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Non-Terrestrial Networks Based on Non-Orthogonal Multiple Access Towards 6G

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ABSTRACT

Until now many regions around the world are still uncovered by cellular terrestrial mobile system services due to the lack of economic feasibility as well as the difficulty of introducing such services. Conversely, a large geographic region can be covered by using only a single satellite, so it is worthwhile to extend the actual terrestrial services using satellite system. The new hybrid integrated "terrestrial-satellite" cellular system, known under the name of Non-Terrestrial Networks (NTN), will see the light with the support of future 6G technology. It is expected that 6G cellular mobile system will play the role of integrating terrestrial, aerial, maritime, and space communications into a universal network that could support a massive number of terminals with ultra-low latency. For the realization of the NTN system, new technologies should be introduced at the level of terrestrial cellular network, arial network, and satellite network. One of these promising technologies is represented by an efficient multiplexing technique known under the name of non-orthogonal multiple access (NOMA). With this technique, multiple users can be served on a single time-frequency resource block by using the concepts of superposition coding at the transmitter and successive interference cancellation (SIC) at the receiver. Moreover, NOMA has an achievable performance gain in terms of spectral efficiency over the traditional orthogonal multiple access (OMA) technique. Evaluation of a NOMA-based NTN system supported by 6G technologies in terms of system parameters and channel capacity represent the main objective of this paper.

1. Introduction

The current cellular infrastructures in most countries may lack the level of reliability, availability, and responsiveness requested by future wireless applications and show vulnerability to catastrophes situations. Connectivity outages during natural catastrophes, in particular, may halt or delay appropriate reactions, create severe damage to the economy and property, and even result in the loss of lives. Correspondingly, the actual mobile cellular system supports only terrestrial services, and many regions around the world are still uncovered by the cellular terrestrial mobile system services because of the lack of economic feasibility and difficulty of introducing such services to those regions [1]. Fortunately, the subject of lack of connectivity in isolated regions will be resolved by the future sixth generation (6G) mobile network, which is expected to integrate terrestrial, aerial, sea, and space communications into a robust network known under the name of Non-Terrestrial Networks (NTN) to achieve global connectivity based on ultra-reliability, ultra-low latency, and ultra-bit rate requirements. The NTN system

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configuration is depicted in Figure 1, which includes three layers: the first one represents the ground or terrestrial network, including the actual cellular system; the second one represents the air network, including the unmanned aerial vehicles (UAVs) beside the high-altitude platform (HAP); and the third one represents the space network, including different altitude satellites constellations. The integration of the NTN was already considered by the 3rd generation partnership project (3GPP) Rel-15, Rel-16, and Rel-17 [2-4]. Nowadays, the NTN is one of the hot subjects in the domain of wireless mobile systems and is widely considered by many researchers. The 6G communication system-related research has gained great interest from both industries and academics, among which the NTN is a promising technique to extend the range of global services and worldwide Internet access [5], [6]. In cellular mobile communications, the design of the radio access network (RAN) is one important aspect of improving system capacity in a cost-effective manner. Orthogonal multi-access (OMA) techniques, under the name of orthogonal frequency division multiple access (OFDMA), are used in the Fourth Generation (4G) long-term evolution (LTE) [7-10]. In OMA, within a cell, each user has exclusive access to the allocated resource blocks. Thus, each sub-channel or subcarrier can only be utilized by at most one user in every time slot with free intra-cell interference between different users belong to the same base station. OFDMA allows multi-user communications using multiple subcarriers, where these subcarriers are orthogonal to each other [11]. However, by its nature, orthogonal channel access is becoming a limiting factor in spectrum efficiency. As mobile data traffic grew dramatically, this led to the birth of 5G technology, which is based on a new type of OMA known as Filter-Bank orthogonal frequency division multiple access (FB-OFDMA) [12], [13]. The FB-OFDMA has a high out-of-band rejection: each sub-band of the FB-OFDM benefits from a filtering stage; therefore, the spectrum leakage in adjacent bands is very low, which leads to increasing the system spectrum efficiency.

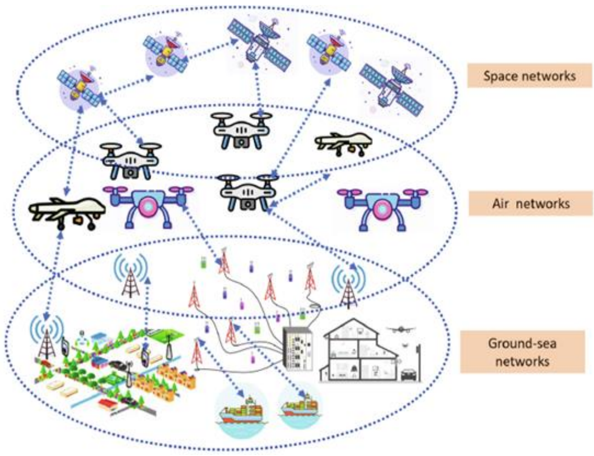

Figure 1. The integrated ground-sea-air-space 6G expected network [14]

Due to the excessive growth in demand for modern applications, as well as the excessive increase in the introduction of devices and equipment required to support them, matters in the present and future have become outside the current technological capabilities of the 5G, so upgrading mobile cellular systems has become an urgent issue, leading to the creation of the 6G mobile system project. The adoption of OMA technology in 6G has become a bottleneck because the limited number of orthogonal resources in this technology will limit the system capacity represented by the number of subscribers required to be accommodated by the mobile system [15]. Furthermore, due to the conventional usage of the OMA scheme, satellite networks provide service in an inefficient way in terms of time, frequency, and code resources, which are solely allocated to one user leading to a limitation on the number of users to be served and further restricting the ability of satellite networks to be integrated with the terrestrial one, where low latency and efficient resource utilization are required [16-18]. To address these challenges in the future of NTN, a new technique for multiple access has recently emerged based on the concept of non-orthogonal multiple access (NOMA), which can achieve better spectrum utilization and connection density than conventional OMA under limited resources [19-23]. NOMA allows allocating one frequency channel to multiple users at the same time within the same cell, which leads to a dramatic improvement in spectral efficiency [11]. Spectrum efficiency and massive connectivity, which are the fundamental challenges of post-5G (B5G), can be met by the introduction of NOMA technology [24]. The key ideas in NOMA are to use the power domain at the transmitter to superpose multiple signals and the successive interference cancellation (SIC) technique at the receiver for signal detection. NOMA has been identified as a potential candidate technology to provide low latency, high reliability, massive connectivity, improved fairness, and high throughput for the B5G and the future 6G technology to support the NTN system [18], [25-27]. The connection density of the 6G networks will approach 10^8 devices per square kilometer, which is 100 times larger than that in 5G. Therefore, 6G researchers are currently focusing on the development of NTN based on the NOMA multiple access technique to promote ubiquitous and high-capacity global connectivity. The actual 6G program was based on a heterogeneous multi-layer NTN in which the traditional mobile cellular terrestrial network will be complemented by UAVs, HAPs, and satellites [28-30]. All networks' nodes are interconnected by inter-satellite links, satellite-gateway links, and user-gateway links simultaneously. The satellite communication network layer consists of many heterogeneous space nodes represented by different satellites at different altitudes.

Satellites are categorized into three groups based on their altitude: geostationary equatorial orbit (GEO), medium earth orbit (MEO), and low earth orbit (LEO) satellites, as shown in Figure 2 [20], [25], [26], [31]. For worldwide coverage, OneWeb, Starlink, and Telesat are some examples of satellite constellation projects that are currently in the works [3], [32].

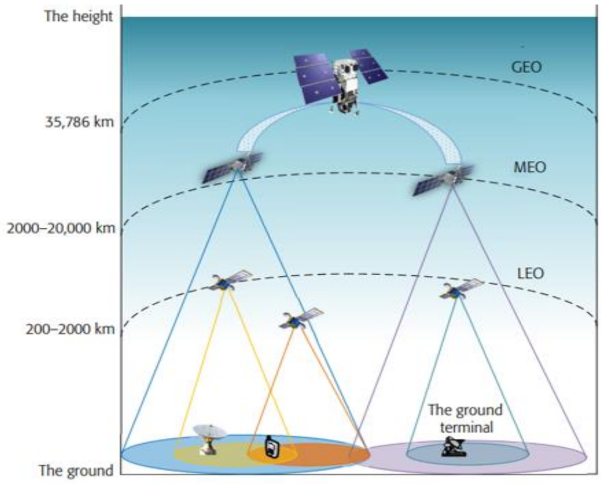

Figure 2. Different satellite constellations [30]

In fact, more research effort was needed to integrate the satellite network to support the NTN concept since the frequency gaps currently adopted in satellite channels differ from those adopted in the terrestrial network, besides the high Doppler shift and high latency inherent in satellite communications. The upgrading stage should be focused mainly on the introduction of the NOMA technique and a new frequency gap in the satellite technology to reduce the system latency to a level comparable to that of the future 6G terrestrial network technology.

In this paper, an evaluation of the NTN-NOMA combination has been achieved with the main purpose of showing that the 6G cellular system will become a reality. This paper is organized as follows: Section II discusses the main NTN system architecture and parameters, including the space layer, air layer, and terrestrial layer. The space layer is represented by different altitude satellites, the aerial layer is represented by the UAV and HAPS platforms, and the terrestrial layer is represented by the actual cellular mobile system. Section III discusses the main futures of the 6G system and describes the ways of exploiting the NTN technology in future 6G infrastructures with the goal of extending accessibility to everyone and everything in isolated and rural regions. Section IV achieved a comprehensive comparison between different types of multiple access techniques used in the G1 to G5 cellular systems, known under the prevision "OMA," and the proposed one for the future 6G system, known under the prevision "NOMA." A detailed analysis in terms of channel capacity for NOMA multiplexing technology was also included in this section. Section V states the main published papers related to the NOMA-based NTN; beside that, the NOMA system has been analyzed in terms of channel capacity by introducing the satellite layer.

2. NTN system architecture

NTN are expected to be a key component of 6G networks as a means to provide cost-effective and high-capacity connectivity via NTN facilities. In the near future, there will be an effective role for the NTN system in terms of providing coverage in remote areas, aircraft, and ships that cannot be actually covered by the traditional terrestrial networks due to the need of expensive investments without ensuring economic feasibility and the desired Quality of Service (QoS) [33-38]. As seen in Figure 3, the NTN consists of three core layers: ground, air, and space, where the whole layers can function independently or inter-operationally by integrating heterogeneous networks across the three layers so as to form a hierarchical broadband wireless network [34]. NTN sub-systems may be integrated at the network (NET) layer or physical (PHY) layer. Integration at the NET layer may allow for different radio access to match the 3GPP standard already applied to the actual terrestrial network. While the integration of the PHY layer signifies that the component of the NTN is required to use the same radio access technology and work at the same frequency gaps as the terrestrial one to ensure global seamless coverage of the user terminals [4], [39], [40].

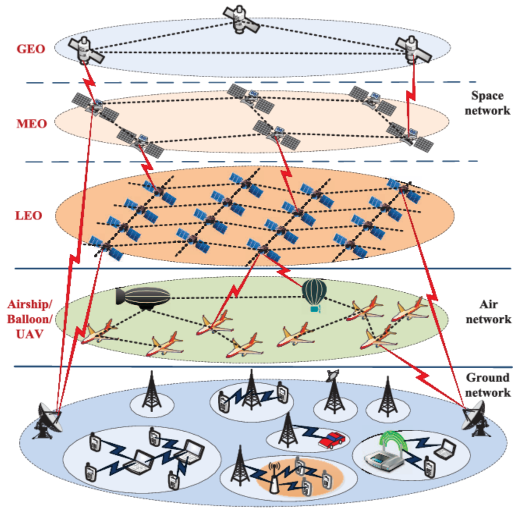

Figure. 3. NTN System Architecture [41]

The higher frequency gap (6 GHz–40 GHz) has already been implemented in the actual terrestrial system, where 4G operates at 6 GHz, 5G at 28 GHz, and the sub-terahertz frequency (40 GHz) is one of the proposed frequencies for the beyond 5G system. The above terrestrial frequency gap overlaps with that of the satellite system working in the C band (4 GHz–8 GHz) and Ka band (26 GHz–40 GHz). Based on the above frequency sharing between the two systems, NTN will start seeing the light at the end of the tunnel and will be introduced into service in the near future. Based on the network switching between the satellite network and the terrestrial network, the ground station and satellite station can communicate with each other. By measuring the transmission cost, the dual-mode satellite station can choose either of the two schemes to communicate, as depicted in Figure 4.

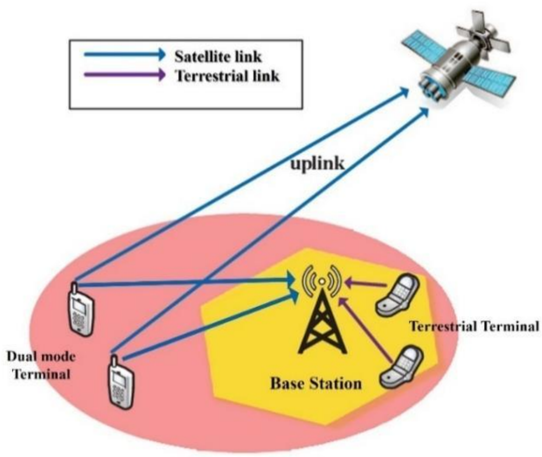

Figure. 4. Terrestrial satellite link [42]

Furthermore, the perfect integration of satellite networks and terrestrial networks remains challenging because of the distinct characteristics of each network. A new spectrum gap in the terahertz band should be assigned for satellite, and at the same time, satellite technology needs to be upgraded to work in the terahertz band. Additionally, the longer propagation delay of satellite networks compared to terrestrial networks caused by the high orbit of satellites, as well as the significant channel fading caused by atmospheric effects on satellite links, will lead to communication outages in the NTN. The above NTN challenges were beyond the scope of this paper, and they will be considered future work. We illustrate here below the main parts of the NTN:

2.1 Space Network

Different characteristics and different orbits of satellites constitute mainly the space network. Satellites in the form of constellations at different altitudes are connected to the mobile terrestrial network via their corresponding terrestrial infrastructures (e.g., ground stations, control centers, and gateways). GEO satellites are the most commonly used category to achieve ground coverage, and due to their wide coverage, only three GEO satellites could achieve global coverage. Numerous satellites are used to construct the LEO and MEO constellations to create a high data rate and to provide users with on-demand service coverage. One of the fastest-growing constellations now is the StarLink system. Starlink is an LEO satellite network offered by SpaceX [2]. The satellite gateway is a vital piece of equipment for 6G-NTN since part of the service demand data from the satellite to the terminal user must pass through the satellite gateway [3], [4], [5], [6]. Satellite constellations configured by using non-GSO satellites, like LEO and MEO, are considered to be the best solution for the 6G system enhancement since they have higher data rates and low latency compared with GSO satellite constellations. On the other hand, due to the dynamic behavior of the non-GSO satellite, a higher handover rate is needed compared with that of the GSO satellite. The different categories of handover are shown in Figure 5 and illustrated here below:

- Intra-satellite handover occurs between satellite beams. In the case of non GSO satellites, frequent intra-satellite handovers are related to high speeds of the beam footprint on the ground.
- Inter-satellite handover occurs between satellites belong to the same constellation and is essentially related to the limited geographical coverage of non GSO satellites.
- Inter-access network handover, also known as vertical handover, occurs either between satellites belonging to different access networks or from the non GSO satellite to the 6G terrestrial network (or vice versa) in integrated terrestrial-NTN systems.

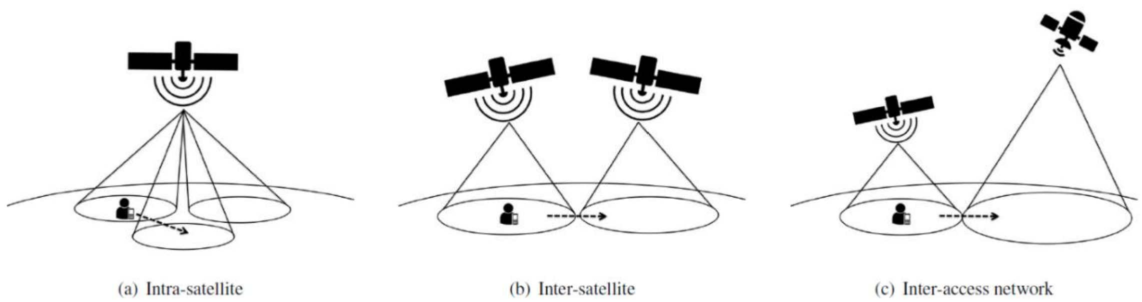

Figure 5. Types of Handovers in NTN [33]

We illustrate below the main specifications of the different satellite systems:

- GEO satellite: At an altitude of 36,000 km with a beam footprint size ranging from 200 to 3500 km, the GEO satellite has a circular and equatorial orbit around the earth, and the orbital period is equal to the earth rotation period, so it is in a fixed position relative to any point on the earth. Due to their high altitude, GEO satellites can provide very wide coverage on earth. In the face of this, GEO satellites are subject to high link attenuation and large propagation delays due to their high altitude. GEO satellites do not require frequent handovers due to their high altitude and their fixed position with respect to the earth.

- MEO satellite: At an altitude between 7000 and 25000 km, the MEO satellite maintains a circular orbit around the Earth. MEO satellites offer unique benefits compared to both LEO and GEO satellites. The coverage of the MEO satellite is larger than that of LEO satellites, while the propagation delay and signal attenuation are smaller than those of GEO satellites. MEO beam footprint size ranges from 100 to 1000 km. MEO is also known as a dynamic satellite for its motion around Earth with a lower period than the Earth's rotation time.
- LEO satellite: At an altitude varying from 300 to 1500 km and a beam footprint size varying from 100 to 1000 km the LEO satellite has a circular orbit around Earth. Due to their relative motion with respect to the earth, LEO is also known as a dynamic satellite. The main benefits of the LEO satellite are its low propagation delay and low path loss compared with the MEO and GEO satellites. However, their structures become more complex as more LEO satellites are needed to cover a large area. Figure 6 shows the path loss for the LEO satellite as a function of elevation angle compared with the GEO satellite for different altitudes and frequencies by considering atmospheric losses and assuming line-of-sight (LOS) conditions [7].

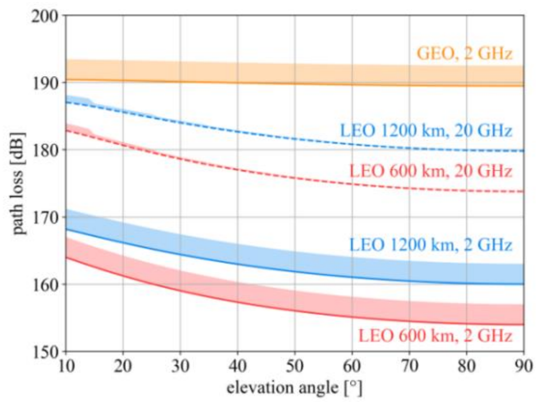

Figure 6. Path loss as a function of elevation angle [44]

- Very low earth orbit (VLEO) satellite: The VLEO satellite was proposed as a future project for enabling the path to the B5G and 6G. The rotation of the VLEO satellite at an altitude of 300 km, which is below that of the LEO satellite, gives this satellite more benefits in terms of latency, link budget, manufacturing cost, and launch cost compared with the LEO and MEO satellites [6], [8]. For NTN integration, VLEO and LEO systems, such as Oneweb, Starlink, and TeleSat have been proposed. Based on these types of satellites, it is expected that the access capabilities will increase, the satellite connections time will decrease, and the fabrication and launching costs will become much lower [8].

2.2 Air network

The main goal of the air network is to create an aerial cellular system to provide a broadband wireless network complementing the existing terrestrial networks by adopting drones and aircraft as carriers for information, acquisition, transmission, and processing. Compared with terrestrial base stations (BSs), air networks have the features of large coverage, low cost, and easy deployment. The airborne category encompasses UAV platforms, drone-based platforms, and high-altitude platform systems (HAPS), which include airships and balloons. Air networks are typically situated at an altitude between 8 and 20 km, as depicted in Figure 7.

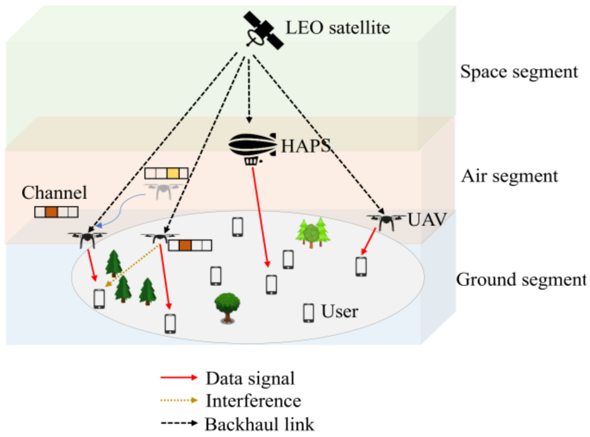

Figure 7. UAV and HAPS system model [9]

- UAV: UAVs, also known as drones, aerial vehicles, flying cars, etc., are able to provide airborne wireless coverage flexibly, serving as aerial base stations for ground users, as relays to connect isolated nodes, or as mobile users in cellular networks. Drones are expected to become the ruling technology in NTNs and play a significant role in B5G/6G and Internet of Things (IoT) applications in the future. UAVs are the lowest-altitude platforms in the NTN, flying around a few hundred kilometers and having many advantages in terms of cost, quick deployment, low latency, and flexibility in flight maneuvers compared to other NTN components [10]. UAV is an intermediate base station between the HAPS stage and the terrestrial layer, as shown in Figure 8. Similar to the GEO satellite, the UAV position can be kept fixed in the sky with respect to a given point on the ground. The UAV beam footprint size ranges from 5 to 200 km [4], [11].

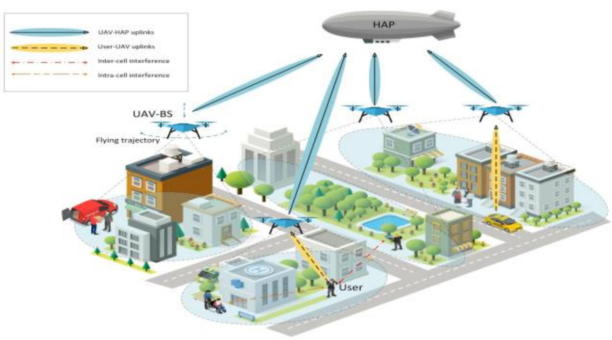

Figure 8. User-UAV and UAV-HAP links [46]

HAPS: The HAPS are aerial base station platforms holding a wireless communication payload powered by solar energy that stay afloat in the stratosphere for several months at an altitude of 20 km and at a speed of around 120 km/hr. HAPS becomes one of the most promising technologies to work as an air mobile system to extend terrestrial mobile services for covering the isolated regain with a higher throughput and lower latency compared to satellite links. A HAPS scenario with a "station-keeping flight pattern" of 6 km in diameter is depicted in Figure 9. However, HAPs may suffer from the need for refueling and challenges related to stabilization in the air. The aircraft must consume significant energy to remain airborne, whilst also providing sufficient residual energy to power its payload. Therefore, payload power consumption, mass, and the available energy supply are all critical factors in the system design [10], [11], [13]. Table 1 shows a comparison between the different space and air networks. Table 1 shows a comparison between the different space networks and air networks.

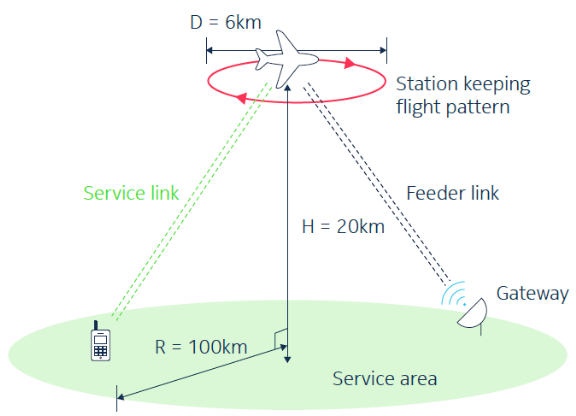

Figure. 9 Typical operating scenarios of airplane-based HAPS [47]

Table 1: Comparison of different space and air networks

Network	Altitude (km)	Orbit position	Footprint radius (km)	Handover
GEO satellite	35786	Fixed with respect a given point on earth	200 - 3500	Non
MEO satellite	7000 - 25000	Non fixed with respect a given point on earth	100 - 1000	-Intra-satellite -Inter-satellite -Inter-access
LEO satellite	300 - 1500	Non fixed with respect a given point on earth	100 - 1000	-Intra-satellite -Inter-satellite -Inter-access
VLEO satellite	< 300	Non fixed with respect a given point on earth	ND	-Intra-satellite -Inter-satellite -Inter-access
UAV & HAPS	8 - 20	Fixed with respect a given point on earth	5 - 200	Non

2.3 Ground Network

The ground network mainly consists of terrestrial cellular mobile networks, wireless local area networks (WLANs), and worldwide interoperability for microwave access (WiMAX) [14], [15]. As the 5G network is fully popularized and commercialized, researchers are focusing on developing better communication technologies for the purpose of building cross-region, cross-air-space, and cross-sea integrated network systems to achieve a truly seamless global coverage network, and this goal will be realized by the introduction of the future 6G technology [16]. Based on the NOMA multiplexing technique. It is expected that 6G cellular mobile system will play the role of integrating terrestrial, aerial, maritime, and space communications into a universal network that could support a massive number of terminals with ultra-low latency [17-19].

Table 2 gives some comparisons between the different subsystems in the NTN. Global coverage on Earth can be achieved through satellite networks, but these links suffer from high latency. Although the lowest latency can be achieved through terrestrial networks, these links are vulnerable to natural disasters. Aerial networks have advantages in terms of low latency and wide coverage, but their limited capacity and unstable links must be carefully considered when deploying such networks [6], [20].

Table 2: Different networks comparison [6]

Network	Type	Latency(ms)	Capacity (Gbps)
Satellite	Starlink	20	0.15
Satellite	Oneweb	70	7
Satellite	Konnect VHTS	700	500
Terrestrial	4G	30	1
Terrestrial	5G	10	20
Terrestrial	6G	0.1	1000

Table 3: 5G Verses 6G Comparison

Parameter	5G	6G
Peak data rate (Gbps)	20	1000
Latency (ms)	1	0.1
Maximum frequency (GHz)	90	10000
Spectral efficiency (bps/Hz)	30	100
Mobility (Km/h)	500	1000
Traffic capacity (Tbps/Km^2)	10	100
Localization precision (cm)	10 on 2D	1 on 3D
Autonomous vehicle	Partial	Fully
Artificial intelligent (AI) integration	Partial	Fully

Satellite integration	Non	Fully
Energy efficiency (Tb/J)	NA	1
Connection device (device/Km^2)	10^6	10^7
Channel bandwidth (GHz)	1	100
Core	Internet of things (IoT)	Internet of every things (IoE)
Real time	No	Yes
Architecture	Massive MIMO	Intelligent surface

3. Emigration From 5G to 6G

Compared with 4G, 5G has greatly improved latency, bit rate, traffic capacity, energy efficiency, and spectrum efficiency [12]. However, the 5G technologies will face many challenges in the near future for meeting the different societal needs in terms of: (1) on-demand service coverage; (2) ubiquitous coverage; (3) high capacity and energy-efficient coverage; (4) and no time-hole coverage, which has prompted researchers and specialized industrial companies to work on the development of a new generation of mobile systems, represented by the 6G system [49], [52]. The 6G system is under design to work in the THZ gap for the purpose of realizing ultra-system performance based on artificial intelligence (AI) technology. Compared to a 5G system operating in the mmWave band, the cellular structure of a 6G system operating in the THz band will become more crowded due to the reduction in the cell radius (about 100 m) due to the severe attenuation of path loss experienced by the THz band, since the wavelength in this case will be comparable to the size of dust particles, snow particles, and rain drops scattered in the atmosphere, which cause high attenuation at the THZ band and this situation is one of the main challenges on the road map for the 6G. This kind of challenge can be solved by applying an efficient backhaul technique using ultra-high-speed free space optics (FSO) links [53], [54], [55]. A comparison between 5G and 6G was illustrated in Table 3 [49].

Satellite constellation links, inter-satellite communications, UAVs, and HAP will get more benefits when working in the THz range. In a space environment, the attenuation in the THz band will become less severe since path loss due to molecular absorption is non-significant [49], [56]. To exploit the promising 6G technology, cooperation between different NTN layers, including the terrestrial layer, UAV layer, HAP layer, and different satellite layers, becomes imperative to improve network performance [37]. Terrestrial service continuity in rush hours can be assured by the adoption of the NTN concept. Services can also be extended in this case to those regions where the installation of terrestrial infrastructure is too expensive or even impossible (e.g., above oceans or deserts). As depicted in Figure 10, the air layer and the satellite network can extend connectivity to everyone and everything in isolated and rural regions. Users outside of the service of terrestrial networks can connect to either the air layer or the satellite network via their own terminals, which may be capacity-limited based on the type of users and terminals [9], [57]. NTN based on 6G technology becomes a super heterogeneous network, where the terrestrial network needs to have access to a huge and complex external network; therefore, AI systems become an urgent solution to create an intelligent heterogeneous communication system with reduced response time and reduced operating costs [38], [49], [58], [59], [60].

In the previous period, the development of the satellite networks had taken place in isolation from the development of the terrestrial networks. With the entry of the 5G into the design phase, the 3GPP standardization adopted the topic of introducing the NTN network to support the 5G terrestrial network. One of the promising space projects for supporting 5G is known under the name SAT5G, and its goal is to extend the coverage of 5G everywhere so as to create a new opportunity for 5G in the international markets [61], [62]. Incorporating the capabilities of both NTN and terrestrial networks, the new system shows promise for the 6G network, providing ubiquitous communication support for IoET systems and enabling global coverage [2], [33], [41], [63], [64], [65].

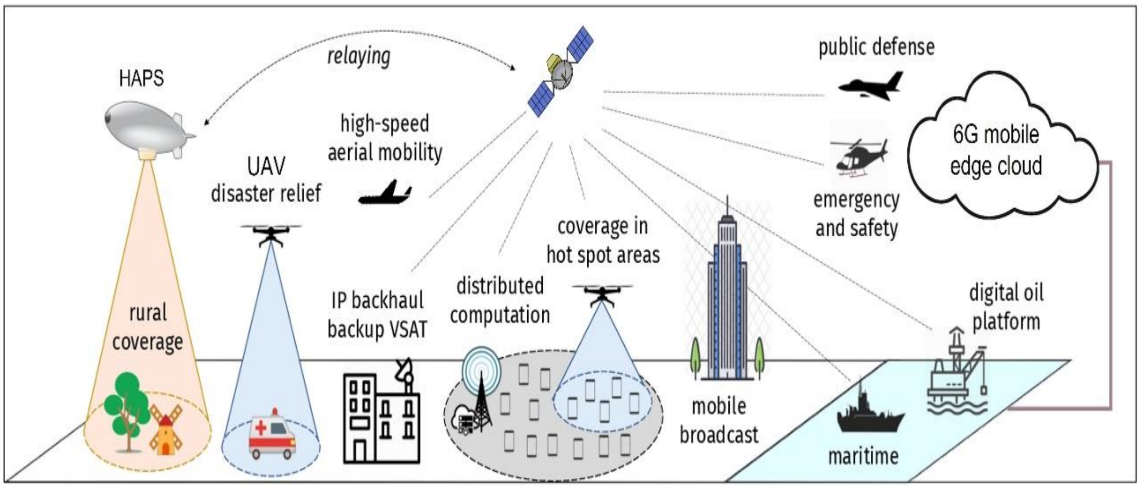

Figure 10. Some applications enabled by non-terrestrial networks [56]

4. Multi-Access techniques

The design steps of multiple access schemes by telecommunication specialists involve careful consideration, as these schemes provide the means for multiple users to access and share system resources in an orthogonal, efficient, and simultaneous manner. Examples of such schemes include frequency division multiple access (FDMA), time division multiple access (TDMA), code division multiple access (CDMA), and orthogonal frequency division multiple access (OFDMA). The orthogonality principle employed in these schemes prevents co-channel interference between different users utilizing the same resources. From a design perspective, these multiple access schemes fall under the category of orthogonal multiple access (OMA), where wireless resources are orthogonally allocated to multiple users in the time, frequency, code, and subcarrier domains [51], [52]. With the rapid growth of mobile data traffic and the subsequent adoption of 5G technology, a new type of orthogonal multiple access (OMA) scheme, known as Filter-Bank orthogonal frequency division multiple access (FB-OFDMA), emerged. This scheme tries to improve the spectral efficiency of traditional OFDMA by utilizing a filter bank structure to improve resource allocation and reduce interference [12], [13], [66]. FB-OFDMA has high out-of-band rejections; each sub-band of FB-OFDM benefits from a filtering stage; therefore, the spectrum leakage in adjacent bands is very low, which leads to increasing the system spectrum efficiency. However, from an information theoretic perspective, it is well known that the use of orthogonal multiple access (OMA) approaches is not optimal in terms of spectral efficiency [18]. However, the OMA technique already has a limited orthogonal resource, which poses a big problem for OMA to satisfy the 6G system requirement, which has to work in the terahertz band with a huge data rate compared with the actual 5G system [17], [49]. The OMA technique experienced a further challenge related to channel-induced impairments, particularly multipath phenomena, which compromised the orthogonality principle. After the introduction of 5G mobile system services in 2020, the increasing demands for new services and applications, compounded by the significant growth in connected devices, resulted in an exponential surge in data traffic and the emergence of various application classes and categorizations. As a result, employing OMA-based resource allocation encountered technological limitations. NOMA emerged as a promising candidate technology capable of providing extensive connectivity during the upcoming 5G upgrading phase, catering to the

NTN configuration. Additionally, for the anticipated deployment of the 6G mobile system in 2030, the NOMA technique has already been approved [67]. Table 4. illustrates the different multiple access techniques applied in different mobile generations.

Table 4: Multiple Access Techniques for different mobile generation

Mobile generation	Standard	Multi-Access Techniques	Peak Data Rate	Year
1G	AMPS	FDM	2 kbps	1980
2G	GSM	TDM	64 kbps	1990
3G	UMTS	CDM	2 Mbps	2000
4G	LTE	OFDM	1 Gbps	2010
5G	BB	FB-OFDM	20 Gbps	2020
6G	Not defined	NOMA	1000 Gbps	2030

4.1 The Potential of FB-OFDM Over OFDM

Multicarrier communication (MC) systems like OFDM and FB-OFDM simultaneously send signals across several subcarriers. In each subcarrier, the information bits are encoded and transmitted as a series of pulses of different amplitudes and phases. OFDM technology is used in 4G mobile communication systems and listed in the technical specifications, such as LTE-A in 3GPP [68]. OFDM uses a cyclic prefix (CP) at the header of each symbol in each sub-carrier to reduce the multipath effects by avoiding intersymbol interference (ISI). For OFDM systems, the main source of jittering comes from the ISI and intercarrier interference (ICI), which represent the main sources of problems that limit the applicability of OFDM in the present and future development of broadband communication systems. FB- OFDM is based on using a bank of filters instead of the CP. This filter is known under the name “PHYsical layer for DYnamic spectrum AccesS and cognitive radio” (PHYDYAS), which will act to reduce the above jittering by separating signals on different subcarriers from one another. When compared with OFDM, FB-OFDM requires a lower system bandwidth for the same data rate [11], [69]. FB-OFDM was already adopted in the first release of the 5G cellular system, promising a very low out-of-band energy of each subcarrier signal when compared to OFDM, leading to a significant improvement in the system spectral efficiency and relaxing synchronization condition [70], [71], [72]. Based on the power spectral density plot, Figure 11 depicts that the OFDM has higher side lobes and out-of-band leakage, while the FB-OFDM has lesser side lobes. So, adopting FB-OFDM leads to the best investment of the allotted spectrum, leading to an advanced spectral efficiency system [68], [73], [74].

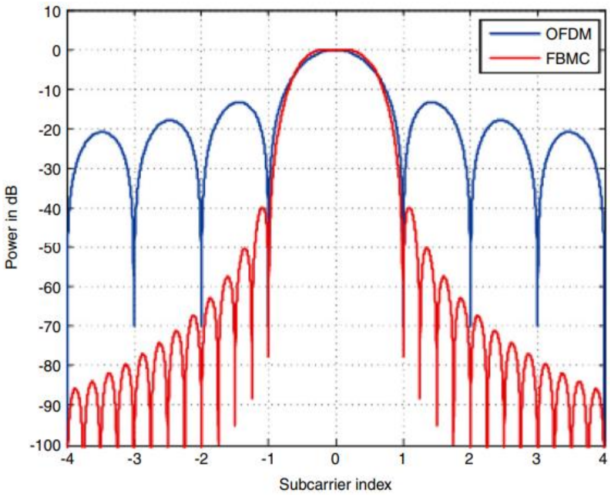

Figure 11. Subchannel frequency responses for OFDM and FB-OFDM [75]

OFDM only works well in the network downlink of a base station, where all of the subcarriers are transmitted from the same point (the base station) and hence can be easily synchronized and undergo the same Doppler frequency shift before reaching each receiver. In the uplink of an OFDM network, an almost perfect carrier synchronization of signals from different transmitting nodes is necessary. In practice, particularly in mobile networks, this is a very hard task to achieve where a number of nodes are transmitting separately. Since, in practice, perfect synchronization in the uplink of an OFDM network may not be possible, additional signal-processing steps have to be taken to minimize interference among signals from different nodes. Such steps add significant complexity to an OFDM receiver [69], [76]. FB-OFDM systems achieve signal separation through filtering, thus avoiding the need for (close to) perfect carrier synchronization. FB-OFDM is an ideal choice for multiple access for broadband data transmission. A comparison between OFDM and FB-OFDM was illustrated in Table 5 [74], [77], [78].

4.2 Non-Orthogonal Multiple Access (NOMA)

Due to the limitation of orthogonal resources, the OMA systems are unable to support the high user density required by the 5G upgrading phase. Thus, the innovative concept of NOMA has been proposed in order to support more users than the conventional OMA technique. Interference cancellation techniques like successive interference cancellation (SIC) are used in the NOMA case to mitigate the impact of the interference [79]. The SIC technique is used to decode the desired signal. In the SIC scheme, the strongest signals are subtracted from the combined signal one after another by the SIC receiver; finally, the SIC receiver extracts the desired signal. It is a gradual interference elimination strategy. As compared to OMA schemes, in NOMA, SIC needs additional implementation complexity because the SIC receiver has to detect and cancel other users' signals prior to detecting its own signal. Furthermore, as the number of users in the cell increases, the receiving complexity also increases. Therefore, a high-performance nonlinear detection algorithm is required at each stage of SIC for error-free propagation [34]. Every user in NOMA operates simultaneously in the same band, distinguished only by their power levels [20]. In the NOMA technique, different users share the same resources in time, frequency, and code. Based on the user's channel gains, each user has a certain power level. Lower power is often allocated for users with higher channel gain. At the receiver, the SIC unit has the role of separating the different users based on the users' power-difference [79]. In OMA, each user is assigned to a subset of subcarriers, whereas in NOMA, each user can use all of the subcarriers. Figure 12 illustrates the spectrum sharing for OFDMA and NOMA for two users. The NOMA concept applies to both uplink and downlink transmissions [80].

Table 5: Comparison between OFDM and FB-OFDM

Property	**OFDM**	**FB-OFDM**
Cyclic Prefix (CP)	Required	Not required
Sensitivity to Time offset between sub-carriers	Highly sensitive	Much less sensitive
Sensitivity to frequency shifting between sub-carriers	Highly sensitive	Less sensitive
Doppler Effect robustness	Non robust	Robust
Inter-symbol interference (ISI) suppression	Efficient	Very efficient
Inter-carrier interference (ICI)	Significant	Non-significant
Sensitivity to synchronization errors	more sensitive	Less sensitive
Hardware complexity	Low	High
Out-of-band leakage Frequency resolution	High	low
Spectrum efficiency	Efficient	Very efficient
Quality of service guard-band	exist	Non
Sensitive to the frequency offset between sub-carriers	very sensitive	Less sensitive
Channel estimation for MIMO applications	Moderate	Complex
Channel capacity	High	Very high

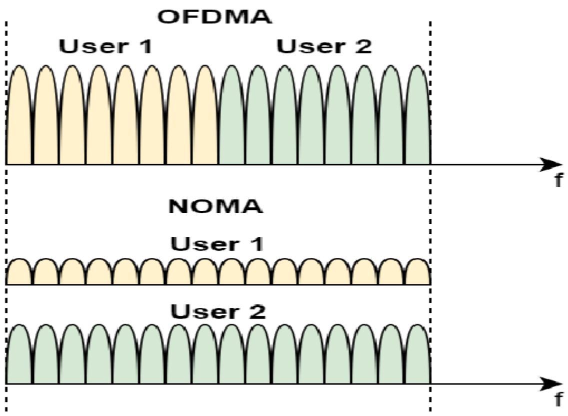

Figure 12. Spectrum sharing for OFDMA and NOMA for two users [80]

NOMA is basically divided into two types: power-domain NOMA and code-domain NOMA [14], [22], [51], [66], [74], [81], [82], [83], [84], [85]. In power-domain NOMA, different users are assigned different power levels according to their channel quality, while the same time-frequency-code resources are shared among multiple users. Code-domain NOMA is similar to multi-carrier CDMA (MC-CDMA). NOMA is distinguished from OMA in the following points [18], [86]:

- More superior in spectral efficiency.
- Interference mitigation through the SIC unit.
- Achieving massive connectivity
- Achieving lower latency transmission
- User-fairness achievement occurs through power control between the strong and weak users.
- Enhances the cell-edge user experience by allocating more power to the weaker user.
- The fees for the tera package will be higher than the fees for the mm-wave package, so the use of NOMA will compensate for an important part of this cost because it has higher spectral efficiency compared with the OFDM type.

A comparison between NOMA and OMA was given in Table 6 [17], [18], [22], [51], [63], [64], [79], [86].

Table 6: Comparison between OMA and NOMA

Specifications	OMA	NOMA
Energy efficiency	Low	High
Receiver complexity	Low	High
System throughput (assumption: user fairness is guaranteed)	Low	High
Assisted Radio Frequency and Visible Light Communications (VLC) Based Energy Harvesting	Moderate	Efficient
Accurate uplink channel state information (CSI) at the BS.	Forsley required	Not required
Cooperative multiple access	Moderate	Efficient
Improving the secrecy rates of the legitimate users	Less	More
Spectral efficiency	Low	High
User fairness	Unfairness for users	Enhanced user fairness
Massive connectivity	Low	High
latency	High	Low
Receiver infrastructure	Simple	Complex
Downlink capacity bound (bps)	Lower	Higher
Reliability	High	Ultrahigh
Exploitation of channel gain difference among users	Non	Yes

4.2.1 Successive Interference Cancellation (SIC)

In contrast to conventional OMA, where every user is served on exclusively allocated radio resources, NOMA superposes the message signals of multiple users in the power domain by exploiting their respective channel gain differences. More power is allocated to the UE located farther from the base station (BS), and the least power is given to the UE closest to the BS. NOMA exploits superposition coding at the transmitter and SIC at the receiver. Figure 13 illustrates the SIC principle, where the three information signals indicated with different colors are superimposed at the transmitter. The received signal at the SIC receiver includes all three signals. The first signal that SIC decodes is the strongest, while others are interference. The first decoded signal is then subtracted from the received signal, and if the decoding is perfect, the waveform with the rest of the signals is accurately obtained. SIC iterates the process until it finds the desired signal. The success of SIC depends on the perfect cancellation of the signals in the iteration steps. The transmitter should accurately split the power between the user information waveforms and superimpose them. The methodology for power splitting differs for uplink and downlink channels [80].

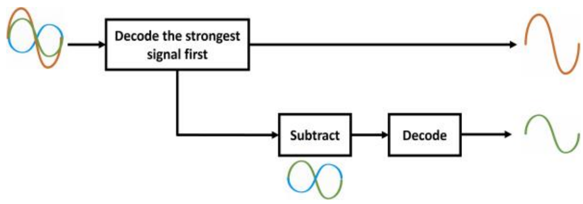

Figure 13. Successive interference cancellation

An example of 2 user NOMA in the downlink direction is shown in Figure 14, where a superposed signals of two users was sent by the base station, where User 1 has a higher channel gain than User 2. We usually refer to User 1 as the stronger user and to User 2 as the weaker user. Using the SIC technique, the User 1 detection branch subtracts the signal of User 2 and then decodes its own signal; the detection branch of User 2 considers the signal of User 1 as interference and detects its own signal directly [82], [84].

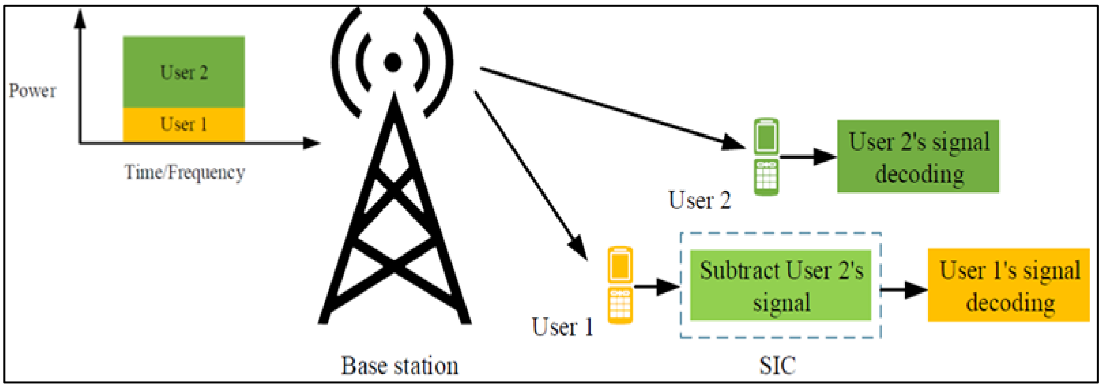

Figure 14. Downlink NOMA in a single cell with one BS and two users

4.2.2 K- users downlink NOMA

A K user's signals were transmitted simultaneously by the BS by multiplexing their signals using superposition coding. The entire system bandwidth was allocated for each user to send its data, while the power resource was shared between different users. We assume that the Channel State Information (CSI) of different users is available at the base station. Based on the CSI data, the ith channel gain h_i and the ith power allocation factor α_i for the ith users Ui can be established. In other words, the BS allocates the ith lowest power Pi to the nearest ith user Ui and ith stronger power P_i to the far ith user, where $P_i = P_t \times \alpha i$ with Pt is the total available power at the BS, αi is the power allocation factor of Ui. Note that $\sum_{i=1} \alpha i = 1$. The weakest user U1 benefits from the highest power allocation, while the least power is given to the strongest user Uk. On the receiving end, each user receives the signal transmitted by the BS, which includes its own signal and the signals of other users. All these signals are multiplexed with different power ratios. The integrated SIC algorithm at the users' terminals level allows the strongest users to eliminate the weak users signals successively. Thus, each user Ui, $i = 1, 2, 3, \dots, K$, K decodes all the signals of users Uk with $k < i$. Unlike the strong users, the weak users consider stronger users signals as interferences with a power denoted by $\sigma_i{}^2$ as depicted in Figure 15 [87].

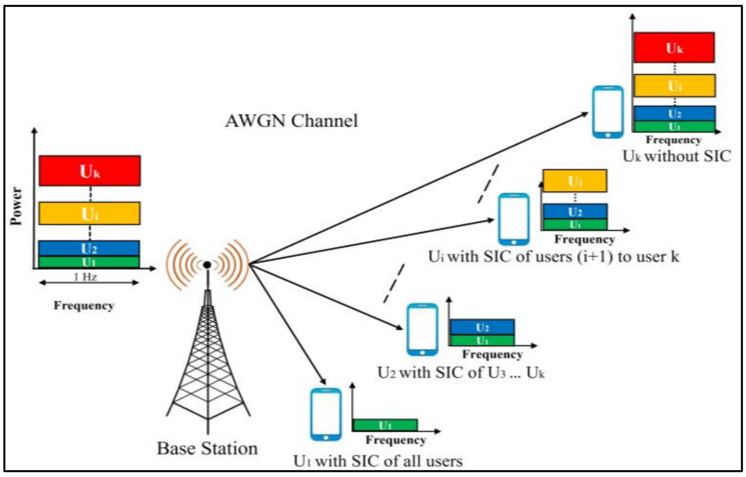

Figure 15. NOMA downlink scenario scheme with K users

According the above scenario we have [87]:

$$\frac{|h_1|^2}{\sigma_1^2} > \frac{|h_2|^2}{\sigma_2^2} > \frac{|h_3|^2}{\sigma_3^2} > \cdots \frac{|h_i|^2}{\sigma_i^2} > \cdots \frac{|h_K|^2}{\sigma_K^2} \quad (1)$$

Hence

$P_1 < P_2 < P_3 \ldots < P_i \ldots < P_k$

The achievable rate of U_1 is given by

$$R_1 = \log_2\left(1 + \frac{P_1|h_1|^2}{\sigma_1^2}\right) \quad (2)$$

The rate of U_i, R_i is represented as

$$R_i = \log_2\left(1 + \frac{P_i|h_i|^2}{|h_i|^2 \sum_{m=1}^{i-1} P_m + \sigma_i^2}\right) \quad (3)$$

Although theoretically there is no limitation on the number of NOMA users, from a practical viewpoint, NOMA in downlink is applied to a small number of users (typically two or three) in a cluster; for a large number of users, there is a degradation in the bit error rate due to error propagation primarily originating from imperfect SIC. Also, as the number of users in a cluster increase, end-user devices require more computing power and higher energy, which might not be feasible in practice [88].

4.2.3 2-Users downlink NOMA

In the NOMA technique, different users are multiplexed in the power domain at the transmitter site, and an SIC technique was exploited at the receiver for different users' demodulation. As shown in Figure 16, the BS sends the superposed signals to two users, where User 1 has a higher channel gain than User 2. By assuming the availability of CSI for different users at the base station, the entire bandwidth is allocated for each user to send the related data, while the power resource is shared between the two users. With worse channel gain and more interference, the weak user is assigned more power to ensure fairness. User 1 first subtracts the signal of user 2 through SIC and then decodes its own signal; user 2 considers the signal of user 1 as noise and detects its own signal directly [88], [89].

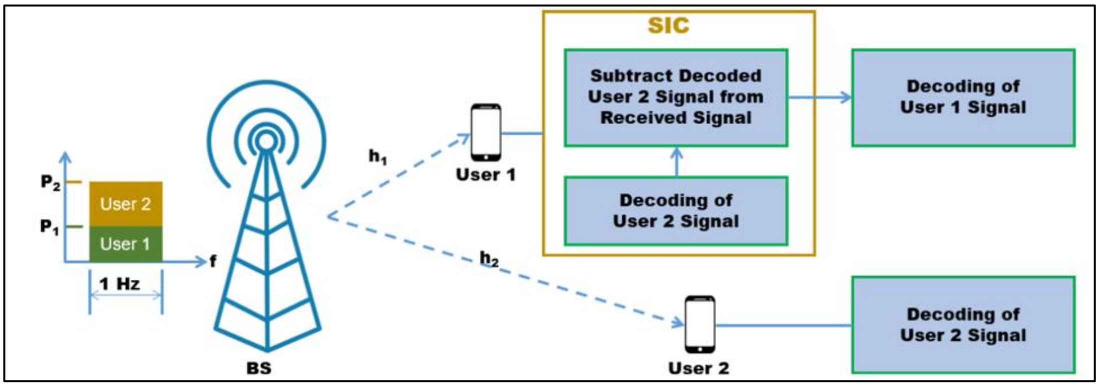

Figure 16. NOMA downlink for tow users in a single cell

The transmitted superposition coded signal S at the BS is given by [88]

$$s = \sqrt{p_1}\, x_1 + \sqrt{p_2}\, x_2 \quad (4)$$

where x_1 and x_2 are the signals belong to user 1 and user 2, respectively.

At the user's terminal, the received signal is given by

$$y_i = h_i s + n_i \quad (5)$$

where h_i is the channel gain between the BS and user i and n_i represents the Gaussian noise plus inter-cell interferences with power spectral density σ_i^2. Using the SIC facility, each user can substantially eliminate interferences from the signals of other users whose decoding orders appear after that user. Therefore, user 1 alternatively called the strong user, can cancel the interference from user 2, referred to as the weak user. Based on CSI information, an updating information on the users' level occurs on the SIC ordering. A higher power is allocated for user having weaker channel strength for a goal to increase its SINR compared to a user with stronger channel strength, hence in this case we have $P_2 > P_1$. So only user 1 performs SIC here. It first decodes x_2, the signal of user 2, and subtracts it from the received signal y_1, after which it decodes its own signal. User 2 treats x_1, the signal of user 1, as interference and thus directly decodes its own signal from y_2 without SIC. Then signal-to-interference-plus-noise ratio (SINR) for the two becomes:

$$\text{SINR}_1 = \frac{p_1|h_1|^2}{\sigma_1^2} \quad (6)$$

$$\text{SINR}_2 = \frac{p_2|h_2|^2}{p_1|h_2|^2 + \sigma_2^2} \quad (7)$$

If the SIC is perfect, the achievable data rate of the NOMA user i, $R_i{}^{\text{NOMA}}$ for a transmission bandwidth B of 1 Hz based on Shannon theorem can be represented as

$$R_1{}^{\text{NOMA}} = \log_2\left(1 + \frac{P_1|h_1|^2}{\sigma_1^2}\right) \quad (8)$$

$$R_2{}^{\text{NOMA}} = \log_2\left(1 + \frac{P_2|h_2|^2}{P_1|h_2|^2 + \sigma_2^2}\right) \quad (9)$$

The total NOMA system capacity R^{NOMA} is given by

$$R^{\text{NOMA}} = R_1{}^{\text{NOMA}} + R_2{}^{\text{NOMA}} \quad (10)$$

For the OMA, with 2 users based on the OFDMA scheme, the 1 Hz transmission BW is divided for the two users so that user 1 uses W Hz while user 2 uses the remaining $(1 - W)$ Hz of the BW and the power allocation ratio ($\alpha 1$: $\alpha 2 = P1$: $P2$) remains the same as for the NOMA scheme. Then, the achievable data rate of the OMA user i, $R_i{}^{\text{OMA}}$ can be represented as [88]

$$R_1{}^{\text{OMA}} = W\log_2\left(1 + \frac{P_1|h_1|^2}{W\sigma_1^2}\right) \quad (11)$$

$$R_2{}^{\text{OMA}} = (1 - W)\log_2\left(1 + \frac{P_2|h_2|^2}{(1-W)\sigma_2^2}\right) \quad (12)$$

The total NOMA system capacity R^{OMA} is given by

$$R^{\mathrm{OMA}} = {R_1}^{\mathrm{OMA}} + {R_2}^{\mathrm{OMA}} \quad (13)$$

With perfect downlink orthogonality, (11) and (12) show that no OMA user suffers from the interference from the signal of the other user, unlike NOMA as indicated by (9). Moreover, (8) and (9) suggest that the BS can control the data rate of each user by tuning the power allocation coefficients α_1 and α_2, such as

$$\alpha_1 = \frac{P_1}{P}, \quad \alpha_2 = \frac{P_2}{P} \quad (14)$$

where $\alpha_1 + \alpha_2 = 1$ for 2 users' case and P is the total transmitted power by the BS.

In term of the total transmitted power (P) by the BS, the transmitted SNR (ρ) is given by (14).

$$\rho = \frac{P}{\sigma^2} \quad (15)$$

By substituting (14) and (15) in (8) and (9), we get

$${R_1}^{NOMA} = log_2(1 + \alpha_1 \rho \, |h_1|^2) \quad (16)$$

$${R_2}^{\mathrm{NOMA}} = \log_2\left(1 + \frac{\alpha_2 \rho \, |h_2|^2}{\alpha_1 \rho |h_2|^2 + 1}\right) \quad (17)$$

Assuming perfect CSI, the total NOMA system rate is expressed as

$$R = {R_1}^{\mathrm{NOMA}} + {R_2}^{\mathrm{NOMA}}$$

$$= \log_2(1 + \alpha_1 \rho \, |h_1|^2) + \log_2\left(1 + \frac{\alpha_2 \rho |h_2|^2}{\alpha_1 \rho |h_2|^2 + 1}\right) \quad (18)$$

Similarly (11) and (12), by considering equal bandwidth allocation for the two users (W = 0.5 Hz) and equal power allocation for each user ($P_1 = P_2 = 0.5P$), can be rewrites as

$${R_1}^{\mathrm{OMA}} = 0.5\log_2(1 + \rho \, |h_1|^2) \quad (19)$$

$${R_2}^{\mathrm{OMA}} = 0.5\log_2(1 + \rho \, |h_2|^2) \quad (20)$$

The total OMA system rate is expressed as

$$R = {R_1}^{\mathrm{OMA}} + {R_2}^{\mathrm{OMA}} = 0.5\log_2(1 + \rho |h_1|^2) + 0.5\log_2(1 + \rho |h_2|^2) \quad (21)$$

As a comparison between OMA and NOMA based on (16), (17), (19), and (20) when $\rho \, |h_1|^2$ and $\rho |h_2|^2$ are set to 20 and 0 dB, respectively, we find that in NOMA case , when the power allocation coefficients are conducted as α_1 = 1/5 and α_2 = 4/5, the user rates will be $R_1 = 4.39$ bps and $R_2 = 0.74$ bps, while for the case of OMA these rate are degrade according to R_1 = 3.33 bps and R_2 = 0.5 bps respectively.

By substituting $\alpha_2 = 1 - \alpha_1$, Eq. (18) can be reduced to, [90].

$$R = \log_2(1 + \rho \, |h_1|^2) \quad (22)$$

As can be seen from (22), the sum rate with the NOMA scheme does not depend on the power allocation coefficient α and the link quality of User 2. In other words, this sum is equal to the rate when the total transmitted power is assigned to User 1.

In Figure 17, we plot the data rate regions of both downlink NOMA and OMA by plotting R_1 with respect to R_2 at different power allocation ratios when $\rho |h_1|^2$ and $\rho |h_2|^2$ are set to 20 and 0 dB, respectively. It is very clear that the rate region of NOMA is much wider compared to OMA. Thus, NOMA is considered a promising multiple-access technique for future 6G cellular systems.

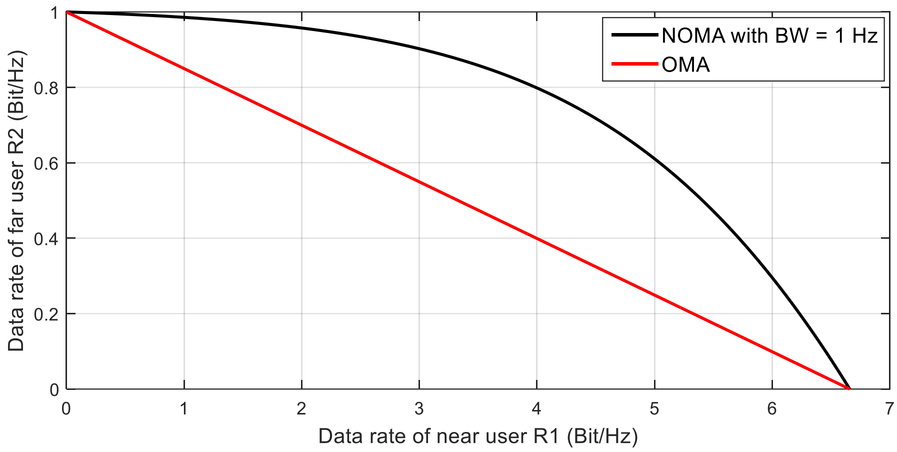

Figure 17. NOMA and OMA data rate region in 2-user downlink situation.

5. NOMA Based NTN

The OMA technique scheme used in actual exiting satellites causes further limitations on the number of users per satellite. In recent years, the NOMA technique has been considered one of the most emerging and promising technologies because of its massive connectivity, high spectral efficiency, and low latency [91]. Presently, the power domain NOMA technique has gained great attention in the scientific research domain and was proposed to be used in the upgraded NTN system at both terrestrial base stations and satellite levels, which gives the possibility of both terrestrial base station and satellite users being served at the same time/frequency block, with the goal of dramatically increasing the system capacity. By means of NOMA, the challenging requirements for the actual deployed 5G system, such as spectral efficiency and massive connectivity, can be partially fulfilled, which will also reflect on the realization of the B5G and 6G systems [90], [92].

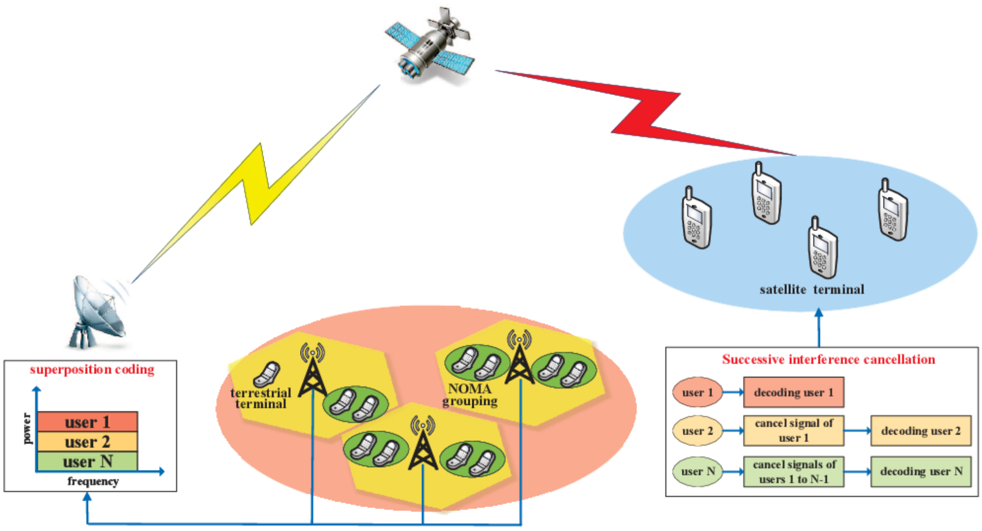

Figure 18. NOMA based satellite-terrestrial model [54]

For the NOMA-based NTN system, as shown in Figure 18, the user's CSI and data are received by the satellite gateway. According to their CSI, the power allocation of different users will be performed by the gateway, and then data will be sent to the satellite terminal after performing superposition coding. The SIC technique will be used at the satellite level for decoding the signals of different users. Stronger user will be decoded first, and weaker user will be decoded from the remaining signals after performing signal subtraction by the SIC unit. At the satellite downlink level, power allocation for each user will be performed by the satellite transmitter by allocating large amounts of power to the weak user to ensure the performance of the terrestrial receiver [2], [7], [42], [67], [90], [93]. The main published journal papers related to NOMA-based NTN is presented in Table 7.

Table 7: Main published papers concerning the NOMA-based NTN system

Ref.	Research objective	Year
[94]	A NOMA-based cooperative NTN was evaluated by adopting the best channel user as a rely for the poor channel user.	2018
[60]	Reviewing the actual NOMA-based satellite network for purposes of becoming the main technological key for 5G realization.	2021
[95]	Performance evaluation of NOMA-based NTN by considering different relay configurations.	2019
[96]	Performance study of the cooperative NTN based on NOMA technique by exploiting the terrestrial BS to act as decoding and a forward relay for the satellite.	2019
[62]	Performance evaluation of a NOMA-based NTN by considering the impact of channel impairments.	2019
[97]	Performance evaluation of a NOMA-based NTN in the millimeter-wave band when the BS acts as a relay for the satellite.	2019
[98]	Using a cooperative multigroup multicast transmission scenario in the NTN downlink channel, where the satellite and the BSs provide the multicast service for ground users in a cooperative manner while reusing the entire bandwidth	2018
[66]	Considering a NOMA-based NTN network in which the satellite and the BSs provide service for ground users cooperatively while reusing the entire bandwidth, Antenna beamforming was adopted at the satellite and terrestrial BSs, while NOMA was applied at the terrestrial level only.	2017
[99]	NTN system development by introducing the cognitive-radio technique in the scenario where the satellite site applied beamforming only while the terrestrial network applied beamforming plus NOMA.	2019
[100]	NOMA and beamforming techniques-based NTN system using cognitive-radio was suggested to serve assigned users.	2019
[69]	Evaluation of the outage probability of NOMA-based NTN by considering the pertinent heterogeneous fading model.	2020
[101]	State the applications of the NOMA scheme for various satellite architectures.	2019
[102]	Evaluating the ergodic capacity of NOMA-based NTN in the downlink scenario.	2017
[103]	Considered an overlay approach in their work. However, they have considered only a single primary user with no direct satellite (DS) communication.	2019
[104]	Evaluating the outage probability of the NOMA-based NTN in the downlink and uplink scenarios and comparing it with the case of using the OMA technique.	2020
[103]	Evaluation of the outage probability of a NOMA-based NTN	2019
[105]	Considering proportional fairness scheduling (PFS) for downlink non-orthogonal multiple access (NOMA) with two users	2016
[106]	Studies the joint beamforming design problem of achieving max-min rate fairness in a satellite-terrestrial integrated network (STIN) where the satellite provides wide coverage to multibeam multicast satellite users (SUs) and the terrestrial base station (BS) serves multiple cellular users (CUs) in a densely populated area.	2021
[57]	The NTN classification, overview, performance evaluation, and main challenges were considered in this paper.	2022
[93]	Performance evaluation of NOMA-based NTN in the downlink scenario by considering LEO satellite.	2022
[60]	A survey on the up-to-date NOMA-based satellite system for 5G upgrading purposes.	2021
[90]	A comprehensive study was conducted on NOMA-based NTN, cognitive NOMA-based NTN, and cooperative NOMA-based NTN.	2019
[107]	Evaluation of the outage probability, hit probability, and diversity order for the NOMA-based NTN.	2022
[4]	Review the NTN wireless system and summarize its main features as per the official 3GPP technical reports, understanding the role of NTN within the 5G New Radio (NR) system.	2020
[92]	Study the performance of the NOMA-based NTN in the presence of hardware impairments (His)	2019
[108]	Derivation of the end-to-end signal-to-interference-plus-noise ratios (SINRs) for each NOMA user. Derivation of the exact and asymptotic outage probability (OP) expressions. Simulation results are provided to show the validity of their theoretical analysis, the superiority of introducing the NOMA-based NTN, and the effects of various parameters on the OP performance of each NOMA user.	2018

[109]	A theoretical study and simulation implementation have been conducted to evaluate the impact of imperfect CSI by considering the pilot-based channel estimation method and the NOMA scenario.	2019
[91]	BER of the NOMA-based NTN had been derived under using power allocation technique.	2022
[93]	The imperfectness of the CSI was taken into consideration in the case of NOMA-based NTN under the Nakagami-m fading channel and the two-user situation.	2022
[110]	An overview of the recent research work related to the NTN system, its parameters, and challenges	2023
[54]	A new technique was proposed to improve spectrum sharing performance by introducing NOMA and cognitive radio (CR) in the spectrum sharing of the NTN network.	2021
[111]	Performance evaluation of the NOMA-based LEO satellite in the downlink scenario.	2020
[112]	Based on 3GPP specifications, the limitations of the NTN on the New Radio (NR) approach were considered for purposes of supporting the future 6G-NTN system technology.	2021
[12]	Minimizing the average age of information (AoI) of the terrestrial users in the NTN based on different locations of UAVs and a HAPS unit and on channel state information (CSI)	2023
[113]	Applying the NOMA technique to enhance the initial access capacity of the terrestrial users in NTN configuration.	2023
[114]	Achieving massive connectivity for Internet of Things (IoT) applications using different techniques, like random access, accurate channel state information (CSI), and efficient allocation of wireless resources.	2023
[115]	For supporting future 6G technology, different multiple access techniques have been investigated in this paper.	2023
[116]	Realization of high connectivity and high spectral efficiency in HAPS level by introducing enhanced NOMA (eNOMA) technique for supporting the future 6G technology.	2023

5.1 Satellite channel modeling

The satellite channel model includes propagation loss represented by free space loss (FSL), geometric antenna pattern represented by beam gain, receiver gain, and channel statistical prosperities [90]. For the case when N Terrestrial users located in the same beam spot, the FSL of the i, $i \in \{1,2,\dots\dots,N\}$, is given by

$$L_i = \left(\frac{c}{4\pi f_c d_i}\right)^2 \tag{23}$$

where c is the speed of light, f_c is the carrier frequency, and d_i is the distance from satellite and the user i. The Beam gain: Given the position of User i, define φ_i to denote the angle between User i and the beam center with respect to the satellite. Then the beam gain $G_i(\varphi_i)$ of User i can be given as

$$G_i(\varphi_i) = G_s \left\{\frac{J_1(u_i)}{2u_i} + 36\frac{J_3(u_i)}{{u_i}^3}\right\} \tag{24}$$

where G_s is the maximum antenna gain at satellite, J (.) is the Bessel function and u_i is defined as

$$u_i = 2.07123\frac{\sin\varphi_i}{\sin\varphi_{i_{3dB}}} \tag{25}$$

with $\varphi_{i_{3dB}}$ being the 3-dB angle [117].

5.2 Downlink for NTN- NOMA Based for Two User's Case

In the NOMA downlink channel, the maximum data rate will be achieved by adopting two users' scenario [87] [118]. Figure 19 depicts the satellite NTN-NOMA downlink, where User 1 is denoted as the strongest user and User 2 is denoted as the weaker user, so more transited power will be allocated for User 2. The difference in the amount of power allocated to both users in the case of the satellite downlink comes, for example, from the fact that User 2 is located at the coverage edge of the antenna lobe and thus requires the allocation of greater transmission power to enable him to eliminate the interference caused by User 1 and decode its information by himself, while in the case of User 1, although it experiences a relatively better channel condition, it must adopt a SIC strategy to decode its own information due to its low allocated transmission power.

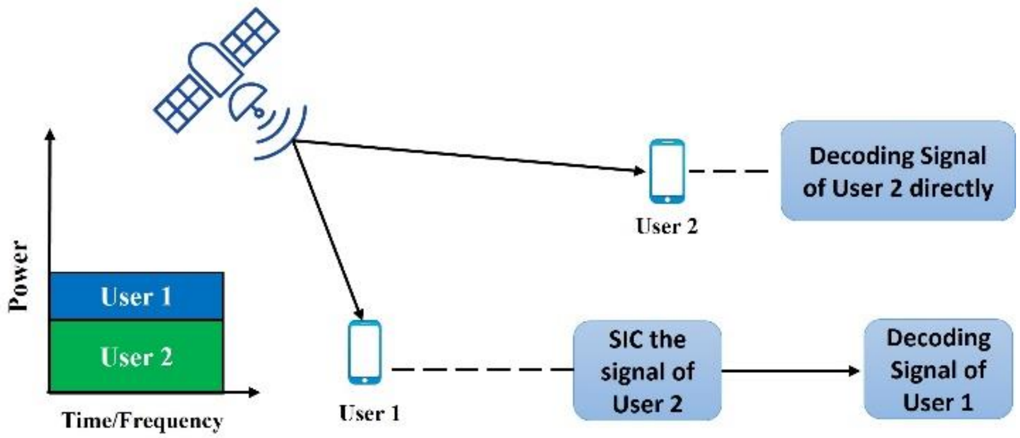

Figure 19. Two users NTN downlink scheme

In general, the amounts of allocated power for the considerable two users vary with time based on the CSI conditions [101]. We denote h_1 and h_2 as the fading coefficients of the channel between satellite and User 1, and User 2 respectively. The total channel condition in this case is defined by Q_1 and Q_2 for User 1 and User 2 respectively [90], where,

$$Q_i = L_i\, G_i\, G_s\, \varphi_i \tag{26}$$

where $i = 1, 2$ with G_i being antenna gain of User i.

Following the same procedure of section (Downlink NOMA for Terrestrial-Base station (BS) under two user's case), the sum rate of the NTN-NOMA is given by [101][119].

$$R = {R_1}^{\text{NOMA}} + {R_2}^{\text{NOMA}} = \log_2(1 + \alpha_1 \rho Q_1\, |h_1|^2) + \log_2\left(1 + \frac{\alpha_2 \rho Q_2 |h_2|^2}{\alpha_1 \rho Q_2 |h_2|^2 + 1}\right) \tag{27}$$

6. Conclusions

Many regions around the world remain unserved by cellular terrestrial mobile system services due to a lack of economic feasibility and the difficulty of implementing such systems. Deploying UAVs, HAPs, and satellite systems to create what it calls Non-Terrestrial Networks (NTN) is thus a worthwhile endeavor to expand the actual terrestrial services. The 6G cellular network, which is anticipated to launch in 2030 and is based on the NTN architecture, will combine terrestrial, aerial, space, and maritime communications into a dependable, fast, and scalable network capable of supporting a large number of devices with ultra-low latency requirements, thereby expanding connectivity to everyone and everything in isolated and rural regions. The realization of the new NTN system required many advanced technologies to achieve the goals of 6G. One of these technologies is non-orthogonal multiple access (NOMA), on which this paper was based. An evaluation of the NOMA and NTN-NOMA techniques has been accomplished in terms of system parameters and channel capacity. A system based on the NOMA technique has a wider rate range compared with that based on the traditional orthogonal multiple access (OMA) technique.

Conflict of Interest

The authors declare no conflict of interest.

Author Contributions

All the authors had written the paper and approved the final version.

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