Spectrum Sharing Method in Satellite and Terrestrial Coexisting Networks

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***Abstract*—This paper introduces the coordinated multi-point (CoMP) non-orthogonal multiple access (NOMA) scheme for hybrid satellite-terrestrial networks (HSTNs). The proposed scheme facilitates seamless support for the satellite network (SN) users, while meticulously preserving the service quality of conventional terrestrial network (TN) users. To validate the efficacy of the proposed approach, extensive Monte Carlo simulations are conducted, employing practical parameters as suggested in third generation partnership project (3GPP) technical reports: TR 38.811, TR 38.821, and TR 38.901.**

***Index Terms*—CoMP, NOMA, hybrid satellite-terrestrial networks, spectral efficiency, interference mitigation.**

I. Introduction

The advent of low-earth-orbit (LEO) communication satellites has ignited a race to establish efficient space networks, raising questions about the optimal approach to achieving a seamless and ubiquitous network. In response, the third generation partnership project (3GPP) introduced the concept of non-terrestrial networks (NTNs) as a study item (SI) in release 15 [1]. The ongoing research endeavors to integrate NTN into cellular standards mark a crucial step towards realizing the promises of lower latency, reliable, and ultimately ubiquitous communication networks.

However, the potential infusion of LEO satellites into the spectrum range of NTN, specifically in the S-band and Ka-band, introduces the risk of spectrum collisions during simultaneous operation with terrestrial networks (TNs). These collisions could disrupt conventional TN operations significantly, prompting the need for NTN service providers to ensure the preservation of TN services even as they serve NTN users.

In parallel, the concept of non-orthogonal multiple access (NOMA) and coordinated multi-point (CoMP) has emerged as a promising contender for the 6th generation (6G) hybrid satellite-terrestrial network (HSTN) for cellular networks [2]. With the advantage of NOMA which allows multiple communication entities to share resources such as time, frequency, code, and power, NOMA holds the potential to dramatically enhance the spectral efficiency of communication systems. This feature makes NOMA a particularly attractive option for satellite networks (SNs) facing the challenge of accommodating an ever-growing number of users within constrained communication resources. CoMP such as joint TN and SN transmission enhances user experience by improving signal-to-interference plus noise ratio (SINR) performance of users suffering from strong interference at the edge of TN, and thereby, is an effective way to mitigate inter-cell interference (ICI) and inter-symbol interference (ISI).

Recent research is showing how significant NOMA is for hybrid satellite-terrestrial networks. In [3], hybrid satellite terrestrial-NOMA-network coding is proposed allowing users to use NOMA through both terrestrial base stations (BSs) and satellite links at the same time. In [4], the outage probability of cooperative NOMA (C-NOMA) scheme in hybrid satellite-terrestrial relay networks (HSTRNs) is investigated. It is shown that the scheme alleviates the masking effect of users with poor channel conditions in heavy shadowing.

This paper proposes coordinated multi-point (CoMP) NOMA in HSTN, which aims at addressing the integration of NTN and TN systems. The core of the proposed scheme is to enable the provisioning of services to NTN users while safeguarding the service quality of conventional TN users. To validate the efficacy of the proposed approach, extensive Monte Carlo simulation, employing practical parameters as specified in references such as [1], [5], [6].

II. System Model

In Fig. 1, the downlink CoMP NOMA-based hybrid satellite-terrestrial network scenario is depicted. The scenario involves a single resource block where the TN serves handheld user equipment (UEs) in an orthogonal multiple access (OMA) approach, and the satellite network (SN) serves both terrestrial and satellite users. The satellite, operating at an altitude of h_n, serves as a base station with a single antenna. The terrestrial base station (TBS), equipped with a single antenna at an effective antenna height of h_t, operates as the primary cell, while the satellite cell functions as the secondary cell. The secondary cell encompasses the primary cell. Two UEs are

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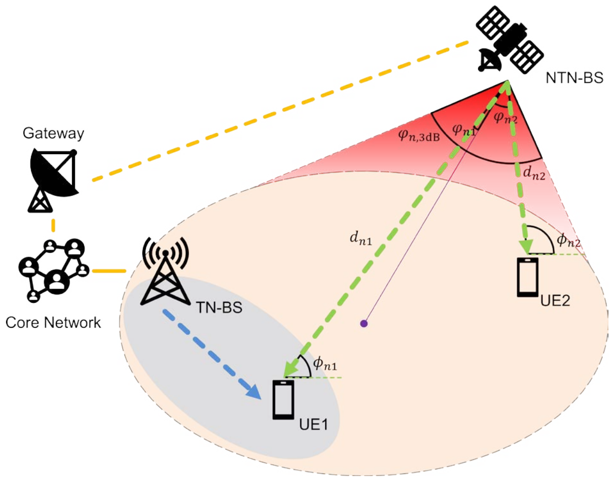


Fig. 1: System model.

present, UE1 in the primary cell and UE2 in the secondary cell, each equipped with a single antenna at an effective height of h_u. It is assumed that UE2 in the secondary cell does not receive interference from the primary cell because of the larger coverage area of SN.

The transmit antenna beam gain, G_{nj} between satellite and j-th UE can be represented by:

$$G_{nj}(\varphi_{nj}) = G_{n,max}\left(\frac{J_1(u_j)}{2u_j} + 36\frac{J_3(u_j)}{{u_j}^3}\right)^2, \quad (1)$$

where φ_{nj} is the angle between the satellite and j-th UE, $u_j = 2.07123\frac{\sin\varphi_{nj}}{\varphi_{3dB}}$, φ_{3dB} is the constant 3-dB beam angle, and $J_l(\cdot)$ indicates the first-kind Bessel function of order l.

The distance, d_{nj}, between satellite and UEs is given by:

$$d_{nj} = \sqrt{{R_E}^2\sin^2(\phi_{nj}) + {h_n}^2 + 2h_nR_E} - R_E\sin(\phi_{nj}), \quad (2)$$

where ϕ_{nj} is the elevation angle between the satellite and j-th UE, R_E is the radius of the Earth (6371 km). It is assumed that $\varphi_{n1} > \varphi_{n2}$, so that the secondary cell user can be treated as a near user for NOMA scheme, and the primary cell user is treated as a far user for the purpose of NOMA decoding.

The channel loss σ_n between the satellite and UEs can be derived as:

$$\sigma_n[\text{dB}] = \sigma_{SF} + \sigma_A + \sigma_{SL} + \sigma_P, \quad (3)$$

where $\sigma_{SF}, \sigma_A, \sigma_{SL}, \sigma_P$ denote a shadow fading margin, atmospheric loss, scintillation loss, and polarization loss, respectively.

A. Pathloss Model

The pathloss of the SN is assumed to be line-of-sight (LOS). According to [5], The pathloss between satellite and j-th UE can be given by:

$$L_{nj}[\text{dB}] = 32.45 + 20\log_{10}(f_c) + 20\log_{10}(d_{nj}), \quad (4)$$

where f_c represents the carrier frequency.

The pathloss between the satellite and the primary user is assumed to follow the COST 231 Hata model, given by:

$$\begin{aligned} L_{t1}[\text{dB}] =& 46.3 + 33.9\log_{10}(f_c) \\ &- 13.82\log_{10}(h_t) - a(h_u, f_c) \\ &+ (44.9 - 6.55\log_{10}(h_u))\log_{10}(d_t1) + C_m, \end{aligned} \quad (5)$$

where $a(h_u, f_c)$ is the mobile station antenna height correction factor in the Hata model for urban areas, given by:

$$\begin{aligned} &a(h_u, f_c)[\text{dB}] \\ &= \begin{cases} 8.29(\log_{10}(1.54h_u))^2 - 1.1, & \text{if } 150 < f_c \leq 200, \\ 3.2(\log_{10}(11.75h_u))^2 - 4.97, & \text{if } 200 < f_c \leq 2000. \end{cases} \end{aligned} \quad (6)$$

Furthermore, C_m denotes a constant offset, which is given by:

$$C_m[\text{dB}] = \begin{cases} 0, & \text{for medium cities and suburban areas,} \\ 3, & \text{for metropolitan areas.} \end{cases} \quad (7)$$

B. Small-Scale Fading Model

The Nakagami-m fading as the small-scale fading channel model for both the SN and TN is considered. [**?**]. This model encompasses a range of realistic fading environments, including Rayleigh fading ($m = 1$) and deterministic channel ($m = \infty$). The SN and TN links follow independent Nakagami-m fading distributions with different fading parameters: m_n and Ω_n for SN, and m_t and $Omega_t$ for TN. The channel power gain distributions between satellite and UEs are given by:

$$f_{|h_{ij}|^2}(x) = \frac{m_i^{m_i}}{\Omega_i^m{}_i\Gamma(m_i)}x^{m_i-1}e^{-\frac{m_i}{\Omega_i}x}, \quad x \geq 0, \quad (8)$$

where $i \in \{n, t\}$, $\Gamma(t) = \int_0^\infty x^{t-1}e^{-x}dx$, m_i represents fading severity, and Ω_i represents average power.

C. Signal Model

The received signal-to-interference plus noise ratio (SINR) of the primary user can be given by:

$$\text{SINR}_1 = \frac{P_tG_tL_{t1}|h_{t1}|^2G_u + b_1P_nG_{n1}L_{n1}\sigma_n|h_{n1}|^2G_u}{b_2P_nG_{n1}L_{n1}\sigma_n|h_{n1}|^2G_u + kTW}, \quad (9)$$

where P_t and G_t are the transmit power and antenna gain of terrestrial BS, respectively, and G_u represents the UE antenna gain. b_1, and b_2 are power allocation coefficients ($b_1 + b_2 = 1$), and k, T, and W denote the Boltzmann coefficient, ambient temperature, and system bandwidth.

The received SINR of the secondary user before successive interference cancellation (SIC) is given by:

$$\text{SINR}_{2\to1} = \frac{b_1P_nG_{n2}L_{n2}\sigma_n|h_{n2}|^2G_u}{b_2P_nG_{n2}L_{n2}\sigma_n|h_{n2}|^2G_u + kTW}. \quad (10)$$

With the SIC, the received signal-to-noise ratio (SNR) of the secondary user is given by:

$$\text{SNR}_2 = \frac{b_2P_nG_{n2}L_{n2}\sigma_n|h_{n2}|^2G_u}{kTW}. \quad (11)$$

III. Simulation results

This section presents the simulation results demonstrating the effectiveness of the CoMP NOMA scheme in simultaneously serving both conventional TN user and SN user. The simulations are based on a Monte Carlo approach with 100,000 runs. The parameters utilized in the simulations are outlined in Table I. The following four scenarios are considered in the simulations:

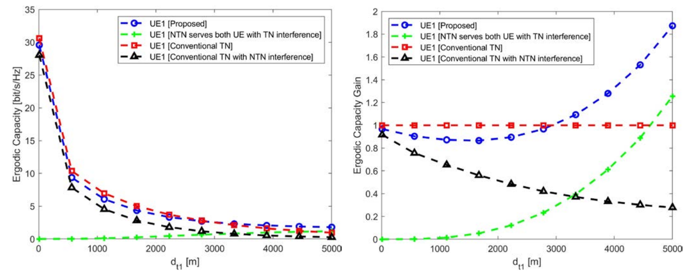
1) Terrestrial network-only operation
2) Terrestrial network with satellite network interference (TN + Satellite interference)
3) Satellite network serving both UE1 and UE2 while TN interferes with UE1 (Satellite-NOMA)
4) Terrestrial network with satellite network using CoMP NOMA to serve UE1 (TN + CoMP NOMA)

TABLE I: Simulation parameters

Parameter	Value
Terrestrial Tx power, P_t	44 dBm
Satellite Tx power, P_n	44 dBm [5]
Terrestrial antenna gain, G_t	14 dBi
Satellite antenna gain $G_{n,max}$	30 dBi [5]
Carrier frequency, f_c	2 GHz [5]
Carrier bandwidth, W	10 MHz
Satellite altitude, h_n	600 km [5]
Terrestrial effective antenna height, h_t	35 m [6]
UE effective antenna height, h_u	1.5 m [6]
Elevation angle, $\{\phi_{n1}, \phi_{n2}\}$	{85.5873°, 90°}
Satellite 3-dB beam angle, $\{\varphi_{3dB}\}$	4.4127° [5]
Angle between the satellite and UEs, $\{\varphi_{n1}, \varphi_{n2}\}$	{4.4127°, 0°}
Nakagami shape parameters, $\{m_t, m_n\}$	{1, 3}
Nakagami spread parameters, $\{\Omega_t, \Omega_n\}$	{1, 1}
Power allocation coefficients, $\{b_1, b_2\}$	{0.8,0.2}
Shadow fading margin, σ_{SF}	1.2 dB [5]
Scintillation loss, σ_{SL}	2.2 dB [5]
Polarization loss, σ_P	3 dB [5]
Atmospheric loss, σ_A	0.1 dB [5]
Ambient temperature, T	290 K [5]

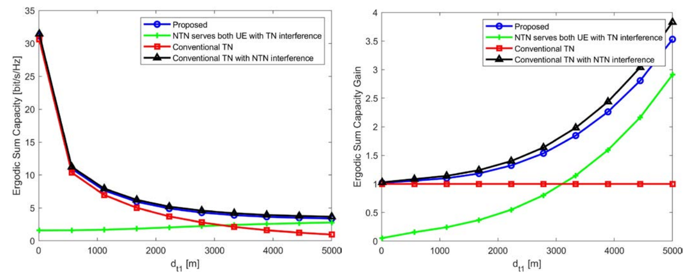
Fig. 2 and Fig. 3 depict the simulation results. Fig. 2a illustrates the ergodic capacity of UE1 in each scenario, while Fig. 2b showcases the capacity gain of UE1 in each scenario relative to the TN-only operation scenario. The results reveal that in TN with a satellite interference scenario, the capacity of UE1 is significantly impacted by the satellite interference. Conversely, when UE1 is served by the proposed CoMP NOMA HSTN, its capacity is effectively maintained. The capacity of UE1 even increases when its distance from the terrestrial network becomes sufficiently large.

Fig. 3a provides an overview of the performance of the network across various scenarios, while Fig. 3b illustrates the ergodic sum capacity gain of each scenario with respect to the TN-only operation scenario. The results show that the proposed CoMP NOMA HSTN scheme achieves a gain of approximately 3 dB when UE1 is located at a distance of 3.5 km from the TN. Most importantly, this scheme not only enhances network capacity but also safeguards TN services.



(a) (b)

Fig. 2: (a) Ergodic capacity and (b) ergodic capacity gain of UE1 with respect to the distance between UE1 and TN BS.



(a) (b)

Fig. 3: (a) Ergodic sum capacity and (b) ergodic sum capacity gain of HSTN with respect to the distance between UE1 and TN BS.

IV. Summary

This paper presents a CoMP NOMA scheme designed for HSTNs. The core of proposed sheme lies in facilitating seamless support for UE within the SN cell, while simultaneously ensuring the impeccable service quality of conventional TN UE.

By integrating the CoMP strategy with the NOMA framework, proposed scheme tackles the challenge of harmonizing the operation of SN and TN systems. This approach enables the SN to efficiently serve its UEs, while carefully safeguarding the performance of TN UEs against potential disruptions due to spectrum collisions or interference.

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