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Abstract

Hybrid satellite aerial terrestrial networks (HSATNs) are a promising solution towards tackling coverage and mobility issues in sixth generation (6G) networks. This paper presents a novel transmission scheme in the context of HSATNs, which allows pairs of terrestrial users to be simultaneously served via the satellite and the aerial base station (ABS). To this aim, non-orthogonal multiple access (NOMA) technique is adopted, at the ABS, by applying a rule-based hybrid NOMA and orthogonal multiple access (OMA) schemes. Comparisons between a standalone NOMA-based satellite transmission and the proposed method, reveal that significant sum-rate gains can be harvested under varying system parameters.

Keywords: keyword 1; keyword 2; keyword 3 (List three to ten pertinent keywords specific to the article; yet reasonably common within the subject discipline.)

1. Introduction

The sixth generation (6G) network has already been commenced as a new research initiative, following on from the evolving 5G network. This new type of network environments sophisticated device-to-device (D2D) and machine-to-machine (M2M) communications, innovative artificial intelligence (AI) techniques, Internet of Everything (IoE) applications connecting people, data, things through processes. Interoperability and convergence between terrestrial and satellite infrastructures will be a prerequisite in the 6G networking. Also, the new space era of non-terrestrial networks (NTNs) comprising of aerial networks, low Earth orbit (LEO) and especially very low Earth orbit (VLEO) satellites has emerged, enabling the path to 6G evolution.

Hybrid satellite-terrestrial networks (HSTNs) have been proposed as an efficient approach towards improving spectral efficiency and increasing the users' reliability all over the world. The available spectrum resources of these networks can be further exploited by adopting the non-orthogonal multiple access (NOMA) principle. However, in the absence of line-of-sight (LoS) conditions, the performance of satellite communication systems is severely deteriorating.

In the context of HSTNs, the unmanned aerial vehicle (UAV)-based communications are expected to improve the performance in various ways. In general, the UAV-aided NOMA schemes have gained the interest of the academia and the industry for various applications in the beyond 5G networks. Focusing on the scenario where the UAVs are adopted in satellite terrestrial communication networks, they could be employed in the NOMA scheme as an intermediate node for increasing the possibility of obtaining LoS conditions.

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All-in-all, and to the best of our knowledge, no studies can be found related to the intelligent integration of aerial and satellite segments in 6G networks by utilizing a hybrid NOMA and orthogonal multiple access (OMA) transmission schemes. Motivated by this observation, in this paper, we propose a novel satellite aerial terrestrial cooperative network scheme, which will be termed SATCON. More specifically, SATCON is formed with the integration of aerial base station (ABS) in the existing satellite network by efficiently combining two unsupervised machine learning (ML) algorithms, namely k-means and k-medoids. Furthermore, the proposed system promotes efficient cooperation between ABS and satellite through an innovative hybrid NOMA/OMA approach, avoiding the waste of resources and energy. Compared to standalone satellite NOMA transmission with optimal user pairing, namely SAT-NOMA, SATCON increases the sum rate and, at the same time, provides higher spectral efficiency for varying satellite channel conditions and ABS bandwidth.

2. Materials and Methods

2.1. Topology

A network consisting of a VLEO satellite as part of a VLEO satellite constellation, an ABS, and $N = 2K$ mobile terminals (MTs), uniformly distributed within the ABS coverage area W is considered. Furthermore, the ABS and the MTs are within the coverage area of the VLEO satellite. Each M_i ($1 \leq i \leq N$) has coordinates $U = \{u_1, u_2, \dots, u_N\} \in W$, where $u_i = (x_i^u, y_i^u, z_i^u)$. The MTs receive their data directly via the satellite link and through the decode and forward (DF) ABS relay, via the air to ground (A2G) link. The satellite is equipped with an antenna with transmit gain G_t^s , and total available transmit power P_s . Also, the satellite downlink operates at a frequency f_s , and the total available bandwidth is B_s . Furthermore, the ABS is equipped with two antennas, one for the reception of the satellite signals via the satellite to air (S2A) link (with an antenna gain denoted as G_r^s) and one for re-transmitting the satellite signals to the MTs via the A2G link (with a gain G_t^d). The operating frequency of the A2G links, i.e., between ABS and MTs, is $f_d \neq f_s$, and the total available bandwidth is B_d . Each MT_i has two antennas, one for the reception of the satellite signal with gain G_r^s and another for the reception of the ABS signal with gain G_r^d . The A2G and satellite signals are received by the MTs simultaneously.

From the system point of view, we consider a zero touch commissioning (ZTC) cloud radio access network (C-RAN) model consisting of a control element that performs automated resource discovery and manages the ZTC procedures in the cloud control center, such as the instantiation, configuration, and synchronization of SATCON. Finally, the formed ondemand 6G network consists of ultra-reliable low latency communication (URLLC) and enhanced mobile broadband (eMBB) network slices responsible for routing the control and data plane information, respectively.

2.2. Channel model

The fading environment for the land mobile satellite (LMS) channel is described through the Loo's model distribution, where the power of the LoS component is log-normally distributed with parameters (α, ψ) , while the power of the multipath component (MP) follows the Rayleigh distribution with the channel complex coefficient being represented by h_i^s for each MT_i assuming zero mean and variance $\sigma_s = \sqrt{0.5 \cdot 10^{\text{MP}/10}} \sim \mathcal{N}(0, \sigma_s^2)$. Also, path loss attenuation using the free space path loss (FSL) model is considered being denoted as L_i^{FS} for each MT_i . In addition, a maximum Doppler shift of 40 kHz is assumed and modeled with the Jakes model.

Regarding the A2G link between the ABS and the MTs, the multipath fading is modeled by the Rayleigh distribution with zero mean and unit variance $\sim \mathcal{N}(0, 1)$. The channel

complex coefficient is h_i^d for each MT_i . Also, path loss attenuation of the ABS's signal is modeled using the elevation angle based path loss model, in an urban environment, and it is expressed as follows

$$L_i^{A2G}(h, r_i) = 20 \log \left(\frac{4\pi y_i f_d}{c} \right) + \eta_{LoS} P_{LoS}(h, r_i) + \eta_{NLoS} (1 - P_{LoS}(h, r_i)), \quad (1)$$

where h is the altitude of the ABS, r_i is the 2D Euclidean distance between ABS and MT_i , $y_i = \sqrt{r_i^2 + h^2}$ is the direct link that connects the ABS and the MT_i , and c is the speed of light. Moreover, P_{LoS} denotes the LoS probability between the ABS and MT_i and η_{LoS} are the coefficients describing the propagation environment. In addition, concerning the S2A channel between the satellite and the ABS, the path loss attenuation is modeled using the FSL model and it is denoted as L_{sd}^{FS} .

Furthermore, the LMS, A2G, and S2A links are degraded by additive white Gaussian noise (AWGN). The noise power is calculated as the product of the Boltzmann constant κ , the receiver system temperature T_g , where $g = \{s, d\}$ and the available bandwidth B_g . Thus, the noise power of the satellite and aerial receiver at each MT is equal to and $N_s = \kappa T_s B_s$ and $N_s = \kappa T_s B_s$, respectively. Additionally, the noise power of the satellite receiver at ABS is $N_{sd} = \kappa T_{sd} B_s$.

3. SATCON

3.1. ABS placement process

For the intelligent integration of the ABS into the existing satellite network, the combination of the k-means and kmedoids unsupervised ML methods is utilized. The two algorithms aim to find the point $p \in W$ where $p = (x_1^p, y_1^p, z_1^p)$ so that the sum of the distances of the users from this point is minimized. The total within-cluster dissimilarity of the kmeans and k-medoids algorithms is $A_q = \sum_{u_i \in U} \|u_i - p_q\|^2$, where $q = \{c, m\}$. The objective of these two methods is to determine the point p_q that minimizes A_q and it can be expressed as follows

$$\arg \min_{p_q \in W} \sum_{u_i \in U} \|u_i - p_q\|^2. \quad (2)$$

From the two suggested points, p_c and p_m , given from kmeans and k-medoids, respectively, if $A_c < A_m$ then $p = p_c$, otherwise $p = p_m$. Due to the nature of these two ML methods to create groups through the input data, i.e., the coordinates of the users U , the initial height of the ABS will be the same as the average height of the users. Therefore, to obtain the optimal altitude at which ABS provides the best quality of service (QoS) to the MTs, first, we should identify the farther MT_i from the point p , where ABS is placed. Thereinafter, we should determine the height of the ABS h where pathloss with the MT_i is minimized through solving $\frac{\partial L_i^{A2G}(h, r_i)}{\partial h} = 0$.

3.2. Satellite NOMA transmission

For the satellite transmission, each MT_l ($1 \leq l \leq N$) periodically reports the channel state information (CSI) of the LMS channel to the satellite that receives the complex channel coefficient h_l^s and calculates the channel gain including additional gains, losses, and the noise power of the satellite receiver N_s as

$$\Gamma_l^s = \frac{G_t^s G_r^s}{L_l^{FS} N_s} |h_l^s|^2. \quad (3)$$

The satellite aims to create K pairs of MTs, where each pair will share the same sub-channel in the power and time domain, assigning different power allocation factors of the

total satellite power P_s to each MT belonging to a pair. Towards this end, a NOMA optimal user pairing policy is adopted, where the satellite sorts the MTs in ascending order by the channel gain $\Gamma_1^s \leq \Gamma_2^s \leq \dots \leq \Gamma_{2K}^s$ and matches the user MT_k with the user MT_{2K-k+1} , for $1 \leq k \leq K$. Hence, each pair consists of the strong satellite channel user MT_j^s , and the weak satellite channel user MT_i^s , with channel gains $\Gamma_j^s \geq \Gamma_i^s$, respectively.

The optimal power allocation factor β_j^s can be calculated by the following expression

$$\beta_j^s = \frac{\sqrt{1 + \Gamma_i^s P_s} - 1}{\Gamma_i^s P_s}. \quad (4)$$

According to the principle of NOMA, MT_i^s will immediately decode its own signal by the received satellite signal, while MT_j^s should first estimate the signal of the MT_i^s and then perform successive interference cancellation (SIC) to retrieve its own signal. The achievable rates of MT_j^s and MT_i^s are

$$R_j^s = \frac{B_s}{K} \log_2(1 + \beta_j^s P_s \Gamma_j^s), \quad (5)$$

$$R_i^s = \frac{B_s}{K} \log_2\left(1 + \frac{(1 - \beta_j^s) P_s \Gamma_i^s}{\beta_j^s P_s \Gamma_i^s + 1}\right). \quad (6)$$

3.3. ABS hybrid NOMA/OMA transmission

As described previously, ABS is integrated into the satellite network to improve the QoS of terrestrial users. Towards this end, the ABS should first receive and decode the NOMA superimposed signals of each pair of MTs via the S2A channel. The S2A channel gain can be expressed as

$$\Lambda_{sd} = \frac{G_t^s G_r^{sd}}{L_{sd}^{FS} N_{sd}}. \quad (7)$$

The maximum achievable decoding rates which succeed by the ABS through the S2A channel for each MT_j^s and MT_i^s in pair are

$$R_j^{sd} = \frac{B_s}{K} \log_2(1 + \beta_j^s P_s \Lambda_{sd}), \quad (8)$$

$$R_i^{sd} = \frac{B_s}{K} \log_2\left(1 + \frac{(1 - \beta_j^s) P_s \Lambda_{sd}}{\beta_j^s P_s \Lambda_{sd} + 1}\right). \quad (9)$$

Note that, the ABS obtains all the pair indices from the VLEO through a dedicated control channel to identify the users comprising each pair and their role, e.g., strong or weak satellite channel users. Also, the ABS acquires the achievable rate R_l^s of each MT_l with the satellite, through the same channel.

Next, the ABS should forward the decoded signals to the MTs through the A2G channel, utilizing the proposed hybrid NOMA/OMA transmission scheme. Consequently, we consider that each MT_l reports the CSI of the corresponding A2G link to the ABS. Therefore, the ABS calculates the channel gain of the A2G link for each MT l as follows

$$\Gamma_l^d = \frac{G_t^d G_r^d}{L_{l}^{A2G}(h, r_l) N_d} |h_l^d|^2. \quad (10)$$

Following the same NOMA user pairing policy as the VLEO, the ABS forms K MT pairs, considering now the channel gains of the A2G links. Therefore, each pair consists of the strong A2G channel user MT_j^d , and the weak A2G channel user MT_i^d , where $\Gamma_j^d \geq \Gamma_i^d$. Subsequently, calculates the optimal power allocation factor β_j^d for the MT_j^d by replacing

s with d in expression 4. Also, the achievable rates in NOMA, R_j^d and MT_i^d , are given by the expressions 5 and 6, respectively, by replacing again s with d . The rates that ABS can offer to MT_j^d and MT_i^d , utilizing the NOMA technique, are $R_j^{dn} = \min(R_j^d, R_j^{sd})$ and $R_i^{dn} = \min(R_i^d, R_i^{sd})$, respectively.

Lastly, the ABS has to decide whether it is profitable for each pair of MTs to transmit the superimposed signal or to transmit only the signal of one MT of each pair utilizing the OMA technique. Also, the ABS can avoid forwarding the satellite signals if the ABS transmission is not profitable for both MTs in pair. Therefore, the achievable rate that each MT_l can achieve from the ABS through OMA, is equal to

$$R_l^o = \frac{B_d}{K} \log_2(1 + P_d \Gamma_l^d). \quad (11)$$

Each MT_l will experience higher rates if the ABS uses OMA, i.e., $R_l^o \geq R_l^d$, since the same bandwidth as NOMA is allocated for OMA transmission, and whole P_d is allocated to MT_l . However, the maximum achievable OMA rate of MT_l is restricted by the expression $R_l^{do} = \min(R_l^o, R_l^{sd})$, since the ABS may provide a higher rate to the MT_l , but the rate at which ABS decoded its signal from the VLEO is lower and vice versa. There are four different cases that the ABS considers for each MT pair

- **if $R_i^s < R_i^{dn}$ and $R_j^s < R_j^{dn}$:** In this case, the pair of MTs formed by the ABS profits from the NOMA transmission as both MTs achieve greater rates if served from the ABS instead of the satellite.
- **if $R_i^s < R_i^{dn}$ and $R_j^s \geq R_j^{dn}$:** In this case, only MT_i^d profits from the ABS transmission. Thus, the ABS utilizes OMA and transmits only to MT_i^d or the timeslot allocated to this pair. MT_i^d achieves a rate equal to R_i^{do} .
- **if $R_i^s \geq R_i^{dn}$ and $R_j^s < R_j^{dn}$:** In this case, only MT_j^d profits from the ABS transmission. Therefore, the ABS utilizes OMA and transmits only to MT_j^d for the timeslot allocated to this pair. MT_j^d achieves a rate equal to R_j^{do} .
- Otherwise, the communication for this MT pair is not profitable and ABS does not transmit to these pair of users in order to save resources.

4. Results

This section may be divided by subheadings. It should provide a concise and precise description of the experimental results, their interpretation as well as the experimental conclusions that can be drawn.

4.1. Subsection

4.1.1. Subsubsection

Bulleted lists look like this:

- First bullet;
- Second bullet;
- Third bullet.

Numbered lists can be added as follows:

1. First item;
2. Second item;
3. Third item.

The text continues here.

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All figures and tables should be cited in the main text as Figure 1, Table 1, etc.



Figure 1. This is a figure. Schemes follow the same formatting.

Table 1. This is a table caption. Tables should be placed in the main text near to the first time they are cited.

Title 1	Title 2	Title 3
Entry 1	Data	Data
Entry 2	Data	Data ¹

¹ Tables may have a footer.

The text continues here (Figure 2 and Table 2).

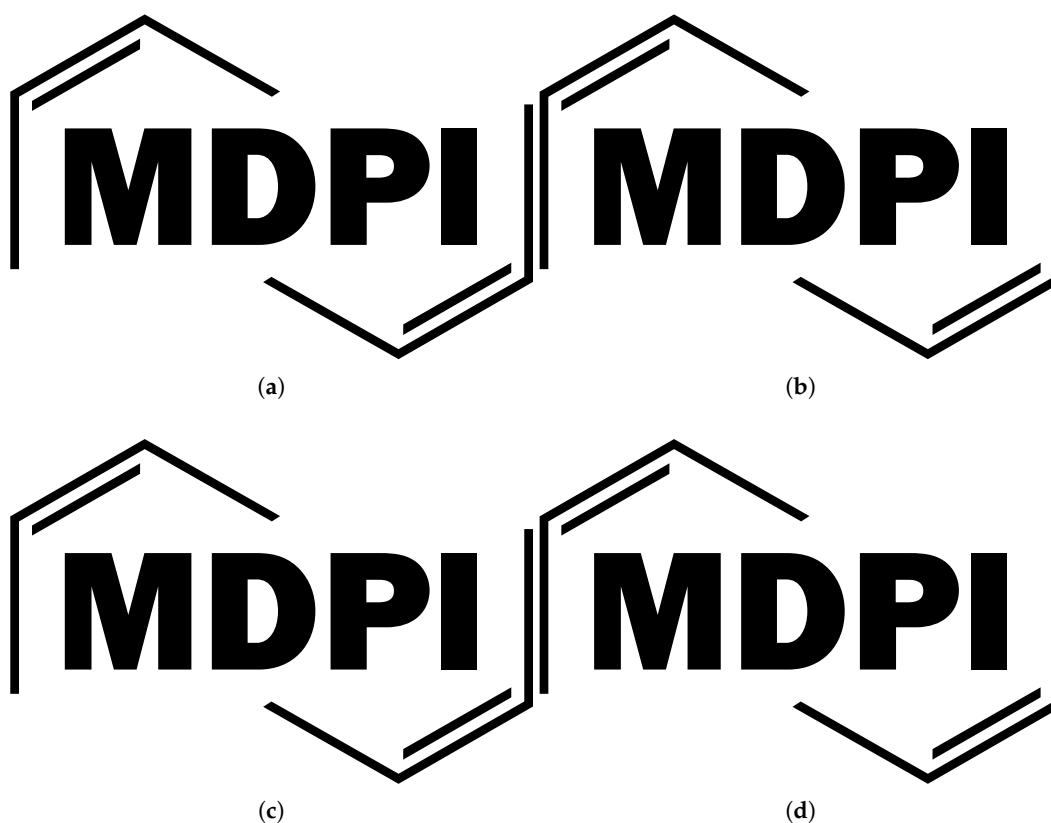


Figure 2. This is a wide figure. Schemes follow the same formatting. If there are multiple panels, they should be listed as: (a) Description of what is contained in the first panel. (b) Description of what is contained in the second panel. (c) Description of what is contained in the third panel. (d) Description of what is contained in the fourth panel. Figures should be placed in the main text near to the first time they are cited. A caption on a single line should be centered.

Table 2. This is a wide table.

Title 1	Title 2	Title 3	Title 4
Entry 1 *	Data	Data	Data
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Entry 2	Data	Data	Data
	Data	Data	Data
	Data	Data	Data

* Tables may have a footer.

Text.

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4.3. *Formatting of Mathematical Components*

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This is the example 1 of equation:

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$$a = 1,$$

(12)

the text following an equation need not be a new paragraph. Please punctuate equations as regular text.

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This is the example 2 of equation:

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$$a = b + c + d + e + f + g + h + i + j + k + l + m + n + o + p + q + r + s + t + u + v + w + x + y + z$$

(13)

Please punctuate equations as regular text. Theorem-type environments (including propositions, lemmas, corollaries etc.) can be formatted as follows:

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Theorem 1. *Example text of a theorem.*

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The text continues here. Proofs must be formatted as follows:

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Proof of Theorem 1. Text of the proof. Note that the phrase “of Theorem 1” is optional if it is clear which theorem is being referred to. □

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The text continues here.

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5. Discussion

211

Authors should discuss the results and how they can be interpreted from the perspective of previous studies and of the working hypotheses. The findings and their implications should be discussed in the broadest context possible. Future research directions may also be highlighted.

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6. Conclusions

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This section is not mandatory, but can be added to the manuscript if the discussion is unusually long or complex.

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7. Patents

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This section is not mandatory, but may be added if there are patents resulting from the work reported in this manuscript.

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Author Contributions: For research articles with several authors, a short paragraph specifying their individual contributions must be provided. The following statements should be used “Conceptualiza-

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tion, X.X. and Y.Y.; methodology, X.X.; software, X.X.; validation, X.X., Y.Y. and Z.Z.; formal analysis, X.X.; investigation, X.X.; resources, X.X.; data curation, X.X.; writing—original draft preparation, X.X.; writing—review and editing, X.X.; visualization, X.X.; supervision, X.X.; project administration, X.X.; funding acquisition, Y.Y. All authors have read and agreed to the published version of the manuscript.”, please turn to the [CRediT taxonomy](#) for the term explanation. Authorship must be limited to those who have contributed substantially to the work reported.

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Abbreviations

The following abbreviations are used in this manuscript:

- MDPI Multidisciplinary Digital Publishing Institute
- DOAJ Directory of open access journals
- TLA Three letter acronym
- LD Linear dichroism

Appendix A

Appendix A.1

The appendix is an optional section that can contain details and data supplemental to the main text—for example, explanations of experimental details that would disrupt the flow of the main text but nonetheless remain crucial to understanding and reproducing the research shown; figures of replicates for experiments of which representative data are shown in the main text can be added here if brief, or as Supplementary Data. Mathematical proofs of results not central to the paper can be added as an appendix.

Table A1. This is a table caption.

Title 1	Title 2	Title 3
Entry 1	Data	Data
Entry 2	Data	Data

Appendix B

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References

1. Author 1, T. The title of the cited article. *Journal Abbreviation* **2008**, *10*, 142–149.
2. Author 2, L. The title of the cited contribution. In *The Book Title*; Editor 1, F., Editor 2, A., Eds.; Publishing House: City, Country, 2007; pp. 32–58.
3. Author 1, A.; Author 2, B. *Book Title*, 3rd ed.; Publisher: Publisher Location, Country, 2008; pp. 154–196.
4. Author 1, A.B.; Author 2, C. Title of Unpublished Work. *Abbreviated Journal Name* year, phrase indicating stage of publication (submitted; accepted; in press).
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