NOMA Application to Satellite Communication Networks for 5G: A Comprehensive Survey of Existing Studies

Joel S. Biyoghe and Vipin Balyan
Department of Electrical, Electronics & Computer Engineering, Cape Peninsula university of Technology, Cape Town, South Africa
Email: joelscientifiq@gmail.com; balyanv@cput.ac.za

Abstract—The 4th generation of communication networks (4G) seems limited and unable to satisfy the growing networks' performances demands of new intended communication services such as the internet-of-things (IoTs). The 5th generation of communication networks (5G) has therefore been envisaged to fill the gap. The non-orthogonal multiple access (NOMA) technology and the satellite communication have been identified as key enabling technologies for the achievement of 5G networks. There are many ongoing NOMA related works for 5G; however, the few existing reviews mostly discuss works that apply NOMA to terrestrial networks. This paper therefore, gives a comprehensive and up-to-date review of existing works applying NOMA to satellite communication networks. More precisely, it presents studies that have either designed or do performance analysis of NOMA-based multibeam satellite-systems (MBSSs) or integrated satellite-terrestrial networks (ISTNs). The surveys presented showed that the application of NOMA to satellite communications for 5G is starting to gain considerable interest. Most of the current PD-NOMA design works attempt to maximize the system capacity (sum-rate), and most of the current PD-NOMA performance analysis works demonstrate the superiority of NOMA over OMA through Ergodic Capacity and Outage probability estimations. The surveys also showed that this field is still quite opened for research, with issues such as user-fairness maximization, satellite capacity improvement, ground-surface moving beams (for LEOs and MEOs satellites) and multiple gateways combination … etc. remaining prospective research areas to be explored.

Index Terms—NOMA, Satellite, MBSS, ISTN, 5G, Power-allocation, Precoding, RAN

List of Abbreviations:

CIs	Channel Impairments
EC	Ergodic Capacity
FDMA	Frequency Division Multiple Access
IMT	International Mobile Telecommunication
IoTs	Internet-of-Things
ISTN	Integrated Satellite-Terrestrial Network
ITS	Intelligent Transportation System
ITU	International Telecommunication Union
MBSS	Multi-Beam Satellite System
NOMA	Non-Orthogonal Multiple Access
OMA	Orthogonal Multiple Access
OP	Outage Probability
PA	Power Allocation
PC	Precoding
PD	Power-Domain
RAN	Radio Access Network
SIC	Successive Interference Cancellation
SR	Secrecy Rate
TDMA	Time Division Multiple Access
UC	User-Clustering

I. Introduction

Radio access networks (RAN) are communication networks in which the user is granted access for a designated period of time to utilise the radio resources of the network (Frequency spectrum) in order to either transmit or receive information [1]. The most popular form of RAN is the prominent mobile telephone networks commonly called cellular networks [2]. These cellular networks have evolved over the past decades, from the initial (1G) to the most recent (4G) one which exhibits performances such as a connectivity density of up to 10^5 connections per Km^2, an end-to-end latency of maximum 10ms, as well as minimum user-experienced data rate of 10Mbps and a peak user data rate 1Gbps [3], [4]

With the ongoing technology advancement, the telecommunication industry intends to provide throughout the 2020 decade, services such as Smart grids, home automation, industrial internet, remote surgery, Intelligent Transportation System (ITS), and the whole-world connection … etc. [5]. All these services constitute elements/components of the bigger project of the international mobile telecommunication (IMT) called the *achievement of the internet of things (IoTs)*, which consists of being able to interconnect millions of devices that can interchange/transfer/share data accurately, reliably and in near real-time [6], [7]. These services set the requirement for network performances such as ubiquity, massive-connectivity, ultra-high speed, ultra-high reliability and low latency [3], [4].

The performances of 4G networks appear to be insufficient to support the new intended services [8]. For this reason, the international telecommunication union (ITU) has developed standards for the next generation of WRANs known as the 5G networks, which should be capable of supporting the new intended services. Some of the 5G performance standards include to achieve: a) a minimum connectivity density of 10^6 connections per Km^2, b) an ultra-low end-to-end latency of maximum 1ms, c) a user-experienced data rate of 100Mbps and a

Manuscript received December 25, 2020; revised May 20, 2021.
doi:10.12720/jcm.16.6.217-227

peak user data rate of about 10Gbps [3], [4]. From these standard metrics, it can be observed that 5G should dramatically outperform 4G in all parameters; that is, by virtually a factor of 10.

According to the international mobile telecommunication union (IMT), any 5G network should support three main communication concepts including the massive machine-type communication (mMTC), the ultra-reliable & low-latency communication (URLLC) and the enhance mobile broadband communication (eMBB) [9], [10]. Some forms of 5G network include Mobile Internet Network (MIN) and wireless sensor network (WSN) [7], [11].

To facilitate the 5G development, a number of emerging technologies have been proposed by the ITU including the millimetre-wave (mmWave) for frequency-spectrum, multicasting for broadcasting, beamforming (BF) for antenna radiation, multi-users-detection (MUD) for ICI mitigation, non-orthogonal multiple access (NOMA) for radio-access, massive multiple-input multiple-output (MIMO) for communication topology, as well as the multi-beams satellite system (MBSS) technologies. The NOMA technology and the satellite communication systems are regarded as key enablers of the 5G development [12]-[15]. In terms of achievable network performances, the superiority of NOMA over the orthogonal multiple access (OMA) technology traditionally used up to the 4G networks has been demonstrated by [5], [7], [16]. Similarly, it has been shown by [17] and [8] that, while terrestrial networks can provide more capacity due to abundance of power and better channel conditions compared to the satellite communications, the satellite system however can provide a broader coverage, allowing to connect users located in remote places; and therefore, achieving the ubiquity required for 5G networks. To make the best use of the benefits from both systems, integration of both system is envisaged as a potential component for the achievement of 5G [18]-[20].

While there are currently many ongoing works on 5G networks development using some of the proposed technologies; this report looks principally at existing works related to NOMA technology. On this basis, it would be essential to first stress that, in general, to the best of author's knowledge, there are not much papers that present a comprehensive survey of NOMA-based networks' studies for 5G applications. Only a very few papers have reported such surveys including [1], [2], [6] and [9]; but all these surveys focus purely on terrestrial networks. Authors in [6] give a comprehensive survey of existing works that combine NOMA and massive MIMO technologies, as well as NOMA and cooperative relay networks scenarios, all for terrestrial network applications. Authors in [1] present works relating the NOMA application to various types of terrestrial networks including cooperative networks, coordinated systems, visible light communication and MIMO networks with beamforming. Authors in [2] presents a comprehensive survey of work done on Cloud-RAN, some of each employ NOMA technology. [9] on the other side presents a survey of existing works on application of NOMA in CN, D2D, WSNs; all from the perspective of terrestrial communications. Clearly, to the best of the author's knowledge, no paper has reported a survey of existing works applying NOMA technology to satellite related networks for 5G implementation.

This paper therefore, gives a comprehensive and up-to-date survey of existing researches that applied NOMA technology to satellite related communication networks for 5G applications. Its contributions are as follows:

- It presents a survey of NOMA-based MBBSs studies, including performances analyses and system designs studies.
- It presents a survey of NOMA-based ISTNs studies, including cooperative-ISTNs and cognitive-radio-ISTNs studies. In each case, it presents reported performances analysis and system designs studies.
- It outlines remarkable observations made from the surveys, and then
- Derives from the observations, a list of possible opened topics for future research in the field of NOMA-Based Satellite-related networks.

The rest of the paper is outlined as follows: section-2 presents an overview of PD-NOMA and satellite-related communication networks. Section-3 provide the comprehensive surveys of existing studies on PD-NOMA application to MBSSs and ISTNs. In section-4, a number of observations from the surveys are outlined followed by identified opened topics for possible future research. Section-5 concludes this paper.

II. Overview of Noma and Satellites RELATED Networks

A. Description of NOMA Concept

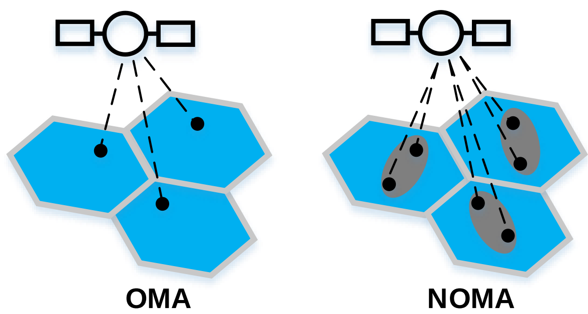
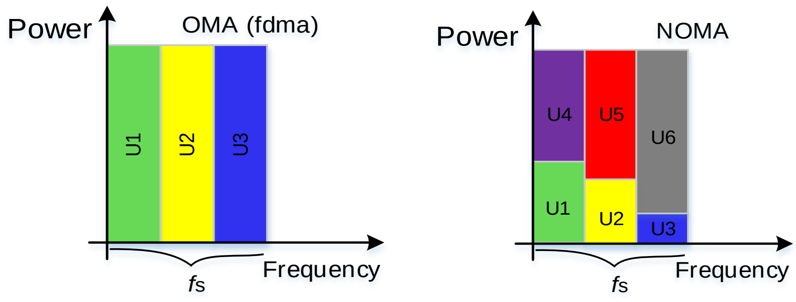


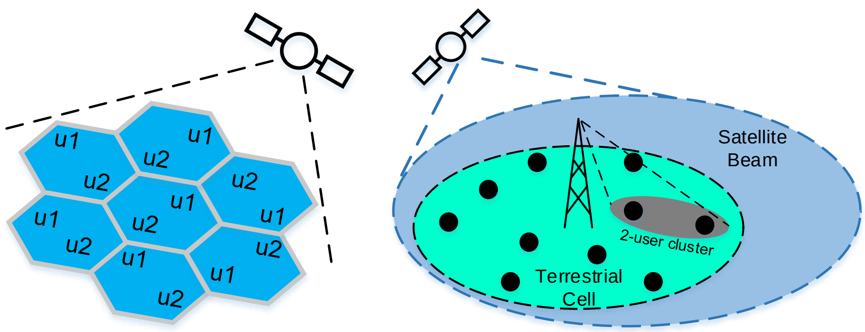
Fig. 1. Geo-spatial illustrations of OMA and NOMA for case of a MBSS

In an orthogonal multiple access (OMA) technology of RANs, only one user is assigned a designated frequency resource at a time. This is the case of the traditional multiple access (MA) techniques such as time-division multiple access (TDMA) and frequency-division multiple access (FDMA) as well as the latest offset-FDMA (OFDMA) used in the 4G era [21], [22]. A geo-spatial illustration of OMA technology, for the case of a MBSS, is given in Fig. 1 (left). The non-orthogonal multiple access (NOMA) is a new Multiple Access (MA) technology of RANs in which more than 1 user are allowed to utilize the same frequency resources simultaneously. In this format, the distinction between information of the respective users that share the same frequency resource is done either by assigning different power levels to users: power-domain NOMA (PD-NOMA); or by assigning different codes to users: code-domain NOMA (CD-NOMA) [4] [6]. Fig. 1 (right) gives a geo-spatial illustration of NOMA technology for the case of MBSS, with 2 users-per-beam.



(a): OMA (b): NOMA

Fig. 2. Illustration power versus frequency for OMA and PD-NOMA.



(a): a MBSS (b): an ISTN-CR

Fig. 3. Illustration of satellite-based communication networks: (a): a MBSS and (b): an ISTN cognitive-radio operation.

In the PD-NOMA implementation, users sharing the same frequency slot are assigned different power levels based on their channel conditions; where the user with worst channel condition is given most power. For each frequency slot, the resulting transmitted signal is a superposition of multiple signals with same frequency. Fig. 2 below illustrates a comparison in power-domain between OMA and PD-NOMA technologies. It shows that, for OMA, the transmitted signal in a given frequency slot only has one power level; whereas for PD-NOMA, the signal transmitted for each frequency slot comprises signal with different power levels. To decompose this signal at the receiver, the concept of Successive Interference Cancellation (SIC) is employed. In the SIC, the user with highest power coefficient decomposes its signal directly as it is sees others signals as noise, and the users with worst power coefficients first have to decompose stronger signals before decoding their own [16], [23].

NOMA technology is being more regarded than OMA in recent years, in both terrestrial, satellite and integrated satellite-terrestrial communications, for implementation of 5G; due to its enhanced system performances including increased connectivity, capacity, reliability, as well as lower latency [9], [10].

However, while NOMA provides better system performances than OMA in most aspects as cited above, its main limitation is that, as the number of users to simultaneously share a frequency slot increases, the complexity of the SIC process also increases exponentially. Increased complexity of the SIC can make the system impractical to implement, and can also lead to a jump in decision errors at the receiver. To this end, this complexity aspect of the SIC force NOMA implementation to be limited to 2 or 3 users-per-beam, and therefore the exploitation of NOMA in its full might. [24].

B. *Satellite Network's Structures*

There are two main categories of satellite related networks, namely, the purely satellite based network and the integration of satellite and terrestrial networks. A purely satellite-based network can consist of a single Multi-Beam Satellite System (MBSS) as illustrated in Fig. 3 (a) below, where a satellite serves multiple users on the ground located in different satellite beams; or consists of a cooperation of multiple satellites. The satellite cooperation can be a relay-cooperation where some satellites serves as relays to a main communication satellite; or a cognitive radio cooperation where two or more satellites systems transmit over the same coverage area using the same radio-frequency spectrum.

Similarly, an integration of satellite and terrestrial systems can be of a cooperative-relay type, where the terrestrial network serves as a relay for the satellite system; or of a cognitive-radio type, where both the satellite system and the terrestrial system transmit over the same coverage area using the same frequency-spectrum, as illustrated in Fig. 3 (b) below. The survey below comprehends studies from either of the above satellite-based network configuration categories.

C. Types of Network's Studies

The two main types of work often carried out during the study of a RAN include the system's analysis, to investigate its statistical performances; and the system design, to evaluate its actual performances. In terms of system analysis, communication networks' performance parameters such as ergodic capacity (EC), outage probability (OP) and asymptotic outage probability (ASOP),…etc. are usually investigated. In terms of system design, the application of PD-NOMA on mobile RANs implies the design at the transmitter side of a user-clustering (UC) algorithm to group users accordingly and a power-allocation (PA) algorithm to achieve desired users' experiences (fairness and capacity). In addition, if the multicast full-frequency reuse (FFR) technology is employed by the access point (base-station or satellite) of the RAN, the UC and PA process designs have to be accompanied by the design of a precoding (PC) algorithm to mitigate inter-cell-interference (ICI) at transmitter side. Moreover, at the receiver side, the PD-NOMA system design implies the design of a SIC algorithm to decode the various signals superposed in the received signal. It might also imply the design of an additional multiuser detection (MUD) algorithm to mitigate the ICI at receiver side, if precoding at receiver seems insufficient. The survey below presents works related to NOMA-based satellite communication networks, which may be either system analysis (EC, OP and/or ASOP) or system design (UC, PA, PC and/or SIC). Note that in the rest of this paper, NOMA will refer to power-domain NOMA (i.e. PD-NOMA).

III. Surveys of Existing Studies on Noma-Based Satellites Networks

A. NOMA-Based Terrestrial Networks' Studies

For the development of 5G terrestrial mobile communication networks (TMCNs), the following work has been done. In terms of system analysis, [16] initiated NOMA-based work on TMCNs by comparing the performance of a TMCN's downlink with NOMA and OMA respectively, through evaluation of their respective CDFs. The work showed a superiority of NOMA technology over the traditional OMA technology. [25] then later investigated the impact of precoding technology on performances of a NOMA-based TMCN's downlink, by evaluating the system's performances with and without precoding. The results demonstrated that precoding technology has positive impacts on the system's performances. [26] thereafter showed the impact of both imperfect channel-state-information (ICSI) and channel impairments (CIs) on the performances (outage probability (OP)) of a NOMA-based TMCN with multiple relays. In terms of system design, [27] developed a TMCN (Air-to-Ground, internet above the cloud) employing NOMA and multicast technologies; and designed a power-allocation (PA) algorithm to maximize the sum-decoding-rate of both downlink and uplink communications. [22] developed a TMCN employing NOMA and single-cast technologies; and design a PA algorithm to maximize the system's energy efficiency. [5] developed a massive TMCN (intelligent-transportation-system network) employing NOMA and multicast technologies; and designs a PA algorithm to maximize the system's total sum-rate. In [28], the authors developed a TMCN employing multicast, NOMA and beamforming technologies; but only presented the design of a precoding algorithm to minimize the system's peak-to-average-power-ratio (PAPR). In [29], the authors implement a two-user MISO TMCN employing multicast, NOMA and beamforming technologies; and design a precoding algorithm to maximize the system's security. Furthermore, [21] developed a TMCN (Air-to-Ground, for internet above the cloud), employing multicast, NOMA and beamforming technologies. They designed a PA algorithm and a precoding algorithm to maximize the system's efficiency and security. [10] also implement a TMCN employing multicast, NOMA and beamforming technologies; in which they design a PA algorithm and a precoding algorithm to jointly achieve Peak-Average Power-Ratio (PAPR) management and joint equalizer & Carrier-Frequency-Offset (CFO) compensation (JECC). In [30], the authors develop a TMCN employing multicast, NOMA and beamforming technologies; in which an Unmanned-Aerial-Vehicle (UAV) is used as the base station. A joint PA and precoding algorithm is designed to maximize the system total throughput.

B. NOMA-Based MBSSs' Studies

The following studies have been done for the application of NOMA on purely satellite communication networks, also general called multi-beam satellite systems (MBSSs).

In terms of system analysis, the performances of a MBSS's downlink with NOMA and OMA were respectively compared in [31]. This was done by evaluating the Ergodic Capacity (EC) and Outage-Probability (OP) in both cases. The superiority of NOMA over OMA has been demonstrated in this paper. Then, [32] showed the deteriorating effects of the inter-channel-interferences (ICIs) on the system's performances. This was done by analysing the impact of the ICIs on the EC and OP of a NOMA-based MBSS. [33] analysed the secrecy-rate of satellite communications with frequency domain NOMA. They found that the level of spectral overlapping is the main factor that affects the secrecy-rate, and that there exists an optimal spectral overlapping factor (SOP) for wish the secrecy rare of the system is maximized. In [34], the authors demonstrated that both the imperfect channel-state-information (ICSI) and the channel-impairments (CIs) have a deteriorating impact of on the performance (OP) of a NOMA-based MBSS. In [35], the physical layer security issues in mmWave satellite networks were investigated, in the context of various satellite communication technologies including MIMO and NOMA. The authors showed that the secrecy capacity in mmWave band is widely dependent on the richness of the radio frequency. While all the above works focussed on the downlink scenario, [36] investigated the ergodic capacity of NOMA-based uplink satellite networks with randomly deployed users. The results from this analysis revealed the capacity performance of the system is strongly impacted by key network parameters such as location information, link quality, transmission power and the imperfection of CSI.

In terms of power-allocation algorithms design, in [37], authors developed a MBSS employing NOMA technology; and designed a PA algorithm to improve the total transmission rate of the system above the OMA performance. In [38]-[40], the authors proposed a MBSS that employs NOMA technology; and they all designed power-allocation (PA) and admission-control (AC) algorithms to maximize the long-term network utility of the system. [41] also proposed a NOMA-based MBSS; and designed a PA algorithm and an AC algorithm to maximize the total number of users of the system. Similar to above works, [42] developed a NOMA-based MBSS; and proposed a PA algorithm to maximize the weighted-sum-rate of the system. Looking carefully, most of these preceding studies focused on designing the PA algorithm to maximize the capacity (sum-rate, number of users, …etc.) of the MBSS. However, [43] deviated from this design goal, and is the reported work to propose a NOMA-based MBSS and design a PA algorithm to maximize the system user-fairness. Furthermore, [44] proposed an optimal joint subcarrier and power allocation for MISO-NOMA satellite networks, with focus on the downlink scenario. Different from other work's design goals, in this study, the authors proposed to minimize the system's total power consumption compared to traditional OMA and SISO techniques. Also, in [45], the authors proposed a novel NOMA-based Irregular Repetition Slotted ALOHA (IRSA) scheme for satellites networks, which is different from other IRSA techniques that are generally based on OMA. Lastly, [46] is one of few reported papers to have looked at the integration of two MBSSs in a cognitive-radio configuration; in this case, CR-underlay. In this work, both satellites systems (MBSS1 and MBSS2) only employs multicast and beamforming without NOMA. The authors designed of a single power-allocation algorithm for both MBSSs to maximize the total sum-rate of the system.

In terms of precoding algorithms design, [47] proposed a MBSS that employs both NOMA and beamforming technologies; and designed a precoding algorithm to maximize the system's spectral-efficiency. Similarly, [48] developed a MBSS employing NOMA and beamforming technologies; and designed a precoding algorithm to maximize the system's total sum-rate. [49] is another work to have looked at the integrating two MBSSs in a cognitive-radio configuration; in this CR-overlay. In this study, one satellite (MBSS1) only employs multicast and beamforming without NOMA, while the other (MBSS2) employs the multicast, NOMA and beamforming technologies. The paper presents the design of a single precoding algorithm for both MBSSs to maximize the total sum-rate of the system. In [50], the authors investigated the performances of a MBSS which combines precoding at the transmitter with MUD at the receiver. The study presented is totally analytical and aimed at demonstrating the precoding alone at the transmitter can't totally mitigate ICI, neither can the usage of MUD alone at the receiver. The result demonstrated that indeed, employing both precoding and MUD jointly yield better system performances than when these two technologies are used alone. [51] also proposed a combination of geographical scheduling and precoding for MBSS, to improve the capacity of the system. A precoding algorithm was designed to maximize the system's throughput; and geographical-scheduling algorithm is then proposed to improve the capacity of system compared to when random scheduling is employed.

C. NOMA-Based ISTNs' Studies

For the development of 5G integrated satellite-terrestrial networks (ISTNs) based on NOMA, the presented work is classified in terms of cooperative-ISTNs studies and cognitive-radio-ISTNs studies as follows.

For the NOMA-based cooperative-ISTNs, the following works have been done. [52] evaluated the performances (EC and OP) 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. [53] 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. [13] investigated the performances (EC 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. [54] did a work similar to [13] 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. [55] 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, [11] 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, [56] investigated the performances (OP) of a NOMA-based cooperative ISTN operating in the millimetre-wave spectrum; in which the terrestrial base station serves as an AF relay for the satellite.

For the NOMA-based cognitive-radio-ISTNs, the following works have been done. In [57], the authors developed a NOMA-based cognitive-radio underlay ISTN in which both the satellite and the terrestrial networks employed multicast, beamforming and NOMA technologies to serve their respective users. The authors in this work suggested a combined precoding algorithm for both networks, which aims at maximizing the total system capacity. This precoding algorithm was developed based on the max-min fair (MMF) optimization concept. Then, [58] investigated the development of a cognitive-radio-underlay ISTN in which the satellite network only employs multicast and beamforming technologies without NOMA, while the terrestrial network employs multicast, beamforming and NOMA. In this study, a single precoding algorithm for both terrestrial and satellite networks was designed, to maximize total sum-rate of the system. This precoding algorithm was based on the iterative-penalty-function (IFP) optimization techniques. Furthermore, [59] developed an ISTN with cognitive-radio underlay cooperation; in which the satellite network only employs multicast and beamforming without NOMA, to serve its users on the ground; whereas the terrestrial network employs all three technologies (multicast, NOMA and beamforming) to serve its users. In this work, the authors designed a single PA algorithm for both terrestrial and satellite networks to maximise the total system's sum-rate; while for precoding, they 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 utilised for the satellite network's algorithm, and the MRT concept was used for terrestrial network's algorithm. Similarly, in [60], the authors developed an ISTN with a cognitive-radio underlay cooperation; in which the satellite network only employs multicast and beamforming without NOMA to serve its users on the ground, whereas the terrestrial network employs multicast, beamforming and NOMA technology to serve its users. However, in this work, different from the previous one, the authors designed a combined algorithm for power-allocation and precoding that serves both terrestrial and satellite network; with the aim of maximizing total system 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. Finally, authors in [61] proposed an ISTN with cognitive-radio overlay configuration, in which both networks employ multicast, beamforming and NOMA, to serve their respective assigned users. In this work, a power multiplexing algorithm and a bandwidth compression algorithm have been proposed, to maximize the total capacity of the integrated system, by taking advantage of both the power and frequency domains.

IV. Observations From the Surveys and Opened Topics for Future Research

A. Important Observations from the Surveys

A number considerable observations have been made from the presented surveys. In this section, these observations will be classified as follows: a) common observations: those that are common to both categories of networks (i.e. the purely satellite networks or MBSSs and the ISTNs); b) observations on MBSSs: those that are specific to MBSSs; c) observations on ISTNs: those that are specific to ISTNs. Note that in each case, observations will be presented for system's analysis studies and for system's design studies.

1) Observations common to MBSSs and ISTNs studies

- *New field*: By considering both the amount of published work and the years of publications, "NOMA application to satellite-related networks for 5G" appears to be a relatively recent field of research, which looks promising for research and still very opened for future work.
- *Dominant studies on downlink*: most studies presented cover the downlink communication scenario. No uplink communication scenarios investigation reported.
- 2-user-per-beam NOMA limitation: most studies limited themselves to the case of 2 users-per-beam for NOMA implementation. No studies investigated cases of more than 2 users-per-beam.
- *No physical layer imperfections consideration*: Most systems design's works assumed perfect CSI, no channel-impairments, and perfect ICI-cancellation; in short, they assumed that there are no physical layer imperfections on the system.
- *Little studies on mmWave spectrum*: all the design studies reported assumed microwave spectrum usage, no work employed mmWave spectrum for their network.
- *Predominant work on MA-encoder blocks*: All the design studies focused on design of MA encoder blocks such as user-clustering, power-allocation and precoding algorithms; no report presented works done on the MA decoder (i.e. the receiver side) for NOMA; which include design of SIC and MUD algorithms.

2) *Observations typical to MBSSs studies*

- *The physical layer security analysis*: No studies investigated the physical layer security problem in satellite networks.
- *Inter-Satellite Cooperation investigation & design*: There is very little reported papers looking at the possible cooperation of multiple MBSSs that employ NOMA.
- *User-clustering algorithms design*: most user-clustering (UC) algorithms designs were based on maximum channel-correlation and maximum channel-gain difference.
- *Power-allocation algorithms design issue*: most power-allocation (PA) algorithms designs focused on maximization of system total capacity; only one reported work looked at system's user-fairness maximization.
- *Precoding algorithms design issue*: most of precoding (PC) algorithms designs are still based on linear-precoding techniques such as ZF. However, there exist some particular precoding algorithms designed based on optimisation techniques such as IFP and overlay-coding & JPMUD.

3) *Observations typical to ISTNs studies*

- *No CR-ISTNs' analysis*: The encountered papers investigating performance of ISTNs were for cooperative-ISTNs, there is no reported work investigating cognitive-radio-ISTNs.
- *Little consideration of physical layer security analysis*: One to two reported works investigated the issue of physical-layer security for the ISTNs networks. However, it, is a domain that still requires significant attention.
- *NOMA only applied on Base-station-to-users' link in Cooperative-ISTNs' analysis*: In all analysis studies, NOMA was only applied on the Base-Station-to-user links. NOMA was not applied on Satellite-to-Base-Station links.
- *NOMA only applied on terrestrial-networks in Cognitive-Radio-ISTNs' design*: Most reported CR-ISTNs design studies (whether UC, PA, or PC algorithms designs) focused on the scenario of 2-users-per-beam for the terrestrial-network and 1-user-per-beam for the satellite-network. Only two of the reported papers proposed to also employ NOMA on satellite-network for a ISTNs.
- *Unique user-clustering algorithm design for CR-ISTNs*: in all reported CR-ISTNs design studies, a unique UC algorithm was designed to group users for both satellite and terrestrial networks.
- *User clustering design techniques for CR-ISTNs*: most UC algorithms are based on Channel-gain difference for PD-NOMA and channel-correlation for beamforming.
- *Unique power-allocation algorithm design for CR-ISTNs*: The reported CR-ISTNs design studies proposed a unique PA algorithm for both satellite and terrestrial networks.
- *No user-fairness maximization power-allocation designs for CR-ISTNs*: all PA design studies for CR-ISTNs focused on maximization of system total capacity. No attention given to user-fairness aspect.
- *Mixed designs for precoding algorithms*: for PC algorithm design for CR-ISTNs, some studies designed a combined PC algorithm for both networks, while others designed separate PC algorithms for each network.

B. *Identified Topics for Future Research*

1) *Common topics for NOMA-Based MBSSs and ISTNs*

- *More investigation of the physical-layer security*: More work is required on physical layer security (PLS) analysis for both MBSSs and ISTNs.
- *Study the uplink communication scenarios*: The study (performance analysis or design) of the uplink scenarios for NOMA-based satellite-related networks (MBSSs and ISTNs) should be done. This will allow to investigate challenges such as "time-offset arrival" of signals from various users.
- *Systems' studies with more than 2-users-per-beam NOMA*: The study (performance analysis or design) of MBSSs and ISTNs with 3-users-per-beam or more for NOMA implementation, should be considered, for possible increase in the capacities of these systems.
- *Systems design with physical-layer imperfections*: The design of NOMA-based MBSSs and ISTNs by considering physical-layer imperfections such as imperfect CSI, CIs, and imperfect ICI cancellation,…etc., is necessary to produce a design with a more accurate imitation of real conditions.
- *Systems design with millimetre-Wave spectrum consideration*: It is important to consider designing NOMA-based MBSSs and ISTNs with mmWave-spectrum; as this will yield increased systems capacity.
- *Design of MA-Decoder blocks*: More design work is required on the MA-decoder blocks such as successive-interference-cancellation (SIC) algorithm and other Multi-User-Detection (MUD) algorithms, for both MBSSs and ISTNs.

2) *Topics typical to NOMA-Based MBSSs*

- *More work on cooperation of multiple NOMA-based satellite systems*: It is necessary to do more studies (performance analysis and system's design) on the cooperation of multiple MBSSs operating with NOMA.
- *More work on user-clustering algorithm design for MBSSs*: while the dynamics concerning the channel-gain and channel-correlation are not always the same for terrestrial networks and MBSSs, it is necessary to do more research on user-clustering algorithms for NOMA-based MBSSs, to concur the complexity of channel-gain in satellite system, for better systems performances.
- *More user-fairness maximization's power-allocation algorithms for MBSSs*: Because fairness is also a critical requirement of 5G networks, it is necessary to

do more research on power-allocation algorithm design for maximization of system's user-fairness, for NOMA-based MBSS.

- *More research on precoding algorithms designs for MBSSs*: Here again, because of the geometrical dynamic associated with satellite systems, it is necessary to do more research on precoding algorithms to best mitigate ICIs on MBSSs for an increase in the total system capacity.

3) Topics Typical to NOMA-Based ISTNs

- *Performance analysis of CR-ISTNs*: It is necessary to do more performance investigation for CR-ISTNs, as these analyses have not been reported before, to the best of the authors knowledge.
- *Application of NOMA on the satellite-network of a CR-ISTNs designs*: While most CR-ISTNs design works proposed to use 1-user-per-beam for the satellite network, that is, no NOMA on the satellite network, it is necessary to consider designing more CR-ISTNs with 2-users-per-beam for satellite network; in order to achieve a considerable increase in the total system's capacity.
- *Complexity of the Users-clustering algorithms design for ISTNs*: The control-centre of the ISTN must have the CSIs of all users with respect to terrestrial and satellite networks respectively, and then carefully assign users to terrestrial and satellite for operation. The exploitation of both set of CSIs simultaneously will increase the complexity of the network users' coordination process at the control-centre. This therefore set a need for more sophisticated user-clustering algorithms than those employed in single network configurations.
- *Power level coordination issue in CR-ISTNs*: In CR-ISTNs, the two networks should not cause severe interference to each other. This will require the control-centre to carefully cooperate the two networks in terms of respective power-allocations; and will therefore, increase the design complexity of the power-allocation algorithm for the system. To address such issues, more research is needed on power-allocation algorithm designs for CR-ISTNs to obtain more performing systems.
- *User-fairness maximization's power-allocation algorithms*: while all design studies thus far have developed power-allocation algorithms to maximize capacity of ISTNs, it is necessary to extend research on power-allocation algorithm design for system's user-fairness maximization.
- *More research on precoding algorithms design for CR-ISTNs*: Due to different geo-spatial dynamics between terrestrial and satellite network, some precoding algorithms employed on terrestrial network can't simply be used on satellite and ISTNs. Therefore, there is a need for more research on precoding algorithm designs for ISTNs.
- *Underlay and overlay cognitive-radio configurations*: The open-research topics discussed here above for the ISTNs domain should be considered for both the cognitive-radio overlay and underlay configurations.

4) Some Research Topics Proposed by Other Papers

In addition to above listed topics identified from the observations of the presented surveys, a few previous review listed some challenges associated with the field of NOMA-based Satellite-related networks. Some of these challenges are listed below:

- *Complexity of non-stationary satellite beams*: in most of the existing researches, there is an assumption for system's simplification, that the satellite beam is stationary on the ground. However, in the case of LEOs and MEOs satellites, this will not be true. The consideration that the satellite beams are not stationary on the ground bring additional complexity in system analysis and design; which there remains a challenge opened for future research.
- *Effect of imperfect CSI on SIC*: Imperfect CSI makes the SIC algorithm more challenging and can lead to serious detection errors which impede considerably the system performance. This challenge needs more research attention [18].
- *The bottleneck challenge*: The limited spectrum for the backhaul between satellite and gateway is referred to as the bottleneck challenge. This limitation reduced the capacity of the satellite networks. Therefore, more research is required to address this problem.
- *ICIs mitigation complexity in multi-gateway cooperation*: Multiple Gateway cooperation seeks to address the problem of limited backhaul spectrum between satellite and gateway, considered as bottleneck challenge. However, in such cooperation, the ICI mitigation becomes more complex; which therefore set a need for more research [62].
- *Difference in Multiuser data framing between satellite and terrestrial networks*: In ISTNs design, this difference will increase the complexity of the network coordinating system such as user-scheduling; which will then impact of the performance of the system if efficient techniques are not used. More research is therefore required to address this challenge [17].

V. Conclusion

This paper has given a comprehensive and more updated review of NOMA related work done on the satellite related communications. It appears that the work done on this field is still at its early stage and therefore the area is still quite opened for further research. While a considerable amount of work is underway on NOMA-based MBSSs design, the field of integrated satellite-terrestrial remains relatively untouched. Some of the possible research areas have been listed for the attention of interested researchers.

Conflict of Interest

We Declare that there are no conflicts of interest in publishing this article.

Author Contributions

Joel S. Bigohe is the main author, he explored the information which is under the supervision of Dr Vipin Balyan took the form of research paper.

References

[1] S. Islam, N. Avazov, O. Dobre, and K. Kwak, "Power-Domain Non-Orthogonal Multiple Access (NOMA) in 5G systems: Potentials and challenges," *IEEE Communications Surveys & Tutorials*, vol. 19, no. 2, pp. 721-742, Second Quarter, 2017.

[2] W. Ejaz, S. Shama, S. Saadat, M. Naeem, A. Anpalagan, and N. Chughtai, "A comprehensive survey on resource allocation for CRAN in 5G and beyong networks," *Journal of Nerwork and Computer Applications*, vol. 160, pp. 1-24, Mar. 2020.

[3] G. Liu and D. Jiang, "Vision and requirements for mobile communication system towards Year 2020," *Journal of Engineering*, pp. 1-9, Mar. 2016.

[4] Y. Wang, B. Ren, S. Sun, S. Kang, and X. Yue, "Analysis of non-orthogonal multiple access for 5G," *China Communications*, vol. 2, pp. 52-66, 2016.

[5] R. Khan and D. Jayakody, "An ultra-reliable and low-latency communications assisted modulation based non-orthogonal multiple access scheme," *Physical Communications*, pp. 15758-15761, 2020.

[6] M. Aldababsa, M. Toka, S. Gokceli, G. Kurt, and O. Kucur, "A tutorial on nonorthogonal multiple access for 5G and beyond," *Wireless Communications and Mobile Computing*, pp. 1-24, Jun. 2018.

[7] X. Yan, K. An, T. Liang, G. Zheng, Z. Ding, S. Chtzinotas, and Y. Liu, "The application of power-domain non-orthogonal multiple access in satellite communication networks," *IEEE Access*, vol. 7, pp. 63531-63539, 2019.

[8] X. Zhu, C. Jiang, L. Kuang, N. Ge, S. Guo, and J. Lu, "Cooperative transmission in integrated terrestrial-satellite networks," *IEEE Networks*, pp. 204-210, Jun. 2019.

[9] A. Anwar, B. Seet, M. Hasan, and X. Li, "A survey on application of non-orthogonal multiple access to different wireless networks," *Electronics*, vol. 8, pp. 1-46, Nov. 2019.

[10] V. Trivedi, K. Ramadan, P. Kumar, M. Dessouky, and F. Abid-El-Samie, "Enhanced OFDM-NOMA for next generation wireless communication: A study of PAPR reduction and sensitivity to CFO and estimation errors," *International Journal of Electronics and Communications*, vol. 102, pp. 9-24, 2019.

[11] X. Li, Q. Wang, H. Peng, H. Zhang, D. Do, K. Rabie, P. Kharel, and C. Cavalcante, "A unified framework for HS-UAV NOMA networks: Performance analysis and location optimization," *IEEE Access*, vol. 8, pp. 13329-13340, 2020.

[12] L. Dai, Z. Wang, and Y. Yuan, "Non-Orthogonal multiple access for 5G: Solutions, challenges, opportunities and future research trends," *IEEE Communications Magazine*, pp. 74-81, Sep. 2015.

[13] X. Zhang, D. Guo, K. An, Z. Chen, B. Zhao, Y. Ni, and B. Zhang, "Performance analysis of NOMA-Based cooperative spectrum sharing in hybrid satellite-terrestrial networks," *IEEE Access*, vol. 7, pp. 172321-172329, 2019.

[14] V. Balyan and D. S. Saini, "Called elapsed time and reduction in code blocking for WCDMA networks," IEEE in *Proc. International Conference on Software Telecommunication an Computer Networks*, SoftCom, 2009, pp. 141-245.

[15] V. Balyan and D. S. Saini, "A same rate and pattern recognition search of OVSF code tree for WCDMA networks," *IET Communications*, vol. 8, no. 13, pp. 2366-2374, 2014.

[16] Y. Saito, A. Benjebbour, Y. Kishivama, and T. Nakamura, "System-Level performance evaluation of downlink Non-Orthogonal Multiple Access (NOMA)," in *Proc. IEEE 24th International Symphosium on Personal, Indoor and Mobile Radio Communications: Fundamentals and PHY Track*, 2013, pp. 611-615.

[17] A. Neira, M. Caus and M. Vazquez, "Non-Orthogonal transmission techniques for multibeam satellite systems," *IEEE Communications Magazine: Mobile Communication and Networks*, pp. 58-63, Dec. 2019.

[18] K. An, X. Yan, T. Liang, and W. Lu, "NOMA based satellite communication networks: Architectures, techniques and challenges," in *Proc. IEEE 19th International Conference on Communication Technology*, 2019, pp. 1105-1110.

[19] S. Kumar and T. Kumar, "Multiple access schemes for cognitive radio networks: A survey," *Physical Communication*, vol. 38, pp. 1-31, 2020.

[20] S. Zhang, D. Zhu, and Y. Wang, "A survey on space - aerial-terrestrial integrated 5G networks," *Computer Networks*, vol. 174, pp. 1-18, 2020.

[21] P. Botsinis, D. Alanis, C. Xu, Z. Babar, D. Chandra, S. Xin, and L. Hanzo, "Air-to-Ground NOMA systems for the 'Internet-Above-the-Cloud'," *IEEE Access*, vol. 6, pp. 47442-47460, 2018.

[22] X. Wang, Z. Na, and K. Yan, "Energy efficiency optimization for NOMA-Based cognitive radio with energy harvesting," *IEEE Access*, vol. 7, pp. 139172-139180, 2019.

[23] M. Caus, M. Vazquez, and A. Neira, "NOMA and interference limited satellite scenarios," *IEEE Asilomar*, pp. 497-501, 2016.

[24] V. Balyan, "Outage probabilty of cognitive radio network utilizing non orthogonal multiple access," in *Proc. 7th International Conference on Signal Processing and Integrated Networks (SPIN)*, Noida, India, 2020, pp. 751-755.

[25] S. Bharathi, L. Nandita, N. Venkateswaran, and R. Subhashini, "Performance analysis of non-orthogonal multiple access techniques with precoding," in *Proc. IEEE WiSPNET 2017 Conference*, 2017, pp. 1878-1882.

[26] X. Li, M. Liu, D. Deng, J. Li, C. Deng, and Q. Yu, "Power beacon assisted wireless power cooperative relaying using NOMA with hardware impairments and imperfect CSI," *International Journal of electronics and Communications*, vol. 108, pp. 275-286, 2019.

[27] Z. Na, M. Zhang, M. Jia, M. Xiong, and Z. Gao, "Joint uplink and downlink resource allocation for the internet of things," *IEEE Access*, vol. 7, pp. 15758-15766, 2019.

[28] I. Baig, N. Hasan, M. Zghaibeh, I. Khan, and A. Saand, "A DST precoding based uplink NOMA scheme for PAPR reduction in 5G wireless network," *IEEE*, pp. 1-4, 2017.

[29] Y. Cao, N. Zhao, Y. Chen, M. Jin, Z. Ding, Y. Li, and F. Yu, "Secure transmission via beamforming optimization for NOMA networks," *IEEE Wireless Communications*, pp. 193-199, Feb. 2019.

[30] W. Wang, J. Tang, N. Zhao, X. Liu, X. Zhang, Y. Chen, and Y. Qian, "Joint precoding optimization for secure SWIPT in UAV-Aided-NOMA networks," *IEEE Transaction on Communication*, pp. 1-14, 2020.

[31] X. Yan, H. Xiao, C. Wang, K. An, A. Chronopoulos, and G. Zheng, "Performance analysis of NOMA-Based land mobile satellite networks," *IEEE Access*, vol. 6, pp. 31327-31339, 2018.

[32] S. Xie, B. Zhang, D. Guo, R. Xu, C. Li, and M. Ma, "Performance analysis of non-orthogonal multiple access with co-channel interference in a satellite commuication system," *IEEE*, pp. 1-6, 2019.

[33] Z. Yin, M. Jia, W. Wang, N. Cheng, F. Lyu, Q. Guo, and X. Shen, "Secrecy rate analysis of satellite communications with frequency domain NOMA," *IEEE Transactions on Vehicular Technology*, vol. 68, no. 12, pp. 11847-11858, Dec. 2019.

[34] F. Zhou, R. Wang, and J. Bian, "Performance analysis of non-orthogonal multiple access based-satellite communication networks with hardware impairments and channel estimations," *Electronics Letters*, vol. 56, no. 1, pp. 52-55, Jan. 2020.

[35] K. Xiao, S. Zhang, K. Michel, and C. Li, "Study of physical layer security in mmWave satellite networks," *IEEE*, pp. 1-6, 2018.

[36] X. Yan, H. Xiao, K. An, G. Zheng, and S. Chatzinotas, "Ergodic capacity of NOMA-Based uplink satellite networks with randomly deployed users," *IEEE Systems Journal*, pp. 1-8, 2019.

[37] X. Liu, X. Zhai, W. Lu, and C. Wu, "QoS-guarantee resource allocation for multibeam satellite industrial internet of things with NOMA," *IEEE Transaction of Industrial Informatics, Journal of Latex Class Files*, vol. 14, no. 8, pp. 1-10, Aug. 2015.

[38] J. Jiao, Y. Sun, Y. Wang, and Q. Zhang, "Network utility maximization resource allocation for NOMA in satellite-based internet of things," *IEEE Internet of Things Journal*, pp. 1-13, 2019.

[39] Y. Sun, J. Jiao, S. Wu, Y. Wang, and Q. Zhang, "Joint power allocation and rate control for NOMA-Based space information networks," *IEEE*, pp. 1-6, 2019.

[40] Y. Sun, Y. Wang, J. Jiao, S. Wu, and Q. Zhang, "Deep-Learning-Based long-term power allocation scheme for NOMA downlink system in S-IoT," *IEEE Access*, vol. 7, pp. 86288-86296, 2019.

[41] R. Wang, W. Kang, G. Liu, R. Ma, and B. Li, "Admission control and power allocation for NOMA-Based satellite multi-beam network," IEEE Access, vol. 8, pp. 33631-33643, 2020.

[42] T. Ramirez and C. Mosquera, "Resource management in the mutibeam NOMA-based satellite downlink," in *Proc. IEEE Conference of ASSP*, 2020, pp. 8812-8816.

[43] A. Wang, L. Lei, E. Lagunas, A. Neira, S. Chatzinotas, and B. Ottersten, "On fairness optimization for NOMA-Enabled multi-beam satellite systems," in *Proc. IEEE 30th Annual Internation Symphosium on Personal, Indoor and Mobile Radio Communications (PIMRC): Track 3: Mobile and Wireless Networks*, 2019, pp. 1-6.

[44] M. Alhusseini, P. Azmi, and N. Mokari, "Optimal joint subcarrier and power allocation for MISO-NOMA satellite networks," *Physical Communication*, vol. 32, pp. 50-61, 2019.

[45] X. Shao, l. Y. M. Sun Z, S. Gu, and Q. Guo, "NOMA-Based irregular repetition slotted ALOHA for satellite networks," *IEEE Communications Letter*, vol. 23, no. 4, pp. 624-627, Apr. 2019.

[46] R. Wan, L. Zhu, T. Li, and L. Bai, "A NOMA-PSO based cooperative transmission method in satellite communication systems," *IEEE*, pp. 1-6, 2017.

[47] N. Beigi and M. Soleymani, "Interference management using cooperative NOMA in multi-beam satellite systems," *IEEE*, pp. 1-6, 2018.

[48] Y. Zhu, T. Delamotte, and A. Knopp, "Geographical NOMA beamforming in multi-beam satellite-based internet of things," *IEEE*, pp. 1-6, 2019.

[49] R. Sirigina, A. Madhukumar, and M. Bowyer, "NOMA precoding for cognitive overlay satellite systems," *IEEE*, pp. 1-5, 2019.

[50] M. Vazquez, M. Caus, and P. Neira, "Performance analysis of joint precoding and MUD techniques in multibeam satellite systems," *IEEE*, pp. 1-5, 2016.

[51] A. Guidotti and A. Coralli, "Geographical scheduling for multicast precoding in multi-beam satellite systems," in *Proc. 9th Advanced Satellite Multimedia Systems Conference and the 15th Signal Processing for Space Communications Workshop (ASMS/SPSC)*, 2018, pp. 1-8.

[52] X. Yan, H. Xiao, K. An, G. Zheng, and W. Tao, "Hybrid satellite terrestrial relay networks with cooperative non-orthogonal multipple access," *IEEE Communications Letters*, vol. 22, no. 5, pp. 978-981, May. 2018.

[53] S. Xie, B. Zhang, D. Guo, and B. Zhao, "Performance analysis and power allocation for NOMA-Based hybird satellite-terrestrial relay networks with imperfect channel-state-iinformation," *IEEE Access*, vol. 7, pp. 136279-136289, 2019.

[54] V. Singh, P. Upadhyay, and M. Lin, "On the performance of NOMA-Assisted overlay multiuser cognitive satellite-terrestrial networks," *IEEE Wireless Communications Letters*, pp. 1-5, 2020.

[55] K. Guo, Z. Ji, B. Yang, and X. Wang, "NOMA-based integrated satellite-terrestrial multi-relay networks with hardware impairments and partial relay selection scheme," in *Proc. IEEE 19th International Conference on Communication Technology*, 2019, pp. 1099-1104.

[56] Y. He, J. Jiao, X. Liang, S. Wu, Y. Wang, and Q. Zhang, "Outage performance of milimeter-wave band NOMA downlink system in satellite-based IoT," in *Proc. IEEE/CIC International Conference on Communications in China (ICCC)*, 2019, pp. 356-361.

[57] X. Zhu, C. Jiang, L. Yin, L. Kuang, N. Ge, and J. Lu, "Cooperative multigroup multicast transmission in integrated terrestrial-satellite networks," *IEEE Journal of Selected Areas in Communications*, vol. 36, no. 5, pp. 981-992, May. 2018.

[58] M. Lin, C. Yiny, Z. Lin, J. Wang, T. Cola, and J. Ouyang, "Combined beamforming with NOMA for cognitive satellite terrestrial networks," *IEEE*, pp. 1-6, 2019.

[59] X. Zhu, C. Jiang, L. Kuang, N. Ge, and J. Lu, "Non-Orthogonal multiple access based integrated terrestrial-satellite networks," *IEEE Journal on Selected Areas in Communications*, vol. 35, no. 10, pp. 2253-2267, Oct. 2017.

[60] Z. Lin, M. Lin, J. Wang, T. Cola, and J. Wang, "Joint beamforming and power allocation for satellite-terrestrial integrated networks with non-orthogonal multiple access," *IEEE Journal of Selected Topics in Signal Processing*, vol. 13, no. 3, pp. 657-670, Jun. 2019.

[61] M. Jia, Q. Gao, Q. Guo, X. Gu, and X. Shen, "Power multiplexing NOMA and bandwidth compression for satellite-terrestrial networks," *IEEE Transactions on Vehicular Technology*, vol. 68, no. 11, pp. 11107-11117, Nov. 2019.

[62] M. Vazquez, A. Neira, D. Christopoulos, S. Chatzinotas, B. A. P. Ottersten, A. Ginesi, and G. Taricco, "Precoding in multibeam satellite communications: Present and future challenges," *IEEE Wireless Communications*, pp. 88-95, Dec. 2016.

Joel Biyoghe was born in 1988 in Medouneu. He received the B.Tech. and M.Eng. degree in Electrical and Electronics Engineering, with honors, from the Cape Peninsula University of Technology (CPUT), Cape Town, South Africa, in 2012 and 2018 respectively. He also received the M.Sc. in Satellite Systems Engineering from ESIEE, Paris, France, in 2018. He is currently pursuing the Doctorate of Engineering (D.Eng.) Degree at CPUT. His current research interests include wireless communications, mobile networks and satellite networks.

Vipiv Balyan received B.E degree in Electronics & Communication with honors in 2003, M.Tech degree in Electronics & Networking from LaTrobe University, Bundoora, Melbourne, Australia in 2006. He received Ph.D Degree in *Efficient Single Code Assignment in OVSF based WCDMA Wireless Networks in 2013. He worked as an Assistant Professor Senior Grade for 7 years in Jaypee Education system. He is currently working as a Senior Lecturer in* Department of Electrical, Electronics and Computer Engineering of Cape Peninsula University of Technology, Bellville Campus, Cape Town, South Africa. His research area includes CDMA, OFDM, VSF-OFCDM, VLC, Fuel Cells.