

Rate-Splitting Approach for Integrated Satellite-Terrestrial Networks

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Abstract—We investigate a downlink rate-splitting multiple access (RSMA) strategy for an integrated access and backhaul (IAB) network wherein a satellite is equipped with a regenerative payload. The satellite provides wireless backhaul to IAB-nodes and simultaneously serves user equipments (UEs). We consider the sum spectral efficiency maximization problem and analyze an RSMA precoding design for the integrated satellite-terrestrial network (ISTN)-based IAB topology. The simulation results show that the RSMA scheme significantly increases the sum spectral efficiency compared to conventional baselines. The results show the potential of RSMA in next-generation non-terrestrial networks (NTNs) with the regenerative satellite.

Index Terms—Rate-splitting multiple access, integrated satellite-terrestrial networks, non-terrestrial networks, integrated access and backhaul

I. INTRODUCTION

Next-generation mobile networks aim for seamless global coverage by integrating terrestrial and satellite systems. Satellite communication is a key technology to expand coverage to rural and remote areas. The integrated satellite-terrestrial network (ISTN) has gained significant attention in both academia and industry. In 5G NR, the integrated access and backhaul (IAB) architecture was introduced to cost-effectively backhaul small cells over wireless links. Building on these concepts, recent studies propose architectures that leverage satellites as IAB donors, providing backhaul connectivity to ground IAB nodes. This integration enables scalable deployments while reducing reliance on terrestrial infrastructure. The convergence of ISTN and IAB opens the door to more flexible and scalable network deployments, particularly in coverage-challenged environments. By performing on-board processing with advanced satellite payloads, these satellite-based IAB scenarios can interface with terrestrial systems [1].

Efficiently managing downlink transmissions to multiple receivers (both IAB-nodes and end users) presents a major challenge. Rate-splitting multiple access (RSMA), a versatile framework that generalizes spatial division multiple access (SDMA) and non-orthogonal multiple access (NOMA), promises significant performance gains [2]. However, its application in satellite-based IAB networks remains largely unexplored. This gap is especially critical given the growing interest in integrating advanced multiple access schemes with non-terrestrial networks to meet future capacity demands.

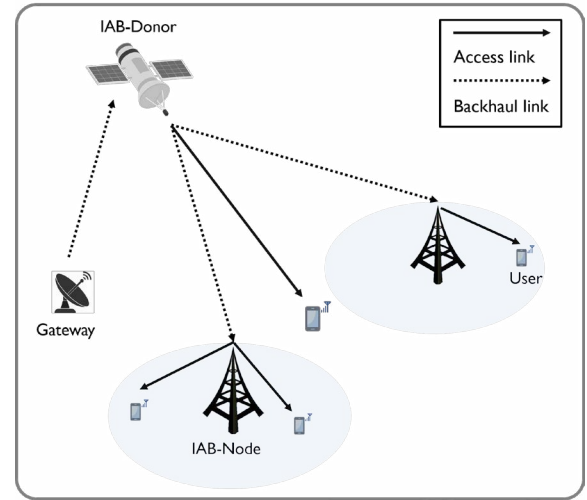


Fig. 1. Examples of ISTNs with satellite IAB donor.

Therefore, in this paper, we investigate RSMA-based downlink transmission optimization for a satellite IAB-donor with regenerative payload. We analyze the spectral efficiency maximization problem under the power limitation and IAB backhaul capacity constraints. Simulation results show that RSMA outperforms conventional schemes in spectral efficiency, highlighting its potential in next-generation satellite-terrestrial integrated networks.

II. SYSTEM MODEL AND PROBLEM FORMULATION

As shown in Fig. 1, we consider a downlink IAB network facilitated by a low earth orbit (LEO) satellite acting as the IAB-donor. The satellite is equipped with a regenerative payload and an array of N_t feeds, enabling multi-beam transmission with digital precoding. Specifically, the satellite serves ground IAB-nodes and user equipments (UEs), and each IAB node serves its local UEs via terrestrial access links. Each ground receiver (IAB-node or UE) is equipped with a single receive antenna and performs successive interference cancellation (SIC) decoding when required by the transmission scheme. For simplicity, we assume out-of-band backhaul and access links, so that an IAB-node can receive data from the satellite and transmit to its UEs simultaneously on orthogonal

resources [3]. We define the IAB-node set as $\mathcal{I} = \{1, \dots, I\}$, where I is the number of the IAB-nodes. When users are connected to the IAB-donor or the IAB-nodes, each user is associated with the nearest transmitting node. Under such circumstances, total users are divided into $I + 1$ groups and the user subset of each group is denoted as $\mathcal{K}_j, j \in \mathcal{I}$, where $\mathcal{I} = \{0, 1, \dots, I\}$ is the set of the user groups. Here, $|\mathcal{K}_0|$ and $|\mathcal{K}_j|, \forall j \geq 1$ are the number of the users served by the IAB donor and that of the IAB-node i , respectively.

The satellite IAB donor serves IAB nodes and UEs through 1-layer rate-splitting (RS) transmission [4]. Each IAB-nodes receives the message from the IAB donor via wireless backhaul link and transmits the downlink signal to the UEs through the orthogonal frequency division multiple access (OFDMA). Definitions and mathematical formulations for the detailed signal model and channel modeling are omitted due to space limitations.

In this work, we formulate the RSMA precoding optimization problem that maximizes the sum spectral efficiency.

$$\max_{\mathbf{U}, \mathbf{c}} \underbrace{\sum_{k \in \mathcal{K}_0} R_k^s(\mathbf{U}, \mathbf{C}_k)}_{\text{users served by IAB-donor}} + \sum_{i=1}^I \underbrace{\sum_{k \in \mathcal{K}_i} R_{k,i}^s(B_{k,i})}_{\text{users served by IAB-nodes}}, \quad (1)$$

where $\mathbf{U}$ is the precoding vector for IAB-donor, $\mathbf{c}$ is the common spectral efficiency vector, $B_{k,i}$ is the backhaul rate, and R_k^s is the spectral efficiency of UE k . The constraints include: (i) the total power consumption must not exceed the satellite's transmit power. (ii) each receiver must be able to decode s_c – this imposes that the rate of the common stream R_c is limited by the lowest SINR among the receivers for s_c ; (iii) each receiver must decode its own private stream with an SINR that supports its allocated private rate; The data rate delivered to each IAB-node from the satellite constrains the sum of rates of UEs behind that node. We assume that the access links of the IAB-nodes have sufficient capacity such that the bottleneck is the satellite backhaul.

This optimization problem can be addressed by alternately optimizing the precoders and the power allocation using a WMMSE-based algorithm [4].

III. SIMULATION RESULTS

In this section, we evaluate the sum spectral efficiency according to the satellite transmit power. We then compare the RSMA scheme with SDMA and NOMA.

Figure 2 presents the sum spectral efficiency as a function of the transmit power for different multiple access scheme. Here, we use $N_t = 2$ (overloaded networks). From this figure, we can see that the transmit power increases, the sum spectral efficiency increases. Furthermore, when applying the rate-splitting technique, it outperforms both SDMA and NOMA. By simultaneously exploiting the spatial domain and power domain, RSMA achieves a more efficient use of the satellite downlink than either SDMA or NOMA alone. These findings align with other recent studies which found RSMA to be superior in efficiency and flexibility for ISTN.

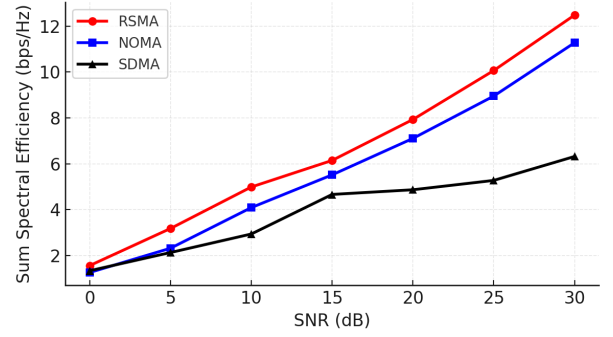


Fig. 2. Sum spectral efficiency as a function of the transmit power for different multiple access scheme.

IV. CONCLUSION

In this paper, we explore an RSMA-based downlink transmission for a satellite serving as an IAB-donor in the ISTN. We consider the RSMA precoding to maximize the sum spectral efficiency, and its performance outperforms SDMA and NOMA approaches. This design enables the satellite to better manage interference and user heterogeneity, which are critical challenges in multi-receiver downlink scenarios. Simulation results show that RSMA offers significant sum spectral efficiency gains. These findings contribute to the growing evidence that the RSMA can substantially enhance the performance of satellite-based IAB networks, paving the way for more efficient and flexible integration of satellites into 6G and beyond.

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