A Survey of Existing Studies on NOMA Application to Multi-beam Satellite Systems for 5G

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Abstract. The non-orthogonal multiple access (NOMA) technology and the satellite communication systems have been identified as key enabling technologies for the achievement of the fifth generation (5G) networks. There are ongoing researches about the implementation of 5G networks, and more precisely, employing NOMA technology. While most existing survey papers on NOMA-based 5G networks' studies focus mainly on terrestrial networks, this paper provides a comprehensive survey of NOMA-based satellite networks studies for 5G. More precisely, this paper gives an up-to-date survey of studies that have investigated the performances (ergodic capacity, outage probability, secrecy rate, … etc.) of NOMA-based satellite networks. It also gives a survey of studies that have designed networks components such as power-allocation algorithms or precoding algorithms for NOMA-based satellite networks. The surveys presented reveal that the field of NOMA application to satellite networks for 5G is still relatively new, and therefore, holds many interested topics opened for future research.

Keywords: Non-Orthogonal Multiple Access (NOMA), Orthogonal Multiple Access (OMA), Satellite, user-clustering, power-allocation, precoding, 5G, 4G, ergodic capacity, user-fairness.

1 Introduction

Mobile networks are radio access communication networks (R.A.Ns) in which a mobile user is granted access for a designated period of time to utilize the radio resources of the network (frequency spectrum) in order to either transmit or receive information [1]. The network access-point can be a terrestrial base-station (in which case the network is called terrestrial network or cellular network), or an earth-orbit satellite (in which case the network is called a satellite network) [2]. General performance parameters of mobile networks include their total capacity, reliability (quality of service (QoS), and user-fairness), latency as well as geographical coverage or span [3] [4]. Based on their achievable performances as well as the technologies used, mobile networks have been classified in various generations over the years. Table 1 below summarizes the evolution of mobile networks, which is applicable to both the terrestrial and the satellites networks.

Table 1. Overview of evolution of mobile network's generations [5] [6] [7] [8].

Generation	Year	Radio access technology	Analog/Digital technologies	Applications
1G	1980s	FDMA	Analog technology	Voice calls only
2G	1990s	TDMA, CDMA	GSM, GPRS, EDGE,	Voice calls, SMS, Packet-switched data services
3G	2000s	CDMA	CDMA-2000, EV-DO, WCDMA	Services from 2G + Video Calls
4G	2010s	OFDMA	LTE, LTE-A	Services from 3G + enhanced quality video calls and live streaming

The 4[th] generation (4G) networks have been the most advanced form of mobile networks throughout the 2010 decade and they deliver performances such as high-connectivity, high capacity, high end-user speed, intermediate latency, low reliability, and a geographical coverage still relatively small (about 20% of earth surface is covered by mobile network). With such performances, 4G networks offer services such as video calls, live streaming, etc. From the 2020 decade, the mobile communication industry seeks to achieve the internet-of-things (IoTs) which include services such as industrial internet, remote surgery and the whole- world-connection [9]. These services require network performances such as massive connectivity, ultra-low latency, ultra-high reliability ultra-high speed and ubiquity [5] [6]; and can't therefore, be supported by 4G networks [10].

To address this need, the firth generation (5G) of networks has been envisaged by the international telecommunication union (ITU) as a technology advancement of 4G networks. The expected performance metrics of 5G networks have been summarized by [6]. The enhance mobile broadband communication (eMBB), the ultra-reliable and low latency communication (URLLC) and the massive machine-type communication (mMTC) are three main communication concepts that should be supported by any 5G network [8] [11]. To enable the development of 5G networks, the ITU has proposed some emerging technological concepts including multiple-input multiple/single-output (MIMO/MISO), non-orthogonal multiple access (NOMA), multicasting, beamforming (BF) and the multi-beam satellite system. The NOMA and the MBSS technologies are regarded as the key enabler of the 5G achievement [12] [13].

To date, various ongoing researches have investigated the development of 5G networks using the above mentioned technological concepts, independently or inclusively. However, since NOMA is regarded as a key technology enabler of 5G and has captured much attention from researchers, this paper will focus on 5G development studies which are based on NOMA technology. In this regards, some existing papers have given a survey of NOMA-based researches for 5G [1] [2] [3] [8]; but these papers focused purely on terrestrial network's related works. To the best of authors knowledge, no paper has presented a survey of researches on NOMA-based satellite networks development for 5G.

This paper therefore, seeks to fill this gap, and gives a comprehensive and up-to-date survey of existing researches that investigated the usage of NOMA technology on

MBSS for 5G application. The surveys presented in this paper can serve as a guide for researchers to know the stat-of-art in the field as well as the gap areas opened for future possible researches. The contribution of this paper include:

- a survey of all studies that have investigated performances (ergodic capacity, outage probability, asymptotic outage probability, secrecy rate) of NOMA-based satellite networks;
- a survey of all studies that designed a power-allocation algorithm for the MA system of NOMA-based satellite networks;
- a survey of all studies that designed a precoding-allocation algorithm for the MA system of NOMA-based satellite networks.

The rest of the paper is organized as follows: section 2 gives a brief overview of the NOMA technology concept. Then, in section 3 the comprehensive surveys of NOMA-based satellite networks studies are given. Important observations made from these surveys and the possible opened-research-areas identified are discussed in section 4. The conclusion is given in section 5.

2 Overview of NOMA Concept

The non-orthogonal multiple access (NOMA) is a novel multiple-access (MA) technology for mobile networks in which more than one users are allowed to utilize a designated sub-frequency resource simultaneously over a given time period [8] [14]. This is unlike the orthogonal multiple access (OMA) technology traditionally used in previous generations of mobile networks (1G to 4G) in a form of time-division multiple access (TDMA), frequency-division multiple access (FDMA) or offset-FDMA (OFDMA); in which only one user is allowed to utilize a designated sub-frequency resource [15] [16] Figure 1 below illustrates two scenarios of a MBSS, one with OMA technology where only one user is served for a given frequency slot; and the other with NOMA technology (case of two users per beam), where two users are served simultaneously using the same frequency slot. In the NOMA technology, the information of respective users utilizing the same frequency resources are separated in either power-level, hence power-domain NOMA (PD-NOMA); or in code-level, hence code-domain NOMA (CD-NOMA) [6] [3]. Figure 2 below gives an illustration of the power diagram of OMA and PD-NOMA technologies. This diagrams show that, in the case of OMA, the one user served at the designated frequency slot utilizes all the power available for that frequency slot; whereas in the PD-NOMA concept, the transmitted signal is a superposition of multiple signals from respective users that share the same frequency, with different power levels. These users share the total power available for the designated frequency slot, and power levels are assigned to users based on their respective channel conditions, where the order of power coefficients is inverse to the order of channel gains. In order words, users with best channel gains are assigned less power and users with the poorer channel gains are assigned more power. At the receiver side, the concept of successive interference cancellation (SIC) is used to decompose the superposed signals. The user with highest power level decomposes its signal directly as it sees other signals as noise. Subsequently, users with lower power levels first have to successively decompose signals of users with higher powers [17] [18]. From what precedes, a few important observations can be made: (a) NOMA delivers better system performances than its predecessor OMA in most network aspects such as achievable connectivity, capacity, latency and fairness [12] [19]; (b) NOMA is compatible with OMA and can therefore be used in system where OMA has been employed without having to upgrade the system considerably [20] [21]; (c) due to the implementation of the SIC concept, the complexity of NOMA receiver is high and keeps on increasing with increase in the number of users to superpose; which may constitute a considerable limitation of the NOMA technology [8] [11] [22].

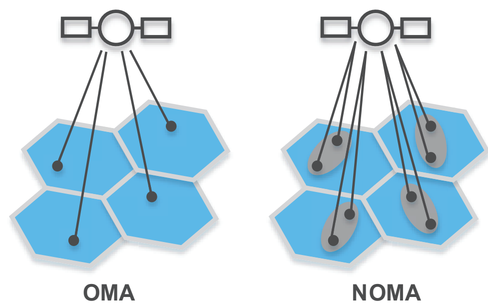

Fig. 1. MBSS illustration with OMA and NOMA

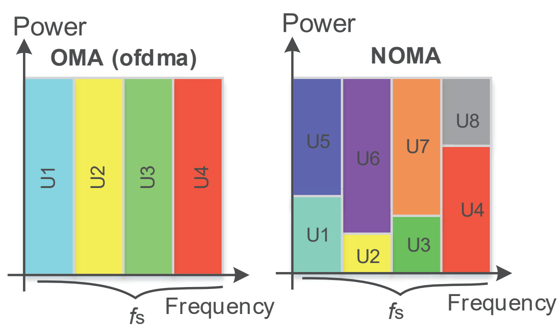

Fig. 2. Illustration of power-domain diagram: OMA vs NOMA

3 Survey of existing NOMA-based satellite networks' studies

3.1 Type of network studies

The study of a RAN network generally involves two types of works, namely, the system analysis and the system design. The system analysis investigates statistical performances of the system such as the outage probability (OP), the asymptotic outage probability (ASOP), the ergodic capacity (EC), and the secrecy rate (SR). The system design on the other hand consist of designing blocks of the multiple access (MA) encoder including the user-clustering (UC) process to group users to be served, the power-allocation (PA) process to assign power levels to respective users and possibly the precoding (PC) process to do execute beam-forming and mitigate inter-cell-interferences (ICIs). It also consists of designing blocks of the MA decoder, which in the case of NOMA would include the SIC process to decompose the superposed signals. The SIC forms part of the multi-user-detection (MUD) techniques, which are used to mitigate the ICIs at the receiver side. The design goal for the user-clustering algorithm is to find the best matching pairs of users to be served together for either intra-beam NOMA power allocation, or for beamforming. For the power-allocation, the design goals usually include to maximize the system capacity or user-fairness. The precoding algorithm design goal is to mitigate inter-cell-interference and therefore to maximize the system capacity. For the three systems, the design considerations for all these design processes generally include the number of users to be paired for NOMA, the users' channel conditions, the type of channel-state-information (CSI) estimation, whether perfect or imperfect, and the channel impairment, wither considered or assumed negligible. In the survey below, all identified works regarding NOMA application to satellite networks for 5G, be it system analysis or system design are presented.

3.2 Survey of network analysis studies

The following system analysis studies presented in Table 2 below have been identified for NOMA-based satellite systems. The following abbreviation should be noted: ergodic capacity (EC), outage probability (OP), secrecy rate (SR), inter-channel-interference (ICI), channel-impairments (CI), channel-state-information (CSI).

Table 2. Summary of system's analysis studies for NOMA-based MBSS

Paper	Analysis study done	Technical details	Outcome
[23]	Compared the performances of a MBSS's downlink with NOMA and OMA	Evaluated EC and OP for both cases	Demonstrated that NOMA > OMA in performances
[24]	Investigated the impact of ICI on the performances of a NOMA-based MBSS	Evaluated EC and OP with ICI	The ICI deteriorate the system performances
[25]	Performed a SR analysis of satellite communications with frequency domain NOMA	SR evaluation	The SR is affected by the level of spectral overlapping
[26]	Investigated the impact of both imperfect CSI and CI on the performance of a NOMA-based MBSS downlink	Evaluated OP with imperfect CSI and CI	Demonstrated that Imperfect CSI and CI deteriorate system's performances.
[27]	Investigated the physical layer security challenges in mmWave, with NOMA and MIMO downlink	Evaluated secrecy capacity for both NOMA & MIMO.	Secrecy capacity depends on richness of the radio frequency

[28]	Investigated the ergodic capacity of NOMA-based uplink satellite networks with randomly deployed users	Evaluated EC	Location information, link performance, transmitted power and imperfection of CSI all impact on system performance.

3.3 Survey of network's power-allocation design studies

The following power-allocation (PA) design studies listed in Table 3 below have been identified for NOMA-based satellite systems. Note the following abbreviations: power allocation (PA), admission-control (AC), particle-swarm-optimization (PSO), deep-learning search (DLS).

Table 3. Identified PA-algorithm's design studies for NOMA-Based satellite systems

Paper	Design study done	Technical details	Outcome
	PA-algorithm's design for single MBSS		
[29]	designed a PA algorithm for a NOMA-based MBSS	PA algorithm designed to improve total system transmission rate	Achievable system rate is above that of OMA
[30]	designed a PA algorithm for a MISO-NOMA satellite system	PA algorithm designed to minimize the system's total power consumption	Performances of proposed algorithm are superior to those of OMA and SISO systems
[31]	designed a PA algorithm for a NOMA-based MBSS	PA algorithm (NOMA+PC) designed to maximize the system's fairness	Performances of NOMA+PC are superior to those of some algorithms such as OMA, NOMA1 and NOMA2
[32]	designed a PA algorithm for a NOMA-based MBSS	PA algorithm designed to maximize the weighted sum-rate system transmission rate	Performances of designed algorithm are superior to those of OMA
	Combined PA & AC algorithm's design for single MBSS		
[33]	developed PA & admission control (AC) algorithm for a NOMA-based MBSS	A joint PA & AC algorithm (NOMA-JOPT) designed to maximize long-term network utility of the system	Performances of NOMA-JOPT are superior to those of other algorithms such as OMA, NOMA-PRO-G.
[34]	developed PA & admission control (AC) algorithm for a NOMA-based MBSS	A combined PA & AC algorithm (NOMA-PSO) designed to maximize long-term network utility of the system, based on DLS concept	Performances of NOMA-DLS are superior to those of another algorithm called NOMA-FuS
[35]	developed PA & admission control (AC) algorithm for a	A combined PA & AC algorithm (NOMA-PSO) designed to maximize long-term network	Performances of NOMA-PSO are superior to those of other algorithms such as OMA, NOMA-PRO-G

	NOMA-based MBSS	utility of the system, based on PSO concept	
[36]	developed PA & admission control (AC) algorithm for a NOMA-based MBSS	A combined PA & AC algorithm (NOMA-algo1) designed to maximize the system's number of users	Performances of NOMA-Algo1 are superior to those of some existing algorithms such as OMA-OFDMA, Dynamic exchange, static-exchange
PA-algorithm's design for an integrated 2-MBBSs			
[37]	designed a PA algorithm for a NOMA-based integrated 2 satellites systems	single PA algorithm for both MBSSs (NOMA-PSO) designed to maximize the total sum-rate of the system	Performances of NOMA-PSO are superior to those few other algorithms such as OMA and NOMA-uniform
[38]	Proposed a NOMA-based Irregular Repetition Slotted ALOHA (IRSA) scheme for satellites networks	The designed NOMA-based IRSA differ from usual OMA-based IRSAs	Performances of NOMA-IRSA proved superior to those of some OMA-IRSAs.

3.4 Survey of network's precoding design studies

The following precoding (PC) design studies listed in Table 4 below have been identified for NOMA-based satellite systems. Note the following abbreviations: multiple-user-detection (MUD), beamforming (BF).

Table 4. Identified PC-algorithm's design studies for NOMA-Based satellite systems

Paper	Design study done	Technical details	Outcome
PC-algorithm's design for single MBSS			
[39]	Designed a precoding-algorithm for a MBSS that employs NOMA and beamforming technologies	Precoding algorithm (overlay-coding-BF) designed to maximize the system's spectral-efficiency	Performances of overlay-coding-BF are superior to those of few other algorithms such as FR4-BF, FR2-BF.
[40]	Designed a precoding-algorithm for a MBSS that employs NOMA and beamforming technologies	Precoding algorithm (Geo-NOMA-BF) designed to maximize the system's sum rate	Performances of Geo-NOMA-BF are superior to those of few other algorithms such as OMA-BF, NOMA-BF-ZF, NOMA-BF-user-scheduling.
Combined PC & UC/MUD algorithm's design for single MBSS			
[41]	Investigated the effect of combining precoding at transmitter and MUD at receiver for a MBSS	Evaluated the performance of the MBSS with only precoding, only	The performance of joint Precoding and MUD outperform those of the system

		MUD and both precoding and MUD	when only one of the two is used
[42]	Combined a geographical user scheduling and precoding for a NOMA-based MBSS	The system (combined GUS & precoding) was designed to maximise the system throughput	The proposed system's performance are superior to those of using precoding alone
PC-algorithm's design for an integrated 2-MBBSs			
[43]	Designed a precoding algorithm for an integrated 2-MBSS that employs NOMA & beamforming technologies	single precoding algorithm (IPF-Based-BF) for both MBSSs designed to maximize the total sum-rate of the system	Performances of IPF-Based-BF are superior to those of few other algorithms such as OMA-BF, SDR-NOMA, and Maxeigen-NOMA.

4 Observations and opened research areas identification

4.1 Observations

Table 5 below presents some observations made (relevant findings) from a careful interpretation of the above presented surveys.

Table 5. List of important observations made from the surveys: relevant findings

General observation
• The research is still quite young as most research range from about end of year 2016 to date (2020); and as a logical consequent, there is only a handful of studies that have been reported so far.
Observations on system analysis's studies
• While most presented studies have investigated system performances of NOMA-based satellite systems under conditions of perfect and imperfect CSIs; no identified papers have reported analysing the system by considering channel impairments. • In most of the researches presented, the number of user per beam for NOMA has been limited to 2, and no paper has reported system analysis for case of more than 2 users per beam for NOMA. • This far only one study has investigated the cooperation of multiple LEO or MEO satellites employing NOMA.
Observations on system design's studies
• Most user-clustering, power-allocation or precoding algorithms design considered only the scenario of two user-per-beam for NOMA. None of the identified studies considered the scenario of more than 2 user-per-beam during their system's design. • All reported design studies assumed the scenario of perfect CSI and no channel-impairments; no reported design work considered scenario of imperfect CSI and/or channel impairment during their system's design. • All reported design studies have considered operating in the microwave-wave frequency spectrum; no identified design works considered millimetre-wave (mmWave) frequency spectrum for their system's design.

- The reported user-clustering algorithm designs, mostly based their designs either on the channel gain, for the intra-beam (NOMA) power allocation process or on channel-correlation, for beamforming process.
- For the case of power-allocation algorithm designs, an outstanding observation is that most reported works design their PA algorithm to maximise the total system capacity; only one reported work designed its PA algorithm to maximise system fairness.

4.2 Opened research areas

Based on the above observations from the surveys presented, the following points can constitute opened areas for future research in the field of NOMA application to satellite networks for 5G:

- System performance analyses to be done with the scenario of more than 2 users-per NOMA-beam.
- System performance analyses to be done by considering channel impairments.
- More investigations of the possibility to cooperate multiple LEO/MEO satellites operating with NOMA.
- Design of user-clustering algorithms to be done for the scenario of more than 2 users-per NOMA-beam.
- Design of power-allocation algorithms to be done for the scenario of more than 2 users-per NOMA-beam.
- Design of power-allocation algorithms to be done by considering imperfect CSI.
- Design of power-allocation algorithms to be done by considering channel-impairments.
- More research on design of power-allocation algorithm for maximization of system's user-fairness.
- Design of precoding algorithms to be done for the scenario of more than 2 users-per NOMA-beam.
- Design of precoding algorithms to be done by considering imperfect CSI.
- Design of precoding algorithms to be done by considering channel-impairments.
- Do above system's design by considering operating in the mmWave frequency spectrum.

It is to be noted that the above listed topics are to be added to a non-exhaustive list of challenges and possible research areas for NOMA-based satellite networks already mentioned in some papers [3] [8] [19] [23] [44] [45]; and which include:

- The challenge of non-stationary ground beam for case of non-geostationary-earth-orbit satellites.
- The satellite to gateway link limitation considered as a bottle neck challenge.
- Inter-cell-interference management in case of multiple gate-way network.
- Very limited work on the physical layer security which requires more attention as satellite communications are very vulnerable to eavesdroppers.

5 Conclusion

In this paper, we have presented a comprehensive survey of existing studies on NOMA application to satellite networks for 5G. Firstly, a survey of studies that have investigated performances (ergodic capacity, outage probability, secrecy rate, ... etc.) of NOMA-based satellite networks was presented. Then, a survey of system design studies including power-allocation algorithm studies and precoding algorithm studies for NOMA-based satellite networks were presented. A few important observations have been drawn from these surveys. Firstly, from a global view, only a very researches exists in this field of NOMA application to satellite networks for 5G, all of them being very recent; meaning that this field is still quite new and is therefore, is still very opened for future research. Subsequently, from a technical observation point of view, most studies have limited themselves to the case of two user-per NOMA-beam; and most studies considered case of perfect CSI and no-channel impairments during their designs. Also, most design studies focused on maximization of system capacity with no much consideration for the user-fairness aspect. These observations constitute opened areas which give way to possible future researches.

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