Traffic-Aware Multilayer Satellite Networks with Rate-Splitting Multiple Access for High Throughput

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Abstract—With the development of low earth orbit (LEO) satellite communication (SATCOM), numerous LEO satellites are in operation to provide global coverage. However, as the number of satellites rapidly increases, available spectrum resources are limited. To alleviate spectrum scarcity, frequency sharing for multilayer satellite networks is attracting significant attention. Additionally, considering the global coverage of SATCOM, a scheme that can accommodate heterogeneous traffic demands for users is required. In this paper, we propose traffic-aware multilayer satellite networks based on rate-splitting multiple access (RSMA) for interference management and subsequently validate the superiority of the proposed scheme through simulation.

Keywords—Multilayer satellite networks, rate-splitting multiple access

1. Introduction

Satellite communication (SATCOM) is expected to play a significant role as a framework enabling 6G hyper-connectivity. However, the proliferation of LEO satellites poses challenges for SATCOM development due to the limited spectrum resources. To address this issue, multilayer satellite networks (MLSNs) have emerged for frequency coexistence between existing geostationary orbit (GEO) and LEO SATCOMs [1]. While MLSNs allow for a greater number of LEO satellites to access the same frequency, interference management techniques are necessary to enhance spectrum efficiency. In this paper, we propose traffic-aware MLSNs with rate-splitting multiple access (RSMA) for high throughput. Numerical results show that our proposed method provides high throughput.

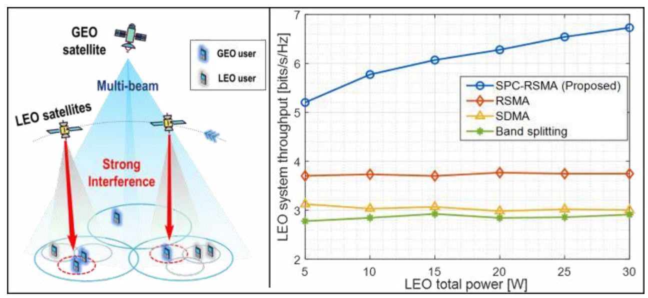

Fig. 1: LEO system throughput for traffic-aware MLSNs

2. Traffic-Aware MLSNs based on RSMA

We consider GEO with N_G antenna feeds and LEO with N_L antenna feeds serve K GEO users and U LEO users. In MLSNs with frequency sharing, mutual interference degrades the throughput for SATCOMs. Note that the ITU regulates LEO SATCOM to protect existing GEO SATCOM from unacceptable interference. Thus, we limit the interference leakage level from LEO satellite to GEO user. While such constraints can protect GEO SATCOM, they pose challenges in ensuring the throughput of LEO SATCOM. To ensure both GEO and LEO SATCOMs, we propose the RSMA with super-common message, which flexibly mitigates inter-system interference, inter-beam interference, and intra-beam interference [2]. Hence, the transmitted signal from LEO satellites is composed of three distinct streams at u-th LEO user: super-common stream s_{spc}, common stream s_{c}, and private stream s_u. The received signals at k-th GEO user can be expressed as

$$y_k = \mathbf{f}_k^H \mathbf{p}_{\text{m}} s_{\text{m}} + \mathbf{z}_k^H \left(\mathbf{p}_{\text{spc}} s_{\text{spc}} + \mathbf{p}_{\text{c}} s_{\text{c}} + \textstyle\sum_{j=1}^{U} \mathbf{p}_j s_j \right) + n_k, \quad (1)$$

where $\mathbf{f}_k \in \mathbb{C}^{N_G \times 1}$ and $\mathbf{z}_k \in \mathbb{C}^{N_L \times 1}$ are the channel vectors between GEO satellite and k-th GEO user, LEO satellite and k-th GEO user, respectively. s_{m} is a multicast stream for GEO users. Assume that the vector of symbol streams from satellite, $\mathbf{s} = \left[s_1, \dots, s_U, s_{\text{c}}, s_{\text{spc}}, s_{\text{m}} \right]^T \in \mathbb{C}^{(N_L+3) \times 1}$, follows $\mathbb{E}\{\mathbf{s}\mathbf{s}^H\} = \mathbf{I}$. $\mathbf{p}_{\text{m}} \in \mathbb{C}^{N_G \times 1}, \mathbf{p}_{\text{spc}} \in \mathbb{C}^{N_L \times 1}, \mathbf{p}_{\text{c}} \in \mathbb{C}^{N_L \times 1}$ and $\mathbf{p}_u \in \mathbb{C}^{N_L \times 1}$ are the precoding vectors for $s_{\text{m}}, s_{\text{spc}}, s_{\text{c}}$, and s_u. $n_k \sim \mathcal{CN}(0, \sigma_n^2)$ is additive white Gaussian noise (AWGN). The interference leakage from LEO satellite to GEO user should be restricted as

$$\left| \mathbf{z}_k^H \mathbf{p}_{\text{c}} \right|^2 + \textstyle\sum_{j=1}^{U} \left| \mathbf{z}_j^H \mathbf{p}_j \right|^2 \leq I_{th}, \quad \forall k \in \{1, \dots, K\}, \quad (2)$$

where I_{th} is the interference threshold level for GEO user.

In this simulation, we consider $N_G = 2$, $N_L = 2$, $K = 2$, and $U = 4$. In Fig. 1, we compare LEO system throughput according to the traffic demand of users for the proposed scheme with existing RSMA, space-division multiple access (SDMA), and band splitting under the strong interference from LEO satellite to GEO users. We can confirm that proposed SPC-RSMA shows the superiority in terms of the throughput compared to other schemes.

References

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