A Comprehensive Survey of Existing Researches on NOMA-Based Integrated Satellite-Terrestrial Networks for 5G

Joel S. Biyoghe and Vipin Balyan

Abstract The fifth generation of mobile communication networks (5G) is expected to provide both massive and global coverage simultaneously, allowing users to remain reachable from anywhere around the planet. To achieve this, the non-orthogonal multiple access (NOMA) technology and the integrated satellite–terrestrial networks (ISTNs) are considered as key components due to their ability to provide massive capacity and ubiquity of the system. While there are various ongoing researches on 5G network development based on NOMA and ISTNs independently or collectively, no paper thus far has, however, reported a comprehensive survey of existing researches that apply NOMA to ISTNs for 5G applications. This paper therefore presents a comprehensive survey NOMA-based ISTNs development studies. More precisely, it presents papers that have investigated performances of NOMA-based ISTNs as well as those that have designed algorithms for power allocation and precoding for NOMA-based ISTNs. A few observations are made from the produced survey and have been used to produce a list of interesting topics opened for future research in this field.

Keywords 5G · Mobile networks · NOMA · Satellite · ISTNs · Cognitive radio · Cooperative · Power allocation · Precoding · Sum rate · User fairness

1 Introduction

The fifth generation of mobile networks (5G) is expected to deliver performances such as ubiquity, massive connectivity, ultra-high capacity, ultra-high reliability, and ultra-low latency so to support the new desired communication services such as the Internet of things (IoT) [1–3]. In order to achieve such networks, some technological concepts have been proposed including the multicasting and beamforming, massive multiple-input multiple-output (MIMO), non-orthogonal multiple access (NOMA), and the millimeter-wave spectrum [4, 5]. The NOMA technology is proposed as a novel

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radio access technology in replacement of previously used orthogonal multiple access (OMA) technologies, as it presents enhanced network performances [6, 7]. Due to its potential, NOMA is considered a key enabling technology for 5G realization [8, 9].

While previous generations of mobile network were mostly based on terrestrial segments (base stations), the satellite technology, however, has been identified as another key component for 5G implementation, due to its ability to provide large and reliable coverage [10]. The combination of both terrestrial and satellite networks has been envisaged to provide a network that provides simultaneously the ubiquity and massive capacity, and the integrated satellite–terrestrial networks (ISTNs) are therefore considered critical in providing a whole-world 5G coverage [11, 12].

The field of ISTNs is still relatively new and therefore has only seen a relatively small amount of researches thus far. Furthermore, only few papers such as [13] have given a comprehensive survey of studies on ISTNs. These reports, however, mostly present OMA-related works applied to ISTNs. To the best of the authors knowledge, there is no paper that gives a survey of NOMA-based ISTNs studies.

This paper, therefore, seeks to provide a comprehensive survey of NOMA-based ISTNs works for 5G. It can serve as a guide to interested researchers in the field, to know beforehand opened research areas to explore. Its contributions are as follows:

- A survey of cooperative ISTNs' studies, which comprise mostly of systems' performances investigations;
- A survey of cognitive radio ISTNs studies, which consists mostly of design studies for network blocks like power allocation, precoding, user clustering;
- A non-exhaustive list of possible topics for future research, drawn based on the observations from the surveys.

The rest of the paper is structured as follows: Sect. 2: Overview of NOMA and ISTNs, Sect. 3: Surveys of NOMA-based ISTNs for 5G. Section 4: Observations and future research topics. Section 5: Conclusion.

2 Overview of NOMA and ISTNs

2.1 Noma

The multiple access (MA) system of mobile radio access networks (RANs) is based on a radio access technology. In previous generations of mobile networks including 4G, orthogonal multiple access (OMA) technologies which allow only one user to use a designated frequency resource at the time were employed for the MA systems [3]. Figure 1a illustrates the power domain diagram of a base station serving users based on FDMA (OMA). Due to the limitation to one-user per frequency slot at the time, OMA technologies provide a relatively low system capacity [1, 14]. This has motivated the search for more efficient radio access technologies to support the

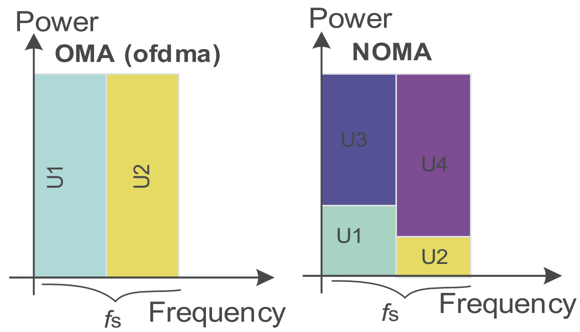

Fig. 1 Illustration of power domain OMA versus NOMA

exponentially growing number of users expected to be connected simultaneously in 5G networks.

The NOMA technology is therefore being proposed as a technology advancement of OMA. NOMA consists of permitting two or more users to share a designated frequency sub-band simultaneously, by using either power domain (PD-NOMA) or code domain (CD-NOMA), which leads to increased capacity compared to OMA [15, 16]. Figure 1 illustrates the PD-NOMA technology in comparison with OMA. In PD-NOMA, the produced signal at transmitter is a superposition of information signals from respective users grouped together [17]. A technique called successive interference cancellation (SIC) is employed at the receiver to decode each information signal. The complexity of the SIC process increases exponentially with the increase in the number of users to group together and therefore limits the full potential of the NOMA technology [11, 12, 18].

2.2 ISTNs

The ISTNs consist of combining satellites and terrestrial base stations for broader coverage and are expected to play a critical role in the outbreak of 5G networks due to their capacity to provide simultaneously ubiquity and ultra-high capacity [13]. There are two main types of integration configuration for ISTNs, namely a *cooperative configuration* and a *cognitive radio configuration.*

In a cooperative integration, the satellite utilizes base stations as relays to transfer information to some intended satellite users. The relaying can be amplify-and-forward (AF) or decode-and-forward (DF) type. This configuration is illustrated in Fig. 2a. It allows to increase the system capacity to some extends with reduced complexity, as the two networks do not initially use the same spectrum [16, 19].

In a cognitive radio integration, the satellite and the terrestrial segment use the same frequency spectrum and cover the same ground area simultaneously [9]. This obviously leads to a network with massive capacity on one side and huge interchannel

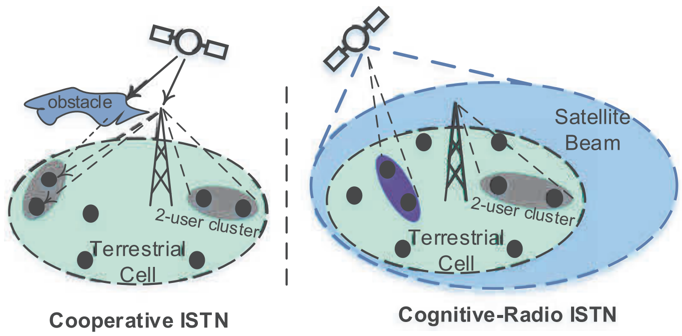

Fig. 2 Illustration of cooperative and cognitive radio ISTN

interference (ICI) between users from the two networks on the other side. Two cognitive radio configurations are proposed: the overlay in which the two networks are not allowed to cause ICI to each other and the underlay, in which the two networks can cause acceptable ICIs to each other [11, 20]. The latter produces more system performances, but has increased design complexity. Figure 2b illustrates a CR-ISTN configuration.

3 Survey of NOMA-Based ISTNs Studies

3.1 Cooperative ISTNs

The following reported researches have investigated performances of cooperative integrated satellite–terrestrial networks based on NOMA technology, for 5G application. The performance (ergodic capacity and outage probability) of a NOMA-based cooperative ISTN in which the satellite user with best channel conditions serves as a relay for the user with poor channel conditions has been evaluated by [21]. In [22], the authors investigated the impact of using different relay configurations (amplify-and-forward (AF) or decode-and-forward (DF)) on the performance (OP) of a NOMA-based cooperative ISTN, in which the terrestrial base station serves as a relay to the satellite. Furthermore, [10] studied the performances (Ergodic capacity and OP) of a NOMA-based cooperative ISTN, where the terrestrial base station serves as a decode-and-forward (DF) relay for the satellite and serves both the satellite user and its own user simultaneously. [23] did a work similar to [10] and investigated the performances (EC and OP) of a NOMA-based cooperative ISTN where the terrestrial base station serves as an amplify-and-forward (AF) relay for the satellite and serves both the satellite users and its own user simultaneously. [24] demonstrated the deteriorating impact of channel impairments (CIs) on the performance (OP) of a NOMA-based cooperative ISTN in which the terrestrial base station serves as a DF relay for the satellite. While most of the above-mentioned works assumed perfect CSI, [5] investigated the performances (OP and throughput) of a NOMA-based cooperative ISTN with imperfect CSI, where the terrestrial base station serves as a decode-and-forward (DF) relay for the satellite. Furthermore, while all the previous analyses operated within the microwave frequency band, [25] investigated the performances (OP) of a NOMA-based cooperative ISTN operating in the millimeter-wave spectrum, in which the terrestrial base station serves as an AF relay for the satellite. In above-mentioned works, there was no specific mention regarding the user clustering, power allocation, or precoding algorithms employed.

3.2 Cognitive Radio ISTNs

The following studies have proposed the design of NOMA-based cognitive radio integrated satellite–terrestrial networks for 5G application, which may include the design of user clustering, power allocation, and precoding algorithms, collectively or individually. In [26], the authors proposed a cognitive radio underlay ISTN in which NOMA, multicast, and beamforming are employed by both the satellite and the terrestrial networks to serve their respective users. In this work, a combined precoding algorithm for both networks was designed, to maximize the total capacity of the integrated system. This precoding algorithm was developed based on the max-min fair (MMF) optimization concept. The authors in [27] investigated the design of a cognitive radio underlay ISTN in which the satellite network does not apply NOMA technology, but only multicast and beamforming, while NOMA is employed by the terrestrial network together with multicast, beamforming technologies. This study designed a single precoding algorithm for both terrestrial and satellite networks, to maximize total sum rate of the system. This precoding algorithm was based on the iterative penalty function (IFP) optimization techniques. In addition, [28] developed a cognitive radio underlay ISTN in which the satellite network only employs multicast and beamforming without NOMA to serve its users on the ground, but the terrestrial network uses all three technologies (multicast, NOMA, and beamforming) to serve its users. In this work, a single power allocation algorithm for both terrestrial and satellite networks to maximize the total system's sum rate is designed; while for precoding, the authors designed one precoding algorithm for the satellite network and a different one for terrestrial network. The combined power allocation algorithm was designed based on a joint optimization concept; while for precoding algorithms, the zero-forcing concept was utilized for the satellite network's algorithm, and the MRT concept was used for terrestrial network's algorithm. Similar to [28, 29] also suggested to design a cognitive radio underlay ISTN in which the satellite network only uses multicast and beamforming to serve its users, but not NOMA, whereas the terrestrial network employs multicast, beamforming, and NOMA technology to serve its users. However, this work differs from the former in that, the authors designed a combined algorithm for power allocation and precoding that serves both terrestrial and satellite network. The design goal of this algorithm was also to maximize the total system's sum rate. This combined power allocation and precoding algorithm was designed based on both the iterative penalty function (IFP) and the initial search point (ISP) optimization concepts. Lastly, in [30], the authors developed a cognitive radio overlay ISTN, in which both networks employ multicast, beamforming, and NOMA, to serve their respective users. This study proposes a power multiplexing and a bandwidth compression algorithm, to maximize the total capacity of the combined system, by taking advantage of the power and frequency domains.

4 Observations and Opened Research Topics

4.1 Observations

A few observations can be made from the survey of NOMA-based ISTNs studies above.

Firstly, from a general perspective, the field is still really opened for future research and looks promising as a research field, with inspiring open topics as presented below.

Secondly, from the perspective of studies on system performances analysis, the following observations can be stated:

- a few researches have investigated performances of various cooperative ISTN; and in most of these studies, NOMA was not applied on the satellite-to-base station's link, but only to the base station-to-user's link.
- In addition, the attention given to physical layer security analysis remains very thin.
- Lastly, no paper reported investigating performance of CR-ISTN configuration.

Thirdly, from the perspective of system design studies, the following observations can be made:

- All reported studies for cognitive radio ISTNs designed a combined user clustering algorithm for both satellite and terrestrial networks, as well as a combined power allocation algorithm for both networks. For the precoding algorithm designs for these CR-ISTNs, some studies designed a combined algorithm for both networks while others designed separate algorithm for respective networks.
- In addition, most of the reported design studies for cognitive radio ISTNs, whether power allocation algorithms or precoding algorithms design, focused on the scenario where NOMA is used for terrestrial network and precisely a two user-per-beam case, whereas satellite network does not employ NOMA, that is a one user-per-beam case.
- Furthermore, all the reported power allocation algorithm designs for cognitive radio ISTN focused on maximization of system total capacity; no studies considered the system's user-fairness maximization.

- Lastly, the reported design studies for the cognitive radio ISTNs all assumed scenario of no physical layer impairments (i.e., perfect CSI, no Cis, complete ICI cancellation before receiver).

4.2 Opened Topics for Future Research

Considering the above observations, the following items have been identified as outstanding challenges; and therefore, possible research topics, for the field of ISTNs:

- Investigate system studies with more than two user-per-beams for more system capacity.
- Do more system's physical layer security analysis to increase security of the ISTNs.
- Do more performance investigation for ISTNs cognitive radio.
- Investigate the power cooperation issue associated with CR-underlay ISTNs.
- Investigate the users' CSIs coordination issue associated with CR-underlay ISTNs.
- Design of power allocation algorithms for CR-ISTNs, to maximize the system's user-fairness.
- Design of more performing precoding algorithms for CR-ISTNs, to best mitigate the ICI on satellite's cell-edge users and hence increase the total system capacity.
- Consider more designs of ISTNs with the scenario of at least two user-per-beams for the satellite network, to increase the system capacity.
- Consider design of ISTNs systems (power allocations and precoding algorithms) with imperfect physical layer impairments (i.e., imperfect CSI, CI, imperfect ICI cancellation, … etc.).
- Investigation of CR-ISTN's performances under the configuration of underlay versus overlay, for various considerations listed here above.

5 Conclusion

This paper has presented a comprehensive survey of reported researches that have developed or investigated NOMA-based integrated satellite–terrestrial networks for 5G. There are two main configurations for ISTNs including the cooperative and the cognitive radio ISTN. A survey of existing studies on cooperative ISTNs was first presented. The survey showed that most studies so far on this network configuration are performances investigations for various scenarios. The survey also showed that most studies in this configuration employed NOMA on terrestrial networks and not on satellite-to-base station links. Secondly, a survey of studies on the cognitive radio ISTN configuration was also covered. The survey revealed that the field of studies is still relatively novel and therefore still very opened for future research. A number of important observations were made from these surveys and helped outlined some outstanding challenges and possible topics for future research.

References

1. M. Aldababsa, M. Toka, S. Gökçeli, G.K. Kurt, O. Kucur, A tutorial on non-orthogonal multiple access for 5G and beyond. Wirel. Commun. Mobile Comput. 1–24 (2018)
2. Y. Wang, B. Ren, S. Sun, S. Kang, X. Yue, Analysis of non-orthogonal multiple access for 5G. China Commun. **2**, 52–66 (2016)
3. A. Anwar, B. Seet, M.A. Hasan, X.J. Li, A survey on application of non-orthogonal multiple access to different wireless networks. Electronics **8**, 1–46 (2019)
4. W. Ejaz, S.K. Sharma, S. Saadat, M. Naeem, A. Anpalagan, N.A. Chughtai, A comprehensive survey on resource allocation for CRAN in 5G and beyond networks. J. Netw. Comput. Appl. **160**, 1–24 (2020)
5. X. Li, Q. Wang, H. Peng, H. Zhang, D.T. Do, K.M. Rabie, P. Kharel, C.C. Cavalcante, A unified framework for HS-UAV NOMA networks: performance analysis and location optimization. IEEE Access **8**, 13329–13340 (2020)
6. V. Balyan, D.S. Saini, Call elapsed time and reduction in code blocking for WCDMA networks, in *IEEE International Conference on Software Telecommunication and Computer Networks* (SoftCom, 2009), pp. 141–145
7. V. Balyan, D.S. Saini, A same rate and pattern recognition search of OVSF code tree for WCDMA networks. IET Commun. **8**(13), 2366–2374 (2014)
8. L. Dai, Z. Wang, Y. Yuan, Non-orthogonal multiple access for 5G: solutions, challenges, opportunities, and future research trends. IEEE Commun. Mag. 74–81 (2015)
9. S. Kumar, K. Kumar, Multiple access schemes for cognitive radio networks: a survey. Phys. Commun. **38**, 1–31 (2020)
10. X. Zhang, D. Guo, K. An, Z. Chen, B. Zhao, Y. Ni, B. Zhang, Performance analysis of NOMA-based cooperative spectrum sharing in hybrid satellite-terrestrial networks. IEEE Access **7**, 172321–172329 (2019)
11. M. Caus, M.A. Vazquez, A.I.P. Neira, NOMA and Interference limited satellite scenarios. IEEE Asilomar 497–501 (2016)
12. X. Yan, K. An, T. Liang, G. Zheng, Z. Ding, S. Chatzinotas, Y. Liu, The application of power-domain non-orthogonal multiple access in satellite communication networks. IEEE Access **7**, 63531–63539 (2019)
13. S. Zhang, D. Zhu, Y. Wang, A survey on space-aerial-terrestrial integrated 5G networks. Comput. Netw. **174**, 1–18 (2020)
14. S.M.R. Islam, N. Avazov, O.A. Dobre, K. Kwak, Power-domain non-orthogonal multiple access (NOMA) in 5g systems: potentials and challenges. IEEE Commun. Surv. Tutorials **19**(2), 721–742 (2017)
15. R. Khan, D.N.K. Jayakody, An ultra-reliable and low latency communications assisted modulation based non-orthogonal multiple access scheme. Phys. Commun. 15758–15761 (2020)
16. D. Wan, M. Wen, F. Ji, H. Yu, F. Chen, Non-orthogonal multiple access for cooperative communications: challenges, opportunities, and trends. IEEE Wirel. Commun. 109–117 (2018)
17. K. An, X. Yan, T. Liang, W. Lu, NOMA based satellite communication networks: architectures, techniques and challenges, in *2019 IEEE 19th International Conference on Communication Technology* (IEEE, 2019), pp. 1105–1110
18. V. Balyan, Outage probability of cognitive radio network utilizing non orthogonal multiple access, in *2020 7th International Conference on Signal Processing and Integrated Networks (SPIN),* Noida, India (2020), pp. 751–755

19. X. Zhu, C. Jiang, L. Kuang, N. Ge, S. Guo, J. Lu, Cooperative transmission in integrated terrestrial-satellite networks. IEEE Netw. 204–210 (2019)
20. X. Liu, X.B. Zhai, W. Lu, C. Wu, QoS-guarantee resource allocation for multibeam satellite industrial internet of things with NOMA. IEEE Trans. Ind. Inf. J. Latex Class Files **14**(8), 1–10 (2015)
21. X. Yan, H. Xiao, K. An, G. Zheng, W. Tao, Hybrid satellite terrestrial relay networks with cooperative non-orthogonal multiple access. IEEE Commun. Lett. **22**(5), 978–981 (2018)
22. S. Xie, B. Zhang, D. Guo, B. Zhao, Performance analysis and power allocation for NOMA-based hybrid satellite-terrestrial relay networks with imperfect channel state information. IEEE Access **7**, 136279–136289 (2019)
23. V. Singh, P.K. Upadhyay, M. Lin, On the performance of NOMA-assisted overlay multiuser cognitive satellite-terrestrial networks. IEEE Wirel. Commun. Lett. 1–5 (2020)
24. K. Guo, Z. Ji, B. Yang, X. Wang, NOMA-based integrated satellite-terrestrial multi-relay networks with hardware impairments and partial relay selection scheme, in *2019 IEEE 19th International Conference on Communication Technology* (2019), pp. 1099–1104
25. Y. He, J. Jiao, X. Liang, S. Wu, Y. Wang, Q. Zhang, Outage performance of millimetre-wave band NOMA downlink system in satellite-based IoT, in *2019 IEEE/CIC International Conference on Communications in China (ICCC)*, China (2019), pp. 356–361
26. X. Zhu, C. Jiang, L. Yin, L. Kuang, N. Ge, J. Lu, Cooperative multigroup multicast transmission in integrated terrestrial-satellite networks. IEEE J. Sel. Areas Commun. **36**(5), 981–992 (2018)
27. M. Lin, C. Yiny, Z. Lin, J.B. Wang, T. Cola, J. Ouyang, Combined beamforming with NOMA for cognitive satellite terrestrial networks. IEEE, 1–6 (2019)
28. X. Zhu, C. Jiang, L. Kuang, N. Ge, J. Lu, Non-orthogonal multiple access based integrated terrestrial-satellite networks. IEEE J. Sel. Areas Commun. **35**(10), 2253–2267 (2017)
29. Z. Lin, M. Lin, J.B. Wang, T. Cola, J. Wang, Joint beamforming and power allocation for satellite-terrestrial integrated networks with non-orthogonal multiple access. IEEE J. Sel. Top. Sign. Process. **13**(3), 657–670 (2019)
30. M. Jia, Q. Gao, Q. Guo, X. Gu, X. Shen, Power multiplexing NOMA and bandwidth compression for satellite-terrestrial networks. IEEE Trans. Veh. Technol. **68**(11), 11107–11117 (2019)