Performance Comparison of Joint ML Detection and SIC for Downlink NOMA in GEO Satellite Networks

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Abstract

6G satellite communication networks are emerging as a key infrastructure capable of providing wide-area coverage, low latency, and high-throughput services. Geostationary Earth orbit (GEO) satellites play an important role in broadcasting, meteorology, and national security due to their continuous connectivity. However, the limited radio resources have become a critical challenge in satellite networks. To address this issue, we investigate the performance of a GEO downlink with power-domain non-orthogonal multiple access (NOMA), considering joint maximum likelihood (JML) detection or successive interference cancellation (SIC) together. We evaluate the bit error rate (BER) of both cases through extensive simulations and discuss the feasibility of employing NOMA with JML or SIC for GEO satellite networks.

Ⅰ. Introduction

The 6G wireless communication system aims to achieve ultra-high data rates, ultra-low latency, and global connectivity, positioning satellite communication networks as a key infrastructure to support these objectives [1]. Although research on low Earth Orbit (LEO) satellites has been actively pursued in recent years, Geostationary Earth Orbit (GEO) satellites continue to play a critical role in providing continuous wide-area coverage, making them indispensable for applications such as broadcasting, meteorology, national security, and disaster response.

Furthermore, heterogeneous satellite networks that integrate LEO and GEO systems have gained increasing attention for their ability to complement the strengths of each orbital layer [2]. Cooperative reception scenarios involving multiple Ground Base Stations (GBS) demand more sophisticated receiver designs to fully leverage these advantages.

However, GEO satellites face limited spectrum availability, requiring efficient utilization. Power-domain non-orthogonal multiple access (NOMA) enables multiple satellites to share time-frequency resources via signal-level superposition. While successive interference cancellation (SIC) is simple, it suffers from error propagation. To overcome this, we propose a joint maximum likelihood (JML)-based cooperative receiver for GEO downlink with multiple GBS, improving decoding accuracy without additional transmission cost. Its performance is validated through simulations.

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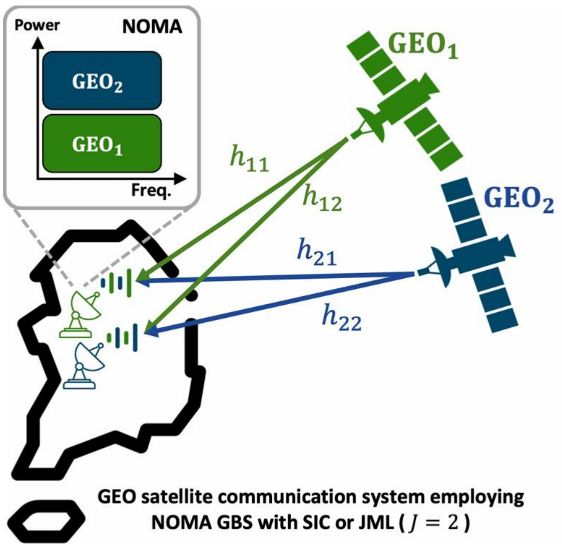

Figure 1. Power-domain NOMA-based system architecture

Ⅱ. System Model and Link Budget Analysis

We consider a GEO satellite communication system where two GEO satellites simultaneously transmit signals to multiple GBS, as illustrated in Figure 1. We assume the GEO satellite and GBS are equipped with a single antenna, respectively. We denote the number of GBS by J. We consider the wireless channel coefficient h_{ij} from satellite i to the GBS j. It is modeled as a shadowed-Rician fading channel under the average shadowing (AS with $b = 0.126, m = 10.1$ and $\Omega = 0.835$) condition of the land mobile satellite (LMS) model [3]. Then, the received signal at the GBS $j \in \{1, \ldots, J\}$ is modeled as

$$y_j = \sqrt{P_1} h_{1j} x_1 + \sqrt{P_{2j}} h_{2j} x_2 + w, \tag{1}$$

where, P_1 and x_1 denote the transmitted symbol and transmit power of GEO $(i \in 1{,}2)$, respectively, and $w \sim \mathcal{CN}(0, \sigma^2)$ is complex Gaussian noise.

We consider the GBS to employ a NOMA receiver with JML detection or the SIC technique, sharing the same time and frequency resources for different GEO satellites by superimposing signals at different power levels. When the GBS employs the NOMA receiver with SIC, it decodes signals sequentially based on received power and subtracts previously decoded signals. The SIC decoding at GBS j is expressed as follows:

$$\hat{x}_1 = \underset{x_1 \in \mathcal{X}}{\operatorname{argmin}} |\mathrm{y} - \mathrm{h}_1 x_1|^2, \quad (2)$$

$$\hat{x}_2 = \underset{x_2 \in \mathcal{X}}{\operatorname{argmin}} |\mathrm{y} - \mathrm{h}_1 \hat{x}_1 - h_2 x_2|^2, \quad (3)$$

where $\mathcal{X}$ denotes the set of possible modulated symbols according to the modulation scheme.

When GBS employs the NOMA receiver with JML detection, it jointly estimates all transmitted symbols by minimizing the Euclidean distance between the received signal and all possible symbol combinations. The decoding procedures of JML decoding at GBS j is expressed as follows:

$$[\hat{x}_1, \hat{x}_2] = \underset{x_1, x_2 \in \mathcal{X}}{\operatorname{argmin}} |\mathrm{y} - (\mathrm{h}_1 x_1 - \mathrm{h}_2 x_2)|^2, \quad (4)$$

To ensure reliable communication between GEO and GBS, a link budget analysis is conducted. The analysis accounts for all gains and losses encountered as the signal propagates from the transmitter to the receiver and is essential for maintaining stable and robust connectivity. Accordingly, the carrier-to-noise density ratio, denoted by β, is expressed as follows:

$$\beta = \left(\frac{E_b}{N_0}\right)_{req} + R_b + \eta, \quad (5)$$

Here, $(E_b/N_0)_{\mathrm{req}}$ [dB] represents the required SNR to achieve bit error rate (BER), R_b [dB above 1 bit/s] denotes the achievable data transmission rate, and η signifies the link margin. The value of β is influenced by various environmental factors, including the satellite transmit power, the performance of the receiving antenna, atmospheric attenuation, and rain fade, among other path losses.

Ⅲ. Numerical Results and Conclusion

Figure 2 illustrates the BER performance comparison between SIC and JML when a single GBS receives signals from two GEO satellites using BPSK and QPSK modulation schemes, assuming a 3 dB transmit power difference. The results show that JML consistently outperforms SIC under identical SNR conditions.

Figure 3 presents extended results for JML detection with the number of GBS set to $J = 1{,}2$ and 4, using QPSK modulation in all cases. As both the number of GBSs and the SNR increase, BER performance improves. When $J = 4$, the BER curve shifts to the left, indicating that reliable performance is achieved at lower SNR. The target BER of 10^{-4} is reached at approximately 13 dB, whereas $J = 1{,}2$ fail to meet this target, demonstrating that increasing the number of GBS enhances JML performance through improved spatial diversity.

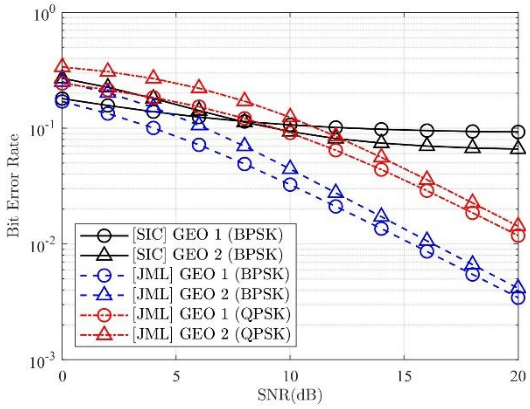

Figure 2. BER performance of NOMA with JML and SIC for BPSK and QPSK modulation

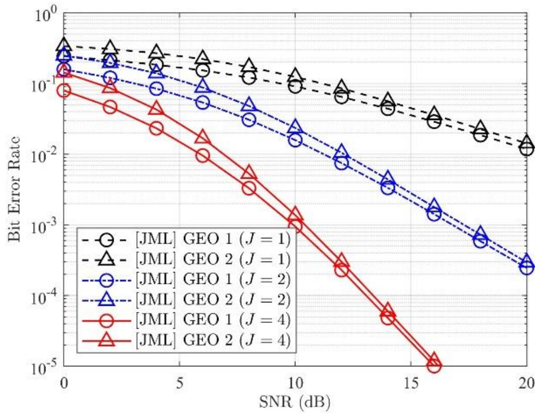

Figure 3. BER performance of NOMA with JML and SIC for the different number of GBS

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References

[1] H. Xie, et al., "LEO Mega-Constellations for 6G Global Coverage: Challenges and Opportunities," in IEEE Access, vol. 9, pp. 164223-164244, 2021

[2] R. Ge, et al., "Non-orthogonal Multiple Access Enabled Two-layer GEO/LEO Satellite Network," 2021 29th European Signal Processing Conference (EUSIPCO), Dublin, Ireland, 2021, pp. 890-894

[3] M. R. Bhatnagar and A. M.K., "On the Closed-Form Performance Analysis of Maximal Ratio Combining in Shadowed-Rician Fading LMS Channels," in IEEE Communications Letters, vol. 18, no. 1, pp. 54-57