Department of Systems and Computer Engineering

6G NTN (Non-Terrestrial Networks): Integrated Terrestrial-Satellite Networks of 2030's and Beyond

Final Project Report Presented to:

Prof. Halim Yanikomeroglu, Ph.D.
Department of Systems and Computer Engineering

Presenters

Group 4

Kaathyayini Neeharika Kajjam
101274433
kaathyayinikajjam@cmail.carleton.ca

Nihal Kulkarni
101178458
nihalkulkarni@cmail.carleton.ca

Acknowledgement

A special gratitude we give to Professor Halim, whose contribution in stimulating suggestions and encouragement, helped us to coordinate our project especially in writing this report. Moreover, we are deeply indebted to him for his guidance and feedback given especially in our project presentation that has improved our presentation skills.

Furthermore, we would also like to acknowledge with much appreciation the crucial role of Carleton University, which gave the permission to use all required resources and the necessary materials to complete the report. We would like to express our deepest appreciation to all those who provided us the possibility to complete this report.

Table of Contents:

Abstract

A breakthrough of 5th generation communication systems is 5G integration and convergence of diverse wired and wireless technologies. Satellite Communications provides the mechanism for seamless integration by utilizing specific use cases which can take advantage of unique capabilities. The SatComs or Satellite Communications has now been with great interest for the investments and the firms with the advancements in the technology. Currently, the Non-Terrestrial Networks (NTN's) integration can provide the seamless connectivity and coverage along with the availability and the scalability. The integration efforts are successful and has been implemented in many applications. One such great example is the IoT, where the applications are deployed in several major fields such as transportation, smart cities management and agriculture. The LEO (Low Earth Orbit) satellites are deemed to offer great range of services providing the low latency and wise span network coverage with flexibility and affordability. This project report is presented based on conducting thorough research and by referring the technical papers, IEEE journals, seminars, and technical reports including careful considerations of the frameworks of the 3GPP specifications.

Keywords

Satellite Networks (SatNets), Non-Terrestrial Networks (NTN), Integration, Internet of Space Things, CDMA, Mobility, RAN, URLLC, Integrity, Connectivity, Wide-Band, Protocols, New Radio, 5G Communications, 6G, NOMA, MIMO, 3GPP, 7G, IoE, NG-RAN, UAV, HAPS, Long Term Evolution, Evolved Packet Core (EPC), Line of Sight, Mobile Satellite Systems (MSS).

Introduction

During the past few years, the 5G deployments have been significantly ramped up across all over the globe with many terrestrial network operators. Initially 5G services were only offered to the smart phone users. Due to the steadily increasing demand, the services have extended to various fields including IoT. It is expected to raise drastically in the coming decades and the network expansion is expected to be enormous. NTN or Non-Terrestrial Networks have been the part of this, and the technology is now shifting to the 6G with integration capabilities.

The satellite-based communication tends to grow and can play a pivotal role in bridging communication infrastructure and the 5G services in near future. Satellite communications are now focussing on the system design, broadcasting, and network services. A major milestone of 5G systems is the integration with satellite networks and wireless technologies.

The global data traffic has been drastically increased over the years and is expected to grow to five-fold by 2025 as per the data from the ITU. As per the data, the 70% of the services are estimated to be the mobile internet usage. This huge demand has been in place due to the requirements for services like full data coverage, fast mobility, high-speed wireless communication with high reliability and ultra-low latency.

This project report discusses the current 5G generation, briefs up current and future satellite networks with the key enabling technologies associated with future satellite networks, provides an overview of the integration of terrestrial and non-terrestrial satellite networks along with the efforts during the previous generations era and future generations era, efforts made by the 3GPP organization for key enhancements, deployment challenges, complexities and provides an overview of applications of SatNets in future with some limitations.

Part I - 5G Networks and Current/Upcoming Satellite Networks

I.a. 5G: Introduction to 5G

5G wireless technology is a new generation that seeks to provide cost-effective solutions and ubiquitous access. Furthermore, it ensures a seamless transfer with no service interruptions and appropriate network selection [1]. In addition, using deep learning approaches for traffic balancing has enhanced system performance. Non-cooperative methods, on the other hand, have limited information exchange [2].

Also, 5G employs a radio access technology known as non-orthogonal multiple access (NOMA). Additionally, the most recent network architecture, which includes a dense "LEO constellation, provides increased reliability and flexibility" [2]. In addition, a positioning-based technique has been considered to reduce the latency and manage the inter-satellite handover. The 5G standard is distinguished by a significant number of interconnected devices. "The Internet-of-Space-Things (IoST) is a system that easily integrates the Internet-of-Things concept [2] into space access networks".

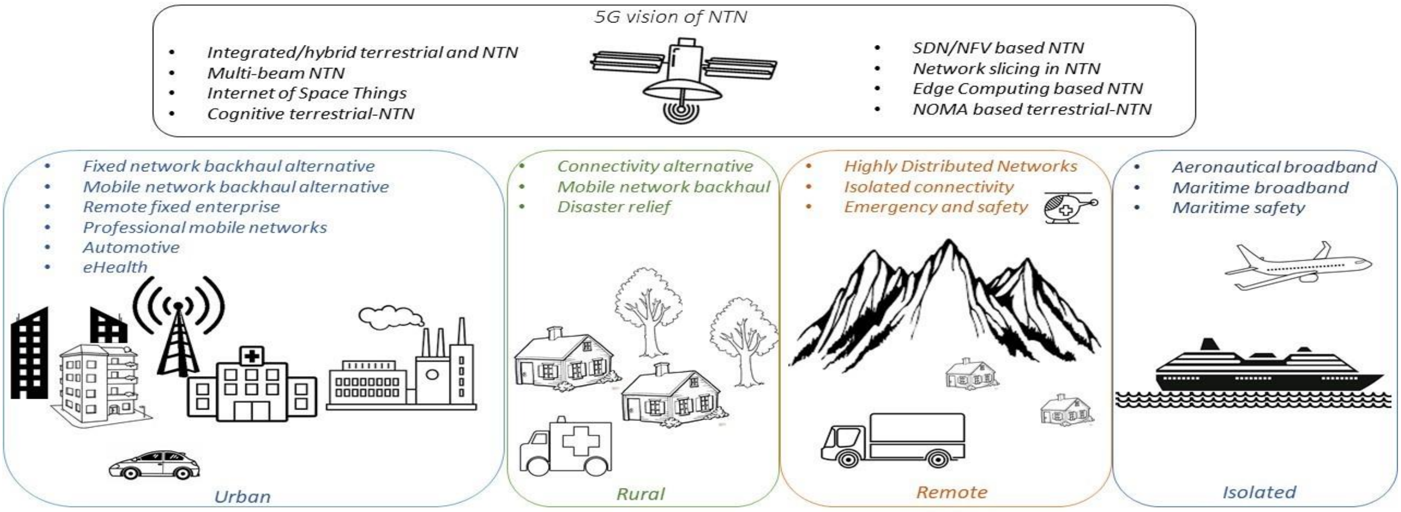

Fig. 1. 5G vision of NTN

How is 5G different from previous generations?

In the 1980s, 1G was launched to provide voice services. The data rate on 1G networks was 2.4 kbps. "However, because 1G was built on analogue transmission, it suffered issues such as insufficient capacity, unreliable delivery [4], and security concerns" [3]. In the 1990s, global systems for mobile communications (GSM) based on digital modulation technologies were created, with a data rate of 64 kbps [3]. In 3G, wide-band code-division multiple access (WCDMA), CDMA2000, unpaired spectrum based on time-division synchronous CDMA (TD-SCDMA) with time division duplex (TDD), and worldwide interoperability for microwave access (WiMAX), high-speed packet access [4] was introduced in 2000 at a data rate of 2 Mb/s to support the increasing demands for different multi-data services such as video calls and internet surfing [4] using various technologies such as wide-band code- (HSPA).

Key indication	1G	2G	3G	4G	5G
Period	1980-1990	1990-2000	2000-2010	2010-2020	2020-2030
Technology	Analog voice	GSM	CDMA-2000	Wi-Fi, WiMAX, LTE	5G NR, IPv6, LAN, WAN, PAN
Multiplexing	FDMA	TDMA, CDMA	CDMA	CDMA, OFDM	OFDM, BDMA
Data Rate	2.4 - 14.4 kb/s	14.4 - 64 kb/s	3.1 - 14.7 Mb/s	100 Mb/s - 1 Gb/s	1 Gb/s and above
Bandwidth	150 kHz	5 - 20 MHz	25 MHz	100 MHz	1 - 2 GHz
Architecture	SISO	SISO	SISO	MIMO	Massive-MIMO
Main Network	PSTN	PSTN	Packet	Internet	Internet
Features	Voice	Voice, SMS	Voice, data	Video	VoIP, ultra-HD
Band-type	Narrow	Narrow	Broad	Ultra-broad	Ultra-wide
Highlight	Mobility	Digitization	Internet	Real-time streaming	Extra-high rate
Switching	Circuit	Circuit, packet	Packet	All packet	All packet
Handoff	Horizontal	Horizontal	Horizontal	Horizontal, vertical	Horizontal, vertical

Fig. 2. Differences between 5G and previous generations [7]

I.b. Current and Upcoming/Future Satellite Networks

Current and future satellite networks are primarily concerned with mobility management, one-way and two-way propagation delay control, and radio resource management. Handovers such as intra-satellite [5], inter-satellite, and inter-access network handovers are used to control mobility [5]. "**Starlink, Inmarsat, Iridium, Globalstar, Lynk Global, and Thuraya** are some of the contemporary satellite networks". Starlink is made up of tens of thousands of small satellites in low Earth orbit (LEO) that connect with ground transceivers [4].

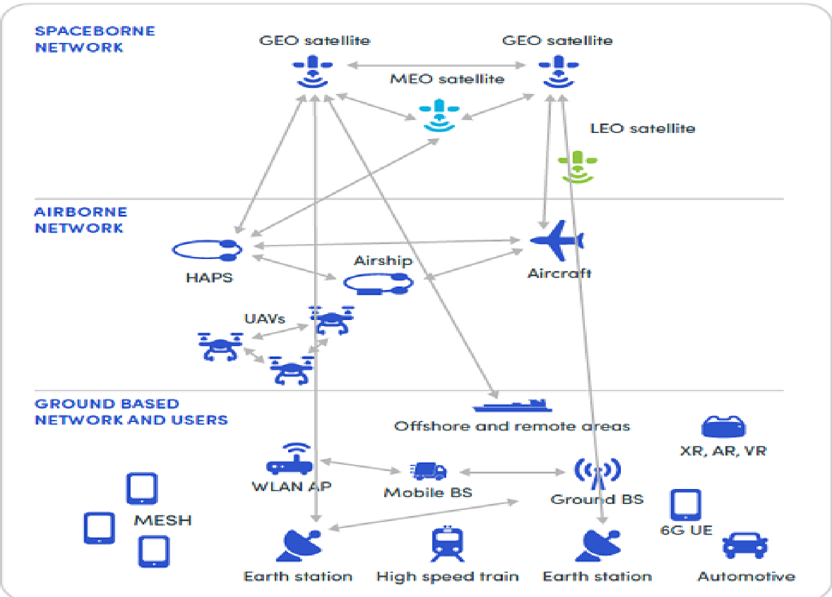

Fig. 3. Satellite Communication Networks [3]

The satellites have krypton-fueled hall thrusters that enable them to de-orbit at the end of their lives. Furthermore, based on uplinked tracking data, the satellites are designed to prevent collisions on their own. SpaceX plans to bring satellite internet connectivity to underserved portions of the globe [3], as well as affordable service in more populated areas [6]. “The business has said that positive cash flow from satellite internet services sales will be required to fund their Mars objectives”. In addition, SpaceX has long-term intentions to construct and launch a Mars-focused version of the satellite communication system. SpaceX launched Starlink Business, a higher-performance version of the service, in February 2022. With a $2500 antenna and a $500 monthly subscription fee, it offers a larger high-performance antenna with stated speeds of between 150 and 500Mbps [6] [9] [10].

Inmarsat is a satellite telecommunications firm based in the United Kingdom that provides global mobile services. It offers voice and data services to users all over the world through portable or mobile terminals that communicate with ground stations via fourteen geostationary telecommunications satellites [6]. It uses an Internet Protocol (IP) satellite modem the size of a notebook computer to provide services at up to 800 kbit/s with a latency of 900-1100 ms [11]. Thuraya is a regional mobile satellite service (MSS) operator based in the United Arab Emirates. The corporation provides telecommunications coverage and operates two geosynchronous satellites [7]. The L-band network of Thuraya provides voice and data services. Because of the service's geostationary nature, it has long round-trip times from satellite to earth, resulting in perceptible lag during voice calls.

Over the entire surface of the Earth, the Iridium satellite constellation delivers L band voice [10] and data information coverage to satellite phones, pagers, and integrated transceivers [8]. The constellation consists of 66 operational satellites in orbit that provide global coverage, as well as reserve satellites that may be used in the event of a breakdown. Satellites orbit the Earth at a height of about 781 kilometers (485 miles) with an inclination of 86.4 degrees. Iridium is a satellite that transmits phone calls across space [10].

Each satellite in the constellation maintains communication with two to four nearby satellites and routes data between them, thus creating a massive mesh network, in addition to connecting with the satellite phones in its footprint. Several ground stations are connected to the network via satellites that are visible to them. Outgoing phone call packets are sent through space to one of the ground station downlinks through the space-based backhaul ("feeder links") [11]. “To boost availability, Iridium ground stations connect the satellite network to land-based fixed or wireless infrastructures around the world. Station-to-station calls between satellite phones can be sent straight through space, without the need for a ground station”. The routing tables are updated as satellites leave the vicinity of a ground station, and packets destined for the ground station are routed to the next satellite just coming into view of the ground station. The frequencies used for communication between satellites and ground stations are 20 and 30 GHz [11].

Globalstar, Inc. is a satellite communications firm based in the United States that maintains a satellite constellation in low Earth orbit (LEO) for satellite phone and low-speed data communications [14]. Globalstar satellites are analogue repeaters with a "bent pipe" design [12]. Lynk Global is a business working on a satellite-to-mobile-phone satellite constellation that aims to give a "cell tower in space". This concept is described in [8]. The capability for global mobile phone service coverage, even in underserved rural areas. “Lynk satellite mobile technology can link to conventional cellphones from altitudes as high as 500 kilometres (310 miles)”. When a satellite mobile service is out of range of its home network, Lynk technology links to mobile phones on the ground in a similar way to roaming networks, where the satellite mobile service connects to another accessible cellular network. Lynk will have to work with multiple geographically scattered [3], and often country-specific, mobile network operators in any area of the world where the service will be offered to complete the regulatory side of this unique telecommunications approach.

I.c. Key enabling technologies in current/future satellite networks

There are a few key enabling technologies for 6G that are predicted to revolutionize cellular network topologies and deliver many homogeneous artificial intelligence-powered services, such as distributed communications, control, computing, sensing, and energy, from the core to the end nodes [6]. New radio, earth orbit satellite constellations, dynamic network topologies, artificial intelligence, and machine learning are some of the fundamentals enabling technologies in current and future satellite networks. Softwarized network management enablers, antenna technologies, SN communication links, edge computing, and caching are all on the list [7]. Aircraft and unmanned aerial vehicles (UAVs) can act as base stations in the air, providing users with better connection. They are also resistant to the elements and are ubiquitous. Furthermore, the capacity is determined by the number of satellites that the UAV can reach. Additionally, satellite networks can relate to high altitude platform stations (HAPSs). The fact that both HAPS and the satellite can be fueled by solar energy is a significant advantage [9].

As Laser Inter-SN Links operate at a higher frequency (or shorter wavelength), they have smaller antennas, are lighter, and take up less space. Other advantages of LISNLs include higher bandwidth, which translates to higher capacity (or data rate), narrower beam divergence (or beam spread), which translates to narrower beams with less interference and more security, and much higher directivity, which translates to lower transmit power [14]requirements. LCTs consume fewer onboard space node resources, are easier to incorporate into SN platforms, and their smaller form factor also helps to reduce SN launching and deployment costs due to their decreased SWaP requirements [14].

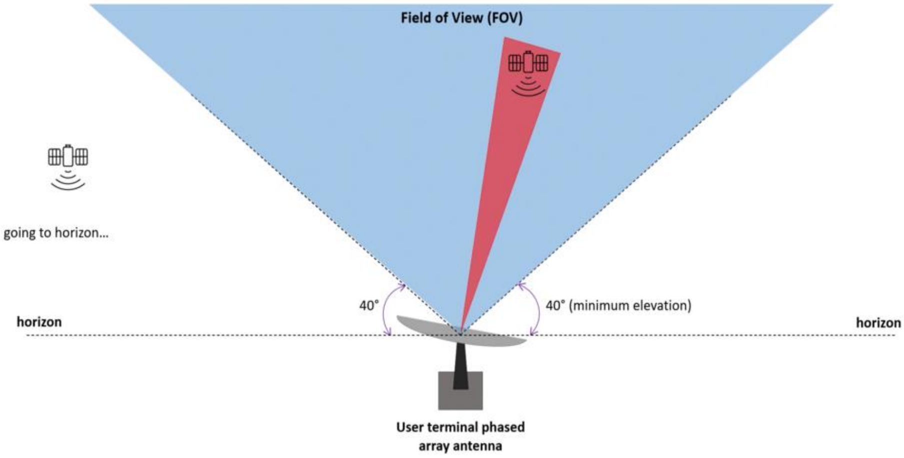

Fig. 4 User Terminal Phased Array Antenna

The satellites will use optical inter-satellite connectivity, phased array beam-forming, and digital processing technologies in the Ku- and Ka-bands [16], as well as inter-satellite laser links. The system will employ a peer-to-peer protocol that is said to be "simpler than IPv6" [13]and will have native end-to-end encryption. For orbit raising and station holding, Starlink satellites use “Hall-effect thrusters” with krypton gas as the reaction mass. When compared to a similar electric propulsion system operated with xenon, krypton Hall thrusters demonstrate much higher flow channel erosion, although krypton is far more common and has a lower market price. The system is connected to pizza-box-sized flat user terminals with phased array antennas that follow the satellites. The terminals can be placed almost anywhere if they have a clear view of the sky. The Ka-band [12] is used by Starlink to communicate with ground stations.

Within the same spot beam, the satellites can also move mobile units to different channels and time intervals. Transceivers use an antenna that is generally the same length as the handset to communicate directly with satellites and have a maximum output power of 2 Watts. For the air interface, QPSK modulation [13] is employed. Standard GSM SIM cards will work in Thuraya phones, and regular GSM SIM cards will work on the satellite network if the SIM supplier has a roaming arrangement with Thuraya. “While making a call, there is a significant lag, as with all geosynchronous voice systems”.

I.d. Limitations of Current and Future Satellite Networks

“Softwarization and virtualization are two of the most common network features used in 5G deployments”. The main challenges faced by satellite networks are that performance is impacted by frequent handovers, long propagation delays in space communications can reduce user [11]satisfaction. The process becomes complicated because nodes are dynamic for handovers, the load on the network increases as the number of handovers increases, traffic patterns are prone to regular changes, and finally, performance is impacted by traffic patterns. Cross Layer Design of the physical and data link layers has a significant impact on networking aspects, there are different handovers associated with network nodes and terminals, low throughput due to bad channel conditions at any communication segment can cause packet congestion at the higher layers, low throughput due to bad channel conditions at any communication segment can cause packet congestion at the higher layers [12].

To summarize, the most significant challenges are latency, number of satellites, capacity, standardization, and cost. Edge computing also faces issues because a single satellite's storage and processing resources are considered limited. This is since a satellite's power, weight, and size are limited, and the atmosphere in orbit is deemed hostile. Because LEO satellites move at such high rates, equipment on Earth must frequently switch [15] from one satellite to another. Satellite-ground and inter-satellite links have a longer propagation delay than wireline links in terrestrial networks. As a result, such delays must be considered while making data offloading decisions. They serve sparsely distributed customers in remote or rural locations, providing edge computing services by putting a domain server in an Earth Observing System (EOS) [16]may not be economically practical. Future EOS, on the other hand, are intended to service urban regions with high user density.

Part II - Integration

II.a. Integration Terminology

Integration literally means the collaboration of the terrestrial and non-terrestrial (satellite) networks. The main objective of this integration is to seamlessly integrate these assets into the 5G systems by studying their peculiarities in terms of architecture and the air interface [11]. Furthermore, the cost can be largely decreased by using 5G chipsets/systems. With this standard, the number of use cases are put forward. “The specific adaption points for the 5G have been suggested to the relevant working groups on air interface compatibility and architectural integration” [11]. To provide ubiquitous coverage, satellites must be integrated with terrestrial networks.

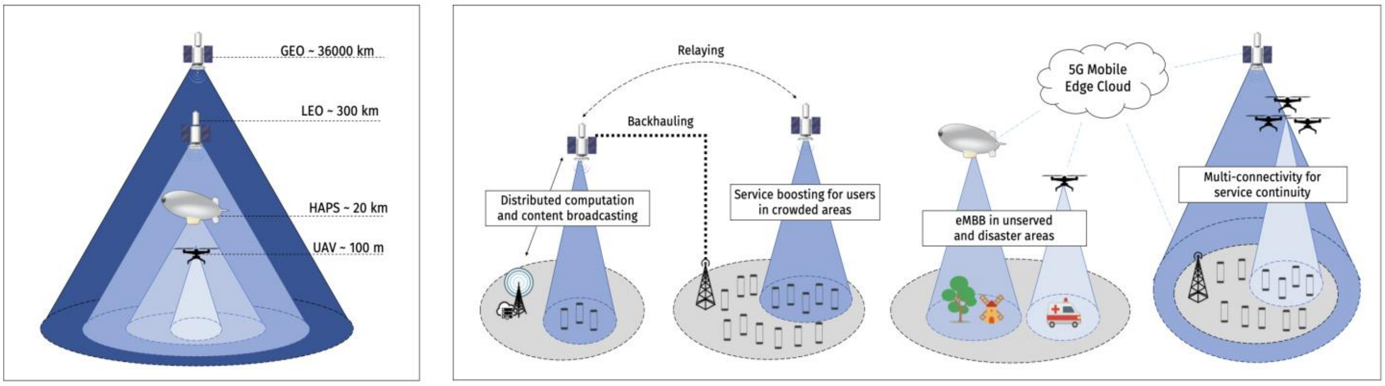

Fig. 5. Integration of NTN with Terrestrial Networks

Importance of Integration:

The Integration is important in various aspects. “The integration provides the high connectivity and capacity with cost effectiveness and full coverage” [12]. One of the major challenges such as latency and the coverage constraints can be improved. This system can be used to enhance the connectivity and increase the wireless coverage to reach blind spots such as deserts, mountains, and seas. The integration between the terrestrial and non-terrestrial platforms can support the network flexibility, scalability, and adaptability. We also compare the latency with specific use cases in this study. “The large latencies approximately about 125 ms to 800 ms will give user an unpleasant experience for the real-time applications such as voice, video streaming and gaming” [12]. The integration of networks with Low Earth Orbits (LEO) satellites at approximately 1000 kms should typically provide a latency range of 30 to 50 ms depending on the location of Data centres and the gateway [13].

II.b. History of Integration during 3G and 4G eras:

Broadband and multimedia services were offered by 3G. It is the technology that takes the first step toward satellite and terrestrial network convergence [14] (i.e., satellite air interface is fully compatible with terrestrial UMTS network infrastructure). Hybrid/integrated satellite-terrestrial networks and HTS were available in 4G. Satellite communications are regarded as essential for enabling global roaming in areas where terrestrial network infrastructure is either unavailable or prohibitively expensive [15]. “Because of the doppler effect, high-speed mobility around Earth, and a smaller coverage area than GEO satellites, integrating LEO satellites with 5G is difficult”.

Due to barriers (e.g., buildings, trees) and their irregularities, Mobile Satellite Systems (MSS) suffer from non-Line-of-Sight (non-LoS) propagation attenuation, also known as multi-path propagation (e.g., foliage). Several challenges arise, including synchronization, bandwidth allocation, and device selection for forwarding and relaying. Link adaptability and radio resource management are two difficulties that 4G technology poses [1]. The variability in access technologies, network designs, and protocols, as well as the demand for diverse types of services, make integrating different radio access networks difficult. As a result, the main roadblocks are radio resource management, mobility, and handover processes.

Why has Integration not happened so far?

“The integration of the Terrestrial and Non-Terrestrial networks has not taken place previously because they cannot be operated over the same frequency with the same wide area spectrum or using FR1 spectrum”. The co-existence of the networks will depend on the local regulators to decide the possible spectrum required for the integration. The coordination between different countries around the world is mandatory to achieve this.

For the frequency spectrum above 24 GHz or FR2 range, the possibility of integrating the TN and the NTN will exist with certain limitations on bandwidth, Roaming and RAN Sharing, UE Ecosystem and Availability, Network Service availability and Mobility. The criteria to blend in the networks is documented precisely in the 3GPP working guidelines.

Obstacles of Integration:

During the 3G era, the concept of a global wireless system was developed, and it has characterized all following wireless technologies to the present day. Wide-area coverage, scalability, service continuity, and availability are all ensured by integration [12]. "To ensure service continuity and scalability in 5G and beyond systems, NTNs and terrestrial networks must be integrated". Also, by providing experienced data rates and reliability to urban and rural areas, provide connectivity among crowded crowds (such as concerts, stadiums, city centres, and retail malls) as well as customers travelling by high-speed trains, airplanes, and cruise ships [12].

II.c. Integration efforts in 3GPP 5G (Rel 15 and 16)

The new radio specifications of 5G have been updated in Release 15 focusing on the Standalone 5G applications. "The previous releases have been focused on Non-Standalone-Applications (NSA), the Release 15 has enabled Standalone applications with slight improvements like LTE and Evolved Packet Core (EPC) which enabled the progress of chip design and network" [13]. The improvements also directed towards wireless convergence in 5G [14], Network automation, and radio schemes. The other activities also focused on expanding the applications of 3GPP to the non-terrestrial networks radio systems along with satellites to base stations and maritime communications. This work further expanded in as Phase 2 in Release 16 with improvements on multimedia service domains, Vehicle-to-everything (V2X) application layer services [14] and 5G satellite access services.

Integration efforts in 3GPP 5G Advanced (Rel 17 and 18)

The Release 17 is mainly focused on the NTN and Satellite Network integration. The collaboration between the mobile and space industries has been eased to great extent. The primary objective revolves around RAN and SA progressing towards integration of satellites as per the 3GPP specifications. "The enhanced applications include physical and access layers specifications, radio and system aspects and the satellites working at LEO, MEO or GEO" [15]. The Rel 17 specification will also support radio-based satellites also supporting the IoT use cases in transport and logistics areas. The integration through collaboration between mobile and space industries will define the 3GPP ecosystem for future satellites. The developments in Rel 17 will define issues of reachability and service continuity and enhance reliability through various technologies and avert disasters.

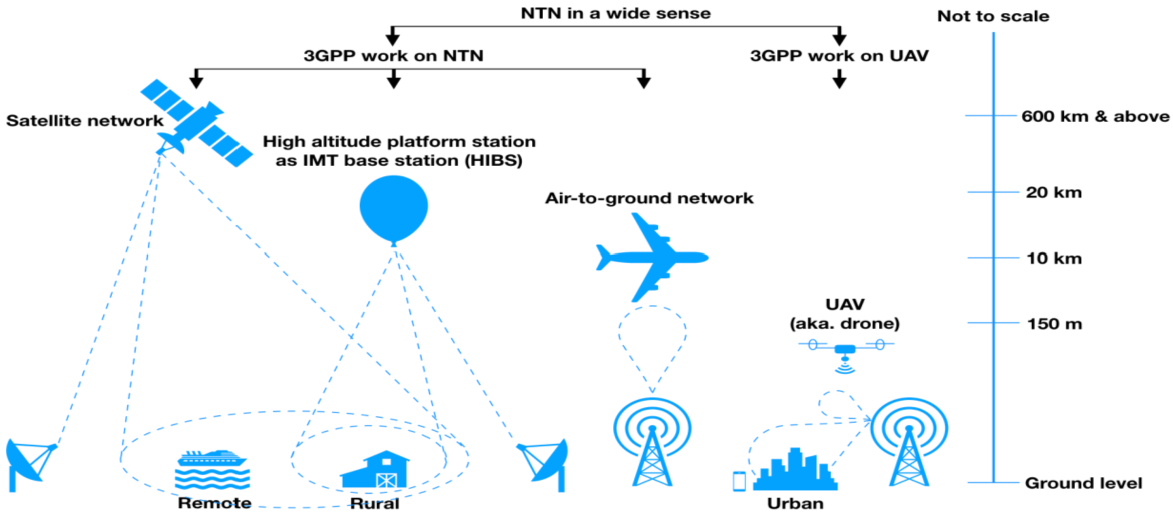

Fig. 6. 3GPP and NTN

"The advancements by the end of current release will be the satellites linked directly to the mobile devices with all specifications embedded into it."

The 3GPP specifications will also support the worldwide access to the 5G systems by the rapid growth in space industry. The Rel 18 will be based on developments of NR-NTN and IoT-NTN. This release is planned above the 10 GHz frequency for applications like aircrafts and UAV's. To ensure service continuity 5G NTN NG-RAN is integrated with the 5G NR terrestrial RAN or with another 5G NTN NG-RAN [16].

3GPP research activities started in 2017 under Release 15 and are still ongoing. A RAN-level 3GPP normative work on NTN NR started in August 2020 for Release 17. Release 15 included the work on "Study on NR to support Non-Terrestrial Networks", Release 16 on "Study on solutions for NR to support Non-Terrestrial Networks" & " Integration of satellite access in 5G" [14]while Release 17 on "Study on architecture aspects for using satellite access in 5G", "Study on management and orchestration aspects with integrated satellite components in a 5G network" [17], "Study on NB-IoT/eMTC support for Non-Terrestrial Networks", "Integration of satellite components into the 5G architecture" & "Solutions for NR to support Non-Terrestrial Networks" [15]. Based on Release 15 of the NR requirements, 5G NR adaptation for satellite communications was investigated. In 3GPP Release 17, 5G NR over NTN is planned to be released, along with a study item on NB-IoT for NTN.

Part III - Future Satellite Networks

III.a. Limitations of Future Satellite Networks

Mobility, tracking area, Delay-CSI-MCS, feeder-link, RRM, and interference are all efficiently managed in future satellite networks [18]. With conclusion, 6G technology contemplates the use of NTN to extend terrestrial coverage and assist in the provision of advanced services whenever and anywhere the existing cellular network is overburdened or unavailable. “RRM is important because it allows satellite and terrestrial networks to work together closely”. Researchers concentrated on developing efficient radio resource allocation methods to decrease all sorts of interference and providing effective link adaptation procedures to provide real-time video services [19]. To provide service continuity, mobility management is required to achieve seamless changeover across heterogeneous wireless access networks [19]. As a result, new procedures for speedy inter-system handover are being developed to reduce service interruptions and optimize network selection.

III.b. Vision for the integrated terrestrial-satellite networks in the 6G eras of 2030’s:

Due to increased capacity (because of high-frequency reuse and precoding techniques) and service continuity even when travelling, global coverage is now possible. “A standalone GEO satellite NG-RAN will enable multi-layer video services in future 5G NR deployments”. RRM is a resource allocation approach that allows for multiple multimedia video flows [20]. The path-based network coding provides higher traffic distribution reliability and efficiency. The integration would be more straightforward while still accommodating multiple services. It would include network coverage augmentation, service-oriented requirements fulfilment, tailored service management, on-demand network reconfigurability, multi-dimensional resource and mobility management, a better management framework, and heterogeneous resource orchestration. It would also benefit from cloud-edge synergy, with networking slicing becoming more refined and integration becoming more efficient. “Automation, stabilization, and customization would all be part of the integration process”.

Drones could be used to supplement terrestrial coverage by providing connectivity to hotspot locations and in situations when the terrestrial signal is weak. Drones and terrestrial gNBs could benefit from NGSO satellite backhauling and coverage extension. Wide-area coverage, significant LoS, as well as low-loss and high-throughput transmissions are all advantages [22]. A joint sensing-communication cooperative sensing UAV network has recently been developed, in which UAV equipment can create a sensing and a communication beam orthogonally to improve spectrum reuse. Better AI utilization, which increases service diversity, enables on-demand services to be handled in a more flexible, efficient, adaptable, autonomous, and cost-effective manner. To provide a more organized perspective on space communications the increased needs for heterogeneous services, comprehensive coverage, ultra-high-speed wireless communications with ultra-high dependability and ultra-low latency have accompanied the massive data traffic demands. Rather than voice traffic [23], devices often consume data capacity (mostly video).

6G may use technologies such as reconfigurable intelligent surfaces, advanced physical layer solutions, new advanced modulation schemes, advanced multi access techniques, holographic radio communications, full-duplex wireless communications, multiple access and modulation, energy harvesting, backscatter communication, edge computing, new spectral bands, integration of terrestrial and non-terrestrial communications, cell-frequency communication, edge computing, new spectral bands [23], integration of terrestrial and non-terrestrial communications, cell-frequency communication. The THz-based IoE applications and services are projected to be supported by 6G wireless communications networks.

III.c. Vision for the integrated terrestrial satellite networks in the 7G eras of 2040's:

The 7G network is a quicker mode of communication that is available all over the world. A 7G network is the fastest way to make a call, whether it's a local or international call. 7G is a Voice Over Internet Protocol (VoIP) standard that requires access to any local or worldwide telecommunication [22]. Satellites would be more capable than those that came before them. "Integration would take place in a more efficient, cost-effective, and environmentally responsible manner, with less complexity". Light pollution, space debris, and flares can all be avoided here. Users are only charged for the quantity of data they send and receive, rather than the period they are connected, with newer services using IP technology with an always-on capability [24]. There may be little or no interference between them. Satellites would have a longer life cycle, allowing integration to continue for a longer period. In addition, while interfacing with satellite networks, the service description framework and service sensing would be top priorities. With additional freedom, integration would be more precise. Joint sensing-communication technique and digital/cyber twin are two possible alternatives. Sensor fusion is a technique that integrates network sensing (the observation of the communication environment using radio waves) with other widely distributed sensors [25].

"The challenge for a 6G service-oriented network is to handle a wide range of long-tail, bespoke services with unique requirements". Worse yet, because the network environment and contexts have a substantial impact on service requirements, the vast range of network scenarios is a critical difficulty in providing on-demand services. In 6G, there is still a lack of a standard structure and methodology for service-oriented networks. Communication services could be delivered more efficiently and with guaranteed performance thanks to network context awareness.

Furthermore, all its customers trust the 7G Network since it provides them with a medium that is faster than ever before while still ensuring the protection of essential business ideas. When we talk about the 7G Network, many people assume it will be expensive [27]. Surprisingly, the 7G Network is not that expensive. It completes a variety of assignments, including business calls and meetings, at industry-leading prices. Therefore, a variety of businesses rely on 7G to provide communication [25].

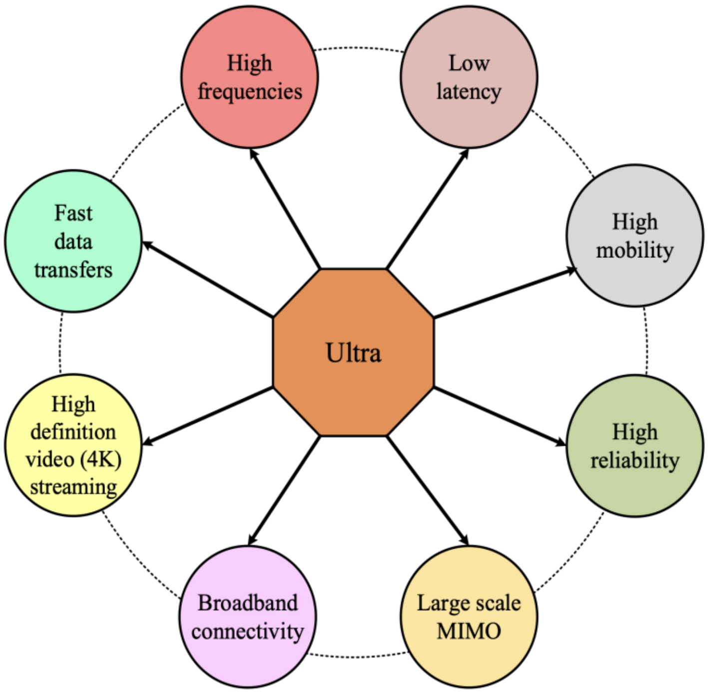

Fig. 7. 7G Vision through Integration

It will deliver increased speed, dependability, connectivity, and communications. Communication, Voice over Internet Protocol, capacity, and connectivity will all be improved in a country that leads as a 7th Generation network provider. In a world powered by 7G, every machine will be linked to people [24] [25]. Every machine will be able to communicate with the others. This is how a 7G networked world will appear. We can't declare that few countries have a 7G or 8G network because of the country's internet speeds [25]. Yes, we can state that the internet speed is comparable to that of a 7G or 8G network. “Norway is the country with the fastest internet speed in the world. In September of last year, Telenor, Norway's largest telecom service provider, raised the speed of personal internet usage”. In Norway, there are three telecom firms, including Telenor, that have built their own mobile network [26]. Also, because 6G utilizes THz (Terahertz) frequencies for a portion of its communications, THz downsides can be considered 6G wireless technology drawbacks.

The terahertz frequency refers to the spectrum of EM (electromagnetic) waves with wavelengths of 30 to 3000 micrometers that range from 0.1 to 10 THz [27]. Terahertz waves have a wide range of applications in space communications and are particularly well suited for use between satellites. The THz signal is extremely sensitive to shadows, which has a significant effect on coverage. To add on, terahertz frequencies with lower frequencies experience more free space fading [28]. The development of ultra-large-scale antennas in THz is a huge difficulty since it necessitates a wide bandwidth and massive quantitative high resolution designing low-power, low-cost 6G devices poses a significant barrier in terms of processing power. As well, because 6G employs visible light wavelengths for part of its communications, VLC flaws might be viewed as flaws in 6G wireless technology [29]. The visible light spectrum ranges from 390-700 nm in wavelength. A 6G system is required to manage many terminals and networking equipment in a more effective and energy-saving manner [30]. The design of network and terminal equipment circuitry, as well as the communication protocol stack, is a problem to achieve this. To meet this demand, energy harvesting technologies are employed.

Conclusion

6G allows for the integration of various networks, such as terrestrial and non-terrestrial networks. 6G will combine network slicing and multi-access edge computing with software defined networks, as well as AI and ML, to enable efficient integration between diverse networks. 6G promises to completely support Tactile Internet connectivity, which requires a latency of less than 1 millisecond to do light surgery.

In a nutshell, the future vision of 6G satellite networks aims to achieve high data rates/spectral efficiency, particularly by moving to higher frequency bands; provide an energy efficiency of 10x higher than 5G networks for green communication, increase connectivity and provide full coverage, maintain security, secrecy, and privacy, achieve ultra-high-reliable and low-latency communication, support externally high mobility of up to 1000 km per hour, and realize intel. Tactile Internet, holographic teleportation (telepresence), Internet of Smart Things (IoST), and multi-sensory extended reality (XR), which includes augmented reality (AR), mixed reality (MR), and virtual reality (VR), are all predicted to be supported by 6G wireless communications networks (VR).

Moreover, 6G terrestrial and integrated satellite networks employs a cell-less architecture as well as multi-connectivity. The UE links to the RAN rather than a single cell in a cell-less design. As a result, flawless scheduling is required for seamless mobility and integration of various types of links. The 7G satellite networks would overcome the challenges faced by 6G integrated satellite networks and previous satellite networks, such as SLA vs. "best-effort," 100% coverage, API-driven network customization, AI networks, area expansion by HAPS, beyond millimeter-wave: terahertz & optical communication, sensing-positioning, charging /power supply, maximum frequency utilization-efficiency, network security, resilience-redundancy-recovery, carbon-free/net-zero, and network security.

References

[1] B. Feng, H. Zhou, H. Zhang, G. Li, H. Li, S. Yu, and H. Chao, “HetNet: A Flexible Architecture for Heterogeneous Satellite-Terrestrial Networks,” IEEE Network, vol. 31, no. 6, pp. 86–92, 2017.

[2] C. Li, Y. Zhang, R. Xie, X. Hao, and T. Huang, “Integrating edge computing into low earth orbit satellite networks: Architecture and prototype,” IEEE Access, vol. 9, pp. 39126–39137, 2021.

[3] F. Fourati and M.-S. Alouini, “Artificial intelligence for satellite communication: A review,” Intelligent and Converged Networks, vol. 2, no. 3, pp. 213-234, Sep. 2021.

[4] M. Giordani and M. Zorzi, “Non-terrestrial networks in the 6G era: Challenges and opportunities,” IEEE Network, vol. 35, no. 2, pp. 244–251, 2020.

[5] M. Hoyhtya, M. Corici, S. Covaci, and M. Guta, “5G and beyond for new space: Vision and research challenges,” in Advances in Communications Satellite Systems. Proceedings of the 37th International Communications Satellite Systems Conference (ICSSC-2019), pp. 1–16, IET, 2019.

[6] M. Giordani and M. Zorzi, “Satellite communication at millimeter waves: A key enabler of the 6G era,” in 2020 International Conference on Computing, Networking and Communications (ICNC), pp. 383–388, IEEE, 2020.

[7] M. Centenaro, C. E. Costa, F. Granelli, C. Sacchi, and L. Vangelista, “A survey on technologies, standards and open challenges in satellite IoT,” IEEE Communications Surveys Tutorials, vol. 23, no. 3, pp. 1693–1720, 2021.

[8] A. Guidotti, A. Vanelli-Coralli, M. Conti, S. Andrenacci, S. Chatzinotas, N. Maturo, B. Evans, A. Awoseyila, A. Ugolini, T. Foggi, et al., “Architectures and key technical challenges for 5G systems incorporating satellites,” IEEE Transactions on Vehicular Technology, vol. 68, no. 3, pp. 2624–2639, 2019.

[9] A. Guidotti, S. Cioni, G. Colavolpe, M. Conti, T. Foggi, A. Mengali, G. Montorsi, A. Piemontese, and A. Vanelli-Coralli, “Architectures, standardisation, and procedures for 5G satellite communications: A survey,” Computer Networks, vol. 183, p. 107588, 2020.

[10] C. Ravishankar, R. Gopal, N. BenAmmar, G. Zakaria, and X. Huang, “Next-generation global satellite system with mega-constellations,” International Journal of Satellite Communications and Networking, vol. 39, no. 1, pp. 6–28, 2021.

[11] F. Rinaldi, H.-L. Maattanen, J. Torsner, S. Pizzi, S. Andreev, A. Iera, Y. Koucheryavy, and G. Araniti, “Non-terrestrial networks in 5g & beyond: A survey,” IEEE Access, vol. 8, pp. 165178–165200, 2020.

[12] O. Kodheli, E. Lagunas, N. Maturo, S. K. Sharma, B. Shankar, J. F. M. Montoya, J. C. M. Duncan, D. Spano, S. Chatzinotas, S. Kisseleff, et al., “Satellite communications in the new space era: A survey and future challenges,” IEEE Communications Surveys & Tutorials, 2020.

[13] “Technical Specification Group Services and System Aspects, Study on Architecture Aspects for Using Satellite Access in 5G,” document TR 23.737, v17.2.0, Release 17, Third Generation Partnership Project (3GPP), 2021.

[14] “Solutions for NR to Support NTN,” document TR 38.821, v16.1.0, Release 16, Third Generation Partnership Project (3GPP), 2021.

[15] 3GPP, “Study on Narrow-Band Internet of Things (NB-IoT) / enhanced Machine Type Communication (eMTC) support for Non-Terrestrial Networks (NTN) (Release 17),” TR 36.763, v17.0.0, Jun. 2021.

[16] “Technical Specification Group Radio Access Network, Study on New Radio (NR) to Support Non-Terrestrial Networks (NTN),” document TR 38.811, v15.4.0, Release 15, Third Generation Partnership Project (3GPP), 2020.

[17] “Technical Specification Group Services and System Aspects, Study on Using Satellite Access in 5G, Stage 1,” document TR 22.822, v16.0.0, Release 16, Third Generation Partnership Project (3GPP), 2018.

[18] Yiming Huo, Wei Xu “Cellular and Wi-Fi Co-Design for 5G User Equipment” University of South California, USA 2018, pp. 256 - 261.

[19] Carl E Landwehr, David M Goldschlag “Security Issues in Network with Internet Access”, Proceedings of IEEE,Vol 85, No 12, USA 1997, pp. 2034 – 2051.

[20] “Technical Specification Group Services and System Aspects, Study on Using Satellite Access in 5G, Stage 1,” document TR 22.822, v16.0.0, Release 16, Third Generation Partnership Project (3GPP), 2018

[21] J. Hill, Y. Demers, A. Liang, E. Amyotte, K. Glatre, and S. Richard, “Multibeam antenna architectures for flexible capacity allocation,” in 39th ESA Antenna Workshop on Innovative Antenna Systems and Technologies for Future Space Missions, October 2018.

[22] E. Doumanis, G. Goussetis, R. Dickie, R. Cahill, P. Baine, M. Bain, V. Fusco, J. A. Encinar, and G. Toso, “Electronically reconfigurable liquid crystal based mm-wave polarization converter,” IEEE Transactions on Antennas and Propagation, vol. 62, no. 4, pp. 2302–2307,April 2014.

[23] T. M. Braun, in Satellite Communications : Payload and System, Wiley-IEEE Press, 2012.
[24] N. Mazzali, M. R. B. Shankar, and B. Ottersten, “On-board signal predistortion for digital transparent satellites,” in Proc. 16th IEEE International Workshop on Signal Processing Advances in Wireless Communications (SPAWC), 2015.
[25] A. Rao, A. Chatterjee, J. Payne, and J. Trujillo, “Multi-beam/multiband aeronautical antenna: Opportunities and challenges,” in 29th ESA Antenna Workshop, October 2018.
[26] J. V. Llop, P. K. Roberts, Z. Hao, L. Tomas, and V. Beauplet, “Very low earth orbit mission concepts for earth observation: Benefits and challenges.” in Reinventing Space Conference, 2014.
[27] L. Reynaud and T. Rasheed, “Deployable aerial communication networks: Challenges for futuristic applications,” in Proceedings of the 9th ACM Symposium on Performance Evaluation of Wireless Ad Hoc, Sensor, and Ubiquitous Networks, ser. PE-WASUN ’12. New York, NY, USA: ACM, 2012, pp. 9–16.
[28] Y. Li, H. Wei, L. Li, Y. Han, J. Zhou, and W. Zhou, “An extensible multi-layer architecture model based on leo-mss and performance analysis,” in 2019 IEEE 90th Vehicular Technology Conference (VTC2019- Fall), Sep. 2019, pp. 1–6.
[29] J. Virgili-Llop, H. C. Polat, and M. Romano, “Attitude stabilization of spacecraft in very low earth orbit by center-of mass shifting,” Frontiers in Robotics and AI, vol. 6, p. 7, 2019.
[30] S. M. Dakka, “Vleo satellites — a new earth observation space systems commercial and business model,” in 36th International Communications Satellite Systems Conference (ICSSC 2018), Oct 2018, pp. 1–11.