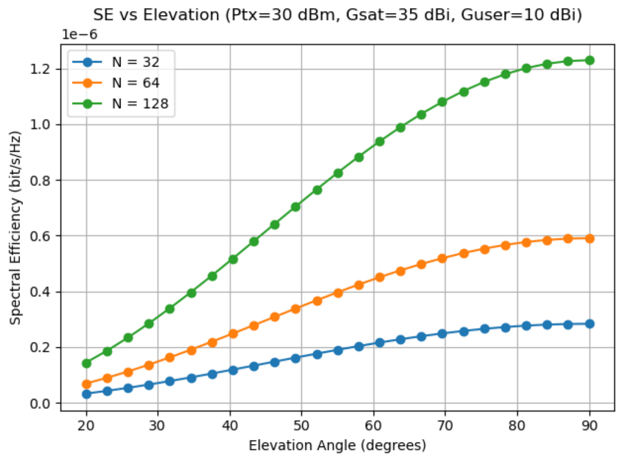

Figure 1 shows the SE performance versus elevation angle for different RIS sizes.

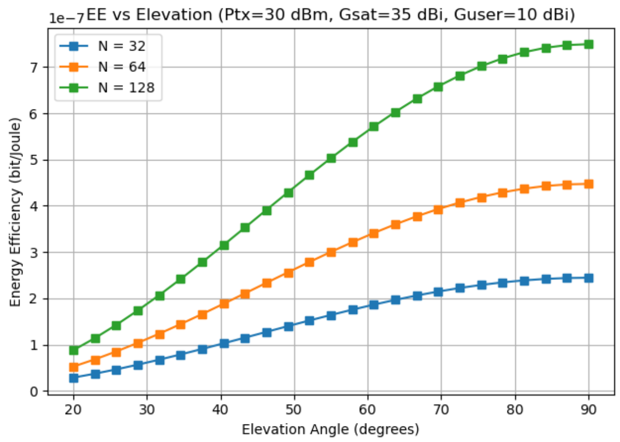

Figure 1 shows the EE performance versus elevation angle.

As shown in Fig. 1, SE increases with elevation angle θ due to reduced propagation distance and path loss. Larger RIS sizes (N=128 vs. N=32) consistently achieve higher SE through coherent combining of the reflected signals at the receiver. As θ increases, channel conditions become more favorable, leading to improved signal strength. These results demonstrate the effectiveness of increasing the number of reflecting elements in enhancing received signal power under satellite mobility.

Fig. 2 presents a similar trend for EE, where higher θ results in improved performance due to the more favorable propagation conditions. As the satellite elevation increases, the improved channel quality leads to higher achievable SE, which in turn enhances the overall EE. In addition, larger RIS sizes consistently achieve higher EE across all elevation angles, demonstrating the effectiveness of passive RIS deployment under satellite mobility.

Ⅲ. Conclusion

This paper analyzed SE and EE of a passive RIS-assisted LEO satellite system under satellite mobility. Satellite movement was modeled using the elevation angle to capture variations in link geometry. The results show that both SE and EE improve with increasing elevation angle and larger RIS sizes, confirming the effectiveness of passive RIS deployment for LEO satellite communications. Future work may extend this study to multi-user scenarios and adaptive RIS configurations.

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