Chapter

Prospects of 5G Satellite Networks Development

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Abstract

In the future, 5G networks will represent the global telecommunication infrastructure of the digital economy, which should cover the whole world including inaccessible areas not covered by 5G terrestrial networks. Given this, the satellite segment of 5G networks becomes one of the pressing issues of development and standardization at the second stage of 5G networks development in the period 2020–2025. The requirements for 5G satellite network will be determined primarily by combination of key services supported by 5G networks, which are combined by three basic business models of 5G terrestrial networks: enhanced Mobile Broadband Access (eMBB), Massive Internet of Things connections (mIoT), and Ultra-reliable low-latency communication (uRLLC). 3GPP as leading international standards body has identified several use cases and scenarios of 5G satellite networks development. 5G satellite networks are understood to mean networks in which the NG-RAN radio access network is constructed using a satellite network technology. The chapter has discussed the spectral and technological aspects of 5G satellite network developments, issues of architecture and role of delays on quality of services of 5G satellite segment, and possibility of constructing a 5G satellite segment based on distributed and centralized gNB base stations. The issues of satellite payload utilization have considered for bent-pipe and on-board processing technologies in 5G satellite segment.

Keywords: 5G satellite segment, WRC-19, 3GPP, 5G core, gNB, SRI, ISL

1. Introduction

Rapid development and unification of the terrestrial part pertained to IMT-2020 (5G) as well as the limitations claimed for global coverage by terrestrial 5G networks, when using millimeter-wave band (MMWB), calls design engineers for special attention to this potential market segment of mobile satellite telecommunications.

In Summer 2017, within the framework of Paris air show in Le Bourget, European Space Agency (ESA) launched its new project "Satellite for 5G," compiling 16 satellite businesses into consortium aimed at study to introduce 5G satellite-based access components [1].

The consortium is made up of such organizations and institutions as: EURESCOM, Fraunhofer Fokus, Fraunhofer IIS, NewTEC, SES, TU Berlin, and Universität der Bundeswehr. They all have conducted the work concerning the design of SATis5 intended to facilitate implementation, deployment, and evaluation of the integrated 5G satellite network, unveiling the advantages of satellite and terrestrial framework integration for advancing new technologies.

Additionally, the Working Group FM44 of ECC CEPT completed the preparation of ECC Report "Satellite Solutions for 5G" [2] that will determine the role of satellite component within 5G conception of in relation to the Regions, where services cannot be carried out in circumvention of satellites. In its turn, CEPT came forward with initiative to estimate the pros of satellites for 5G in terms of efficiency, capacity, and stability. Since CEPT Administrations are considering the issues related to 5G implementation in the nearest future, so the studies of satellite access in 5G are expected to facilitate the process of decision-making regarding the potential role of satellite subscriber's links in the 5G ecosystem.

2. Concept of 5G satellite implementation

The implementation of 5G satellite component for 5G service access on principles "at any time with any user in any place" helps to meet many challenges. However, there are numerous other hindrances requiring comprehensive and global studies.

Generally, the regions that are subject to coverage by terrestrial mobile networks of radio access are of fragmentary nature and correspond with the places of population concentration, regarding the economic expediency of base stations building. In some cases, the sparsely populated territories not covered by modern telecommunications. Thus, at the outset of 3G (IMT-2000) development, the universal coverage by mobile services was the key prerequisite for network construction, contributing to the formation of global 3G segment. However, in the course of 4G network evolution, the idea of global coverage by these networks was not even contemplated, in the hope of finding the convergent solutions in the field of satellite and terrestrial mobile telecommunications.

The concept of 5G satellite component considered nowadays rests upon the following preconditions [3]:

- 5G satellite component is to be integrated into other mobile and fixed networks, but not as autonomy one for the provision of 5G services. The integration of satellite and terrestrial 5G segments forms the key aspect of this vision;

- Satellite communication systems are fundamental components for reliable delivering of mobile services, not only in Europe, but also in other regions of the world as by continuum over time and at a reasonable price;

- 5G satellite component will facilitate universality of 5G networks as well as the solution for various issues dealt with maintenance of multimedia traffic growth, global coverage, M2M, and critical telecommunications (emergency and natural disasters) in optimizing costs for end-users;

- Satellite component may become a part of configuration for 5G hybrid network, consisted of combination of broadcasting and broadband infrastructures, run in a manner to ensure uninterrupted and online convergence of 5G services for all end-users.

The requirements for 5G satellite component will be defined by, first of all, the aggregate of services carried out by 5G, consolidated in the families of usage scenarios of 5G terrestrial segment [4, 5]: enhanced Mobile Broadband (eMBB), Massive Machine-Type Communications (mMTC or mIoT), and Ultra-Reliable Low Latency Communication (URLLC).

The potential of satellite networks to uphold the key scenarios for 5G applications is specified by already existing characteristics applicable to modern satellite networks as well as tendencies in satellite technology development in future:

- *eMBB scenario*. According to this scenario, satellite networks are capable of maintaining data transfer at speed up to several gigabits per second, meeting the requirements for extended services of mobile broadband eMBB. Nowadays, satellite technologies can broadcast thousands of channels with the content of high bandwidth (HD and UHD). In its turn, this potential can be used to support the mobile network services of future generation. At present, satellites are being used as transport networks within 2G/3G in many regions of the world, whereas high-throughput satellites (HTS) of modern and future generations on geostationary and non-geostationary orbits can maintain transport infrastructure of mobile networks 4G/LTE and 5G in future.

- *mMTC scenario*. Satellite communication systems are already keeping up the technology of SCADA and other global applications for cargo and object tracking in the context of IoT devices mass use. Their capabilities can be scaled up to support devices and services of IoT within the direct control channel or as a feedback line with IoT and M2M devices from remote locations, ships, and other carrying vessels.

- *uRLLC scenario*. Satellite communication systems gained notoriety owing to its and their satellite communication systems gained notoriety by owing to its and their ability to meet the case concerning the requirements for network signal delays, aiming at procuring critical and highly reliable communications. The principal users of these networks are international broadcasters, mobile network operators, governmental bodies, and commercial users. The applications that turn out to be more sensitive to signal delays can be bolstered via new medium and low earth orbit satellite networks, which will to be deployed.

5G satellite networks are such networks, where radio access network NG-RAN is designed by means of satellite network utilization. Technical specifications of 3GPP [3] identified several cases for 5G satellite network use, presented below.

Case 1. Roaming between terrestrial and satellite networks. In this case, 5G satellite network operator provides data services delivery on globally coverage basis. An operator of terrestrial 5G network, in its turn, concludes roaming agreement with the operator of 5G satellite network operator as well as the other terrestrial network operators. User terminal exploits 5G satellite network only in the absence of radio coverage by terrestrial 5G networks.

Case 2. Broadcast and multicast with a satellite overlay. In this case, the operator of 5G satellite network provides video broadcasting or any other delivery of services within the global territory. The existing terrestrial mobile networks, supplying broadcasting services, can rely on 5G satellite network aiming at meeting its primary objectives related to the expansion of radio resource, broadcasting content, and ensuring global access to content.

Case 3. Internet of Things with a satellite network. In this case, 5G satellite network operator provides the delivery of IoT-services globally. Space segment of 5G satellite network uses low-orbiting satellites so as to ensure radio connections for IoT devices with low power consumption.

Case 4. Temporary use of a satellite component. In this case, a number of 5G network operators with access to the satellite component grant access to their network with a minimum set of service (such as voice, messaging, and mail) so as to provide to each user devices under the satellite coverage a guaranteed access.

Case 5. Optimal routing or steering over a satellite. The 5G networks will combine available terrestrial and satellite network components to optimize the connectivity of user devices in accordance with the requested QoS. Depending on the quality requirements to QoS-parameter 5QI as well as bandwidth, the optimal traffic routing is secured within the territories of joint radio coverage (of satellite and terrestrial networks). In a 5G network with satellite access, user devices with terrestrial access and supporting satellite networks access will be capable of dual connectivity with a satellite access network and a terrestrial access network. A 5G network with satellite access will be capable of establishing independently uplink and downlink connectivity through the 5G satellite and 5G terrestrial access networks.

Case 6. Satellite transboundary service continuity. This case provides for 5G global satellite network within the territory of a few countries. According to the prerequisites established by legislation of the relevant states, subscribers' traffic is to be terminated in user location, within the licensed network. Consequently, in compliance with this statement, 5G satellite network is being designed as access network to respective terrestrial networks, covering the territories of various states. Therefore, it can also be used as autonomous 5G network on neutral territories.

Case 7. Global satellite overlay. In this case, global low-orbiting satellite network will be utilized as the overlaying network of terrestrial data network. The topology of communication links will be defined on basis of minimizing delivery time of protocol data unit. Thus, the main idea considers that delay of signal propagation equals the speed of light (299,792,458 m/s) in airspace, whereas in optical fiber, this parameter achieves up to 2/3 of speed of light. Based on the above, time duration equals 1 ms correlates with propagation distance of 300 km in airspace and 200 km in optical fiber (excluding curvature of circuit). With more large distance between the source and recipient of a message (reaching several thousand km), the difference in time delivery may be significant and actually for a series of applications in banking, burs exchange, and industry fields.

Case 8. Indirect connection through a 5G satellite access network. This case will be assumed that mass user devices will be deprived access to satellite interface. Interaction of these 5G user devices with satellite networks is carried out through relay user units (Relay UE), supporting satellite interface. This relay UEs can function separately or will be set into rescue vessels, air planes, and railway carriages. While implementing these indirect connections of 5G user devices through satellite access networks, it is vital to solve the issues dealing with security, tariffing, etc.

Case 9. 5G fixed Backhaul between NR and the 5G core. This option considers the use of satellite network by organizations of transport channels Midhaul, Backhaul between stationary base stations gNB and 5G core network. The interfaces between the 5G core and NR are transported directly over the satellite link.

Case 10. 5G Moving platform Backhaul. This case considers the utilization of satellite network for transport link organizations in 5G network (Moving Platform) such as Midhaul, Backhaul between moving gNBs and 5G core network. Moving 5G base stations can be placed on river and maritime vessels, trains, etc.

Case 11. 5G to premises. This case implies that 5G satellite network interoperates with non-3GPP technologies (for instance, IEEE 802.11, IEEE 802.16). It is using a home/office gateway unit to combine the available signals from 5G satellite network and to present modern Wi-Fi coverage within the premises.

Case 12. Satellite connection of remote service center to off-shore wind farm. In this use, case 5G satellite network based on Low Earth Orbit (LEO) satellite used for set up satellite link connection with local control center in the wind power

Types of satellite orbits	Height, km	Number of satellites
Low earth orbit (LEO)	800	≈ 80
	1400	≈ 50
Medium earth orbit (MEO)	8000	≈ 10
Geostationary earth orbit (GEO)	35,786	≈ 3

Table 1.
Minimum satellites needed to maintain global radio coverage.

Types of satellite orbits	Delays in link "User terminal-satellite", ms		Maximum one-way delay, ms
	Minimum	Maximum	
LEO	3	15	30
MEO	27	43	90
GEO	120	140	280

Table 2.
UE to satellite propagation delay.

plant communication network includes a 5G satellite user device. It will be provided low satellite communication latency and high uplink/down data transmission volume.

However, these cases do not finish and limit possibility of 5G satellite segment applications and will be proceeded in 3GPP study in Release 17 on 5G evolution.

The main flaw of satellite segment consists in increased delay of information transfer owning to distance between user units and gNB base station. The requirements submitted to the quality of service for data transfer within 5G satellite segment also depend on the relevant number of satellites in operation. The minimum quantity of satellites in operation needed to maintain radio coverage for orbits of different heights [6] is shown in **Table 1**.

The signal delays forming for different satellite orbits and satellite limits on satellite segment delays are presented in **Table 2**. Additionally, the indicated delays are summarized with 5 ms delay, added by satellite. Therefore, maximum delay limits reach 30, 90, and 280 ms.

Other QoS-requirements (Default Priority Level, Packet Delay Budget, Packet Error Rate) for 5G satellite segment have set in 3GPP technical specifications.

3. Spectrum aspects of 5G satellite segment use

On the one hand, spectrum and wide bandwidth for 5G terrestrial networks will require utilization of millimeter-wave (mm-wave) bands to provide data transfer speed reaching up to 20 Gigabits per second in 5G radio interface connect with the process of delivery of the extended broadband mobile access (eMBB) service. On other hand such requirements to use frequency channels with bandwidth from 50 up to 400 MHz for eMBB-services can provide only in mm-wave bands which already utilized within satellite networks. That is why mm-wave bands in nearest future will turn out to be the most requested in 5G and satellite communications.

World Radiocommunication Conference 2019 (WRC-19) allocated of additional mm-wave frequency bands 24.25–27.5 GHz, 37–43.5 GHz, and 66–71 GHz for 5G terrestrial networks on a global basis. In a series of countries and regions, frequency bands of 45.5–47 GHz and 47.2-48.2 GHz received complimented allocation to terrestrial segment of IMT. This decision WRC-19 will be allowed to use some part of mm-wave bands on spectrum sharing basis for 5G satellite and 5G terrestrial network segments.

Table 3 shown the basic frequency bands allocated to fixed and mobile satellite services, sited within the band from 10.7 to 275 GHz, designed for satellite networks and satisfied the needs for 5G channel bandwidths [7].

The analysis of spectrum bands within 12.5–86 GHz has revealed the availability of frequency bands with total bandwidth equals 17.75 GHz in up-link (UL) bands and within 10.7–76 GHz – the availability of frequency bands with total bandwidth equals 20 GHz in down-link (DL) bands for satellite networks.

In order to ensure the provision of services in the field of mass deployment of IoT devices in 5G satellite segment, it was suggested that part of S-band should utilize as a potential option with 30 MHz bandwidth [8]:

- uplink (IoT device–satellite) in band: 1980–2010 MHz;
- downlink (satellite–IoT device) in band: 2170–2200 MHz.

The connection between satellite 5G base station gNB and feeder link of satellite network can be performed in one of the fixed satellite service bands.

Furthermore, the study of most popular frequency bands, namely Ka-band (28 GHz) and Q/V-bands (37–53 GHz), has exposed the following features which are to be considered while elaborating the solutions for 5G.

While considering the use of Ka-band for 5G satellite segment, one should bear in mind that:

- Ka-band is a traditional satellite band, enhancing access for satellite networks;
- a part of this band has allocated for 5G terrestrial networks on a global basis by WRC-19;
- a few national administrations are reviewing this band in terms of 5G terrestrial networks use.

While considering the use of Q/V-bands (37-53 GHz) for 5G satellite network, one should bear in mind that:

- V-band has not been used yet for satellite applications, in particular, for feeder lines of satellite network;
- a part of V-band has been added into bands which has allocated for 5G terrestrial networks on a global basis by WRC-19;
- 3GPP accelerates common efforts on joint researches as well as study of requirements attached to satellite as well as terrestrial segment of 5G in V-band in Release 17.

Thus, 5G satellite segment can be constructed as the multiband one, as well as 5G terrestrial segment, which was divided into frequency bands lower 6 GHz (FR1) and higher 6 GHz (FR2) also.

Up-link		Down-link		Intersatellite link	
Frequency range (GHz)	Bandwidth (GHz)	Frequency range (GHz)	Bandwidth (GHz)	Frequency range (GHz)	Bandwidth (GHz)
12.5–13.25	0.75	10.7–11.7	1.0	22.55-23.55	1.0
13.75–14.8	1.0	17.7–21.2	3.5	25.25-27.5	2.25
27.5–31.0	3.5	37.0–42.5	5.5	59.0-66.0	7.0
42.5–47.0	4.5	66.0-76.0	10.0	66.0-71.0	5.0
48.2–50.2	2.0	123.0-130.0	7.0	116.0-123.0	7.0
50.4–51.4	1.0	158.5-164.0	5.5	130.0-134.0	4.0
81.0–86.0	5.0	167.0-174.5	7.5	174.5-182.0	7.5
209.0–226.0	17.0	191.8-200.0	8.2	185.0-190.0	5.0
252.0–275.0	23.0	232.0-240.0	8.0		
Total of bandwidth	**57.75**	Total of bandwidth	**56.2**	Total of bandwidth	**38.75**

Table 3.
Frequency bands allocated to fixed and mobile satellite services.

4. Satellite segment architecture for 5G networks

The main standardization body – 3GPP responsible for technical specifications on 5G equipment and 5G infrastructure conducted first studies regarding 5G satellite segment use, while elaborating Release 14 within Technical report 3GPP TR 38913 [4].

5G satellite options, presented by 3GPP related to the deployment of 5G satellite segment, are designed for 5G services delivery in areas, where their provision by 5G terrestrial segment is impeded as well as for the services supported by satellite systems.

According to Report [4], 5G satellite segment is to complement 5G services, which delivering especially on road, rail and waterways as well as in rural regions, where access to 5G terrestrial segment is unavailable. 5G services supported via 5G satellite segment go beyond data and voice communications, providing connection with IoT devices and M2M, access to broadcasting services and a number of other services, that is tolerant of signal delays.

Partnership project 3GPP has come up with three options in respect of deployment, shown in **Table 4** [4].

The satellite orbits, shown in **Table 4** and in **Figure 1** enable using:

- Geostationary satellites (GEO), located at an altitude of 35,786 km, providing full coverage of the Earth by a constellation ranging from one up to three satellites between 70°N and 70°S;

- Medium Earth orbit (MEO), located at an altitude of 8000–20,000 km over the surface of the Earth, providing full coverage of the Earth by satellites ranging from 10 up to 12 satellites.

- Low Earth Orbits (LEO) at an altitude of 500–2000 km above the Earth secures the continuity of coverage by satellite network with satellites ranging from 50 up to 100 satellites.

Technical parameters	Option 1	Option 2	Option 3
Carrier frequency	Around 1.5 or 2 GHz for both DL and UL	Around 20 GHz for DL Around 30 GHz for UL	Around 40 or 50 GHz
Duplexing	FDD	FDD	FDD
Satellite architecture	Bent-pipe	Bent-pipe, on-board processing	Bent-pipe, on-board processing
Typical satellite system positioning in the 5G architecture	Access network	Backhaul network	Backhaul network
System bandwidth (DL + UL)	Up to 2 × 10 MHz	Up to 2 × 250 MHz	Up to 2 × 1000 MHz
Satellite orbit	GEO, LEO	LEO, MEO, GEO	LEO, MEO, GEO
UE distribution	100% out-of-doors	100% out-of-doors	100% out-of-doors
UE mobility	Fixed, portable, mobile	Fixed, portable, mobile	Fixed, portable, mobile

Table 4.
Satellites and frequency band options for 5G deployment.

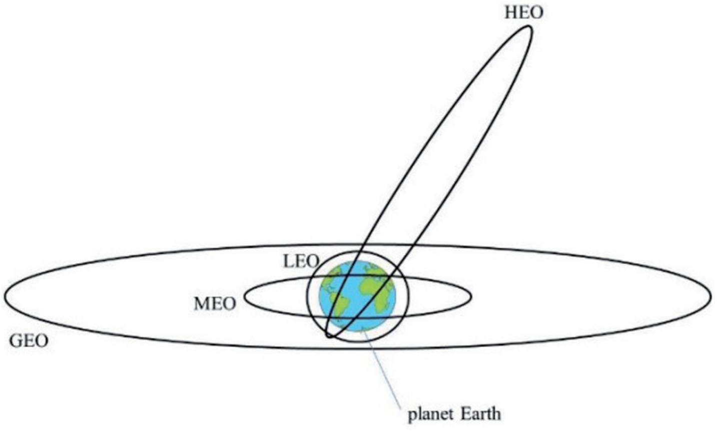

Figure 1.
Typical earth orbit of communication satellite.

The frequency bands, specified in **Table 4**, are applicable solely to a part of satellite bands (**Figure 1**), whereas modern satellite networks are deployed in broad spectrum of frequency bands, including L-band (1–2 GHz), S-band (2–4 GHz), C-band (3.4–6.725 GHz), Ku-band (10.7–14.8 GHz), Ka-band (17.3–21.2 GHz, 27.0–31.0 GHz), Q/V-bands (37.5–43.5 GHz, 47.2–50.2 GHz and 50.4–51.4 GHz), and higher.

The system architecture of 5G satellite segment is being constructed based on the use cases, mentioned in Section 1 of this chapter and two satellite technologies:

1. The architecture based on the technology of bent-pipe (with invisible satellite transponders without On-Board Processing) – this option envisages signal reception from user devices, its amplification, its transfer on other frequency and relaying in the direction of satellite gateway.

2. The architecture based on the technology of On-Board Processing (with satellite transponders, complimented with data processing on board) – this

option implies signal reception from user devices, its regenerations, including modulation and demodulation, encryption and decryption of these signals. The architecture on-board processing also provides for the partial allocation of base station equipment on the board of a satellite.

In December 2017, 3GPP in scope of work on Release 16 was published Report on using satellite access in 5G [3]. The Report submitted new business cases of 5G satellite segment utilization, including Internet of Things alongside with the requirements for performance of cross-border connections and the key characteristics for satellite segment of 5G: types of orbits, coverage area, and signal delays during propagation, network architecture for 5G satellite segment.

In accordance of proposed solutions, 5G satellite segment is inculcated into the integrated radio access network (5G RAN), which will be used satellite infrastructure and 5G core network (5G Core). 5G core can be linked up with the other generation RANs, in particular, 4G RAN, apart from satellite segment for 5G.

System architecture of 5G satellite segment, which is to be set up in accordance with the technology of bent-pipe (with transparent satellite transponders) when signal use solely to amplification and signal conditioning on retention of a modulation type has shown in **Figures 2** and **3**.

As one can see in **Figures 2** and **3**, bent-pipe architecture refers to the architecture where the satellite transponders are transparent: only amplify and change frequency but preserve 5G waveform.

One of the important features of 5G radio access network design is that gNB base stations have a distributed architecture (**Figure 4**) and consist of a central module gNB-CU and one or more distributed modules gNB-DU(s) [9].

The gNB-CU and gNB-DU modules are connected by a logical interface F1. The distributed module gNB-DU supports one or more cells and can only be attached to one central module gNB-CU. This architecture of the gNB base station allows to implement the concept of building an integrated 5G radio access network by placing the gNB-CU and gNB-DU modules at earth stations and realization of F1-interface as a space link based on bent-pipe technology.

System architecture of 5G satellite segment when gNB-CU and gNB-DU modules connected each other through F1-interface by satellite links for on bent-pipe technology has shown in **Figure 5**.

Next options of bent-pipe architecture of 5G satellite segment has used for retranslation NG1 and NG2 interfaces, which connecting 5G base stations gNBs to 5G core. This architecture of 5G satellite segment is shown in **Figure 6**.

In case where 5G user device (UE) has opportunity to use satellite modem with non-3GPP radio interface for bent-pipe architecture of 5G satellite segment, the architecture option of such segment could design as shown in **Figure 7**. 5G satellite segment architecture shall support different configurations where the radio access network is either a satellite NG-RAN or a non-3GPP satellite access network, or both.

Figure 8 shows the 5G satellite segment system architecture implemented on the basis of on-board signal processing technology (with partial deployment of base

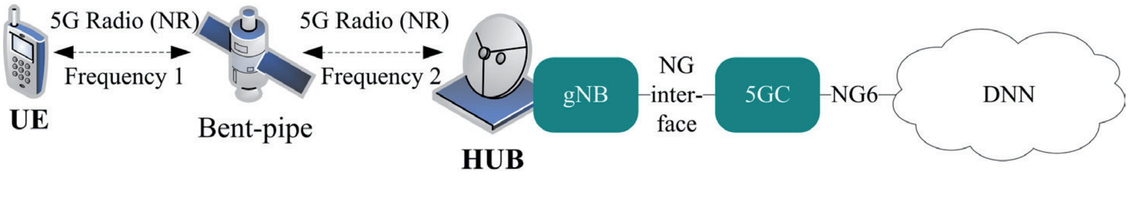

Figure 2.
Signals relay architecture for 5G NR radio interface.

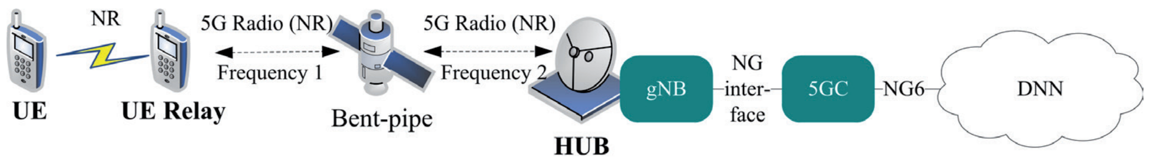

Figure 3.
Relaying architecture based on 5G user device with UE relay.

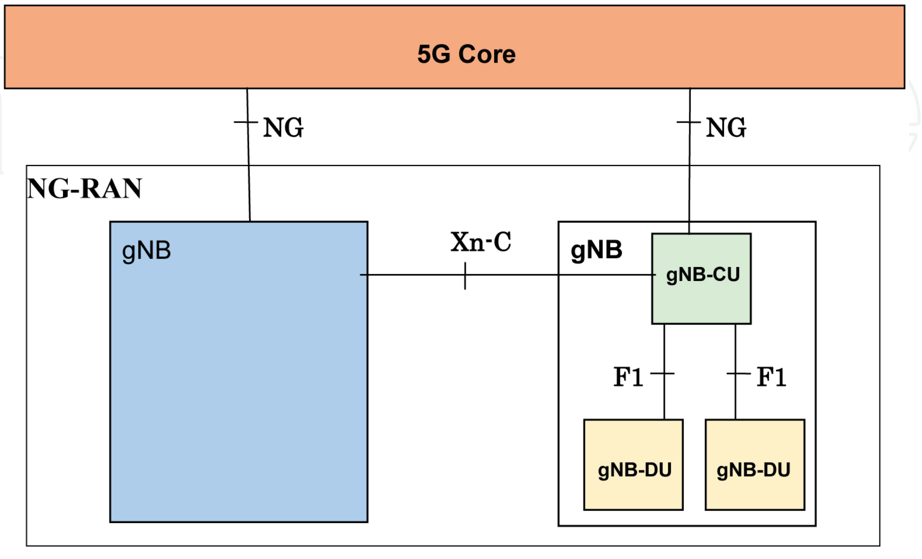

Figure 4.
Architecture 5G base station gNB.

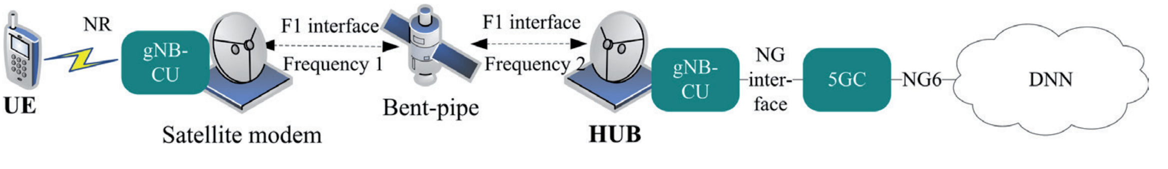

Figure 5.
Architecture 5G base station gNB with F1-satellite interface.

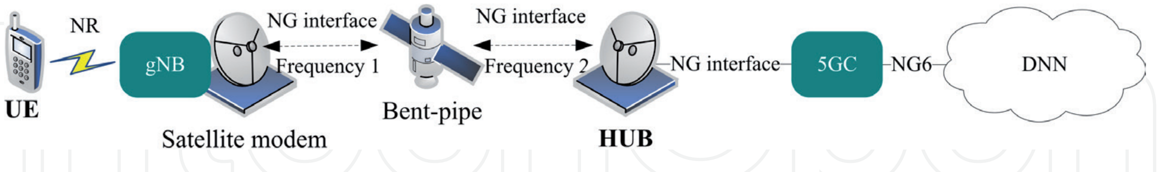

Figure 6.
Signals relay architecture for NG1 and NG2 interfaces.

station processing equipment in satellite). As on-board signal processing payload uses distributed module gNB-DU of 5G base station and as satellite link utilizes 5G NR radio interface.

In accordance design principle of base stations gNBs, some distributed modules gNB-DUs can connect to only one central module gNB-CU. That makes easier 5G coverage of big areas. The solution for 5G satellite segment architecture on regenerative payload enabled NR-RAN with intersatellite links (ISL) for regional or global coverage shown in **Figure 9** [10]. Intersatellite links provide logical F1-interface between distributed modules gNB-DUs, which use Satellite Radio Interface (SRI) over F1 as a transport link between remote radio unit with gNB-CU and satellites.

Second solution for 5G satellite segment architecture (**Figure 10**) has used 5G base station gNB on satellite (as regenerative payload) enabled NR-RAN with ISLs that provide SRI application over Xn-C and Xn-U interfaces. In this case between remote radio units and satellite gNBs will be used, and 5G standard NG-interfaces connect these gNBs with 5G core network.

Mobile devices of 5G satellite segment architecture (**Figures 2–10**) will be presented on the market by user terminals as well as the other wearable devices, installed in cars, ships, planes, etc. Nowadays the potential of wearable satellite user

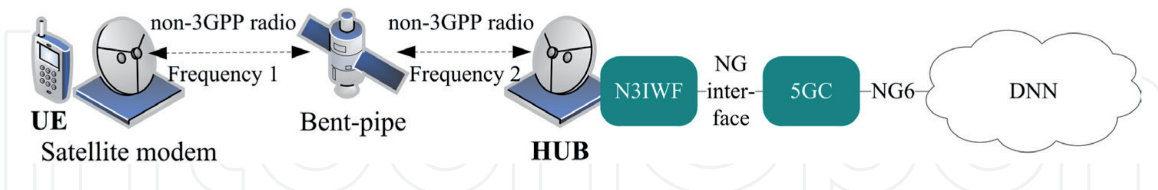

Figure 7.
Signals relay architecture for non-3GPP interface.

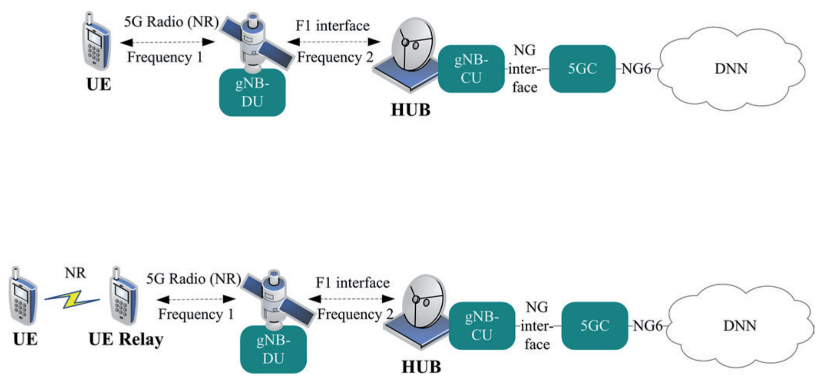

Figure 8.
5G satellite segment architecture based on the on-board processing technology [4].

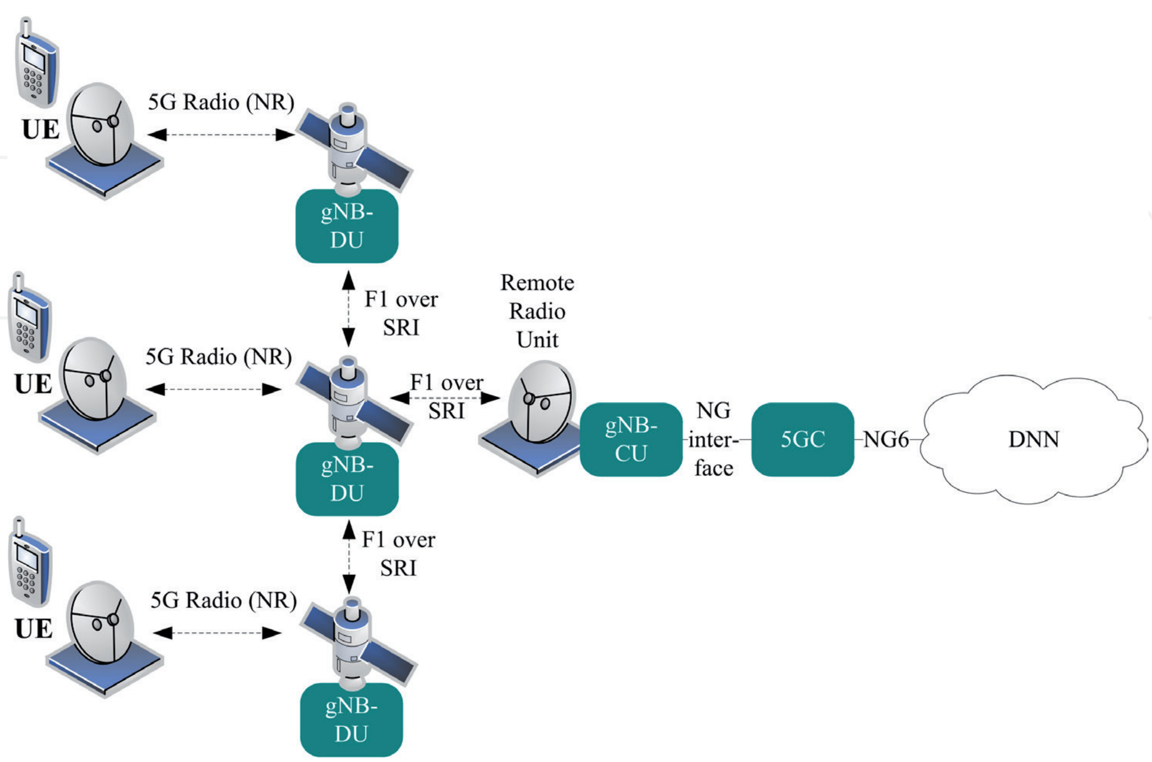

Figure 9.
5G satellite segment architecture on regenerative satellite payloads enabled NR-RAN, with ISL for regional or global coverage.

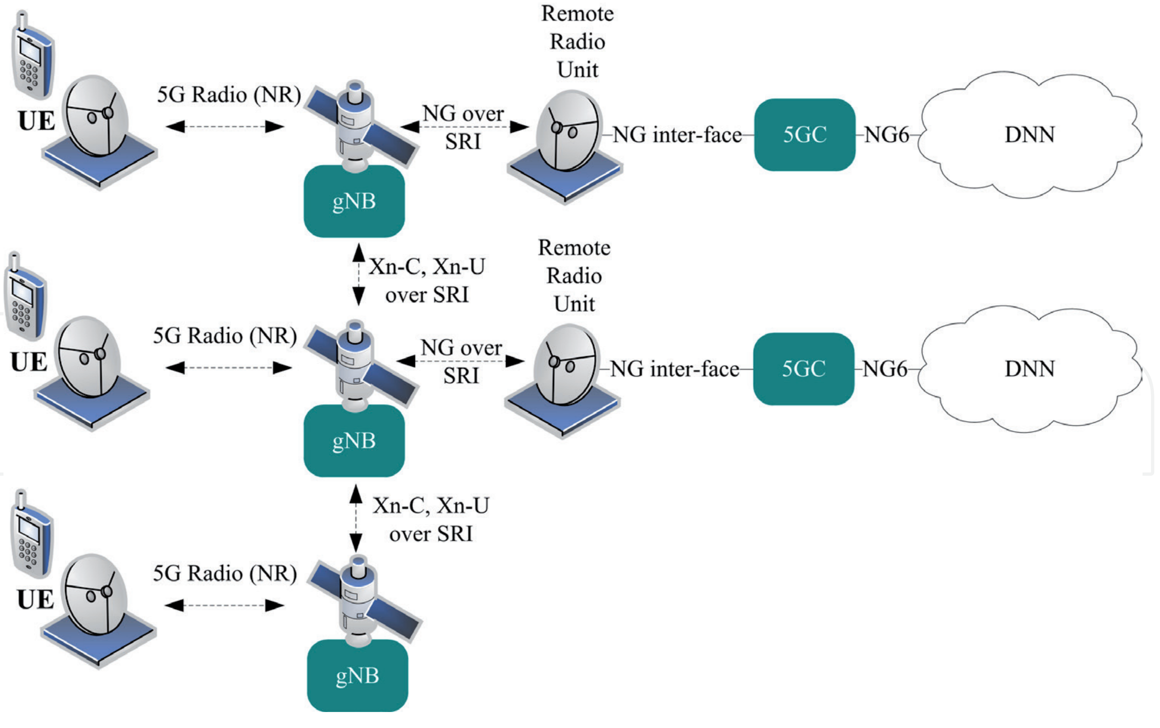

Figure 10.
5GS with regenerative satellite enabled NR-RAN, with ISL and multiple 5G Core connectivity.

terminals is limited to L- and S-frequency bands. However, the studies regarding the potential functioning of 5G satellite user terminals within Ku and mm-wave bands are still ongoing.

5. Projects of the leading manufacturers and researchers

Analysis of proposals and technological projects launched by leading manufacturers and related to usage of satellite networks for expanding the capabilities of 5G networks shows that Boeing [11] and Samsung [7] companies have already tried to make presentations of their projects applicable for 5G satellite segment deployment.

The Boeing company requested the US Federal Communications Commission for permission to launch and operate fixed satellite service (FSS) network on non-geostationary orbit (NGSO). The network would operate in a low-Earth orbit (LEO) in the frequency band 37.5–42.5 GHz (space-Earth) and in the frequency bands 47.2–50.2 and 50.4–52.4 GHz of V-band (Earth-space); it would be used as a NGSO system providing solution of 5G satellite segment operation issues.

The Boeing proposed NGSO system as depicted in **Figure 11** and considered as a 5G satellite segment that is designed to provide a wide range of modern telecommunication services alongside with 5G internet services for a broad types of V-band earth stations and user terminals. V-band user terminals use modern antenna arrays for transmitting and receiving broadband signals in channels of different pass bands. It is to note that a high throughput is supported by multichannel and multiple polarization terminals.

The Boeing presented NGSO system would consist of 2956 LEO satellites for the fixed satellite service network providing high throughput low latency access for user terminals connected through gateway (“hubs”) access to 5G network and to a terrestrial optic-fiber network as backhaul connecting to 5G.

The system gateways are expected to be located outside the densely populated areas in the regions with relatively low consumer demand for 5G services. Each

NGSO satellite would form beams, corresponding to cell diameter from 8 up to 11 km on the Earth surface within the overall satellite coverage area.

The NGSO system gateways would operate in the same V-band as user terminals. These gateways would support both frequency and polarization selection of signals with two types of antennas polarization LHCP (Left Hand Circular Polarized) and RHCP (Right Hand Circular Polarized). In addition, the access gateways may contain more than one antenna thereby providing simultaneous access to multiple NGSO satellites visible from a relevant access gateway.

At the first stage of deployment, the Boeing NGSO system would comprise a constellation of 1396 LEO satellites in an altitude of 1200 km. The initial satellite constellation would consist of 35 circular orbital planes with an inclination of 45° and additional 6 circular planes inclined at 55°.

The NGSO system payload (**Figure 12**) would use the improved space-time processing in the course of antenna beam-forming as well as on board digital

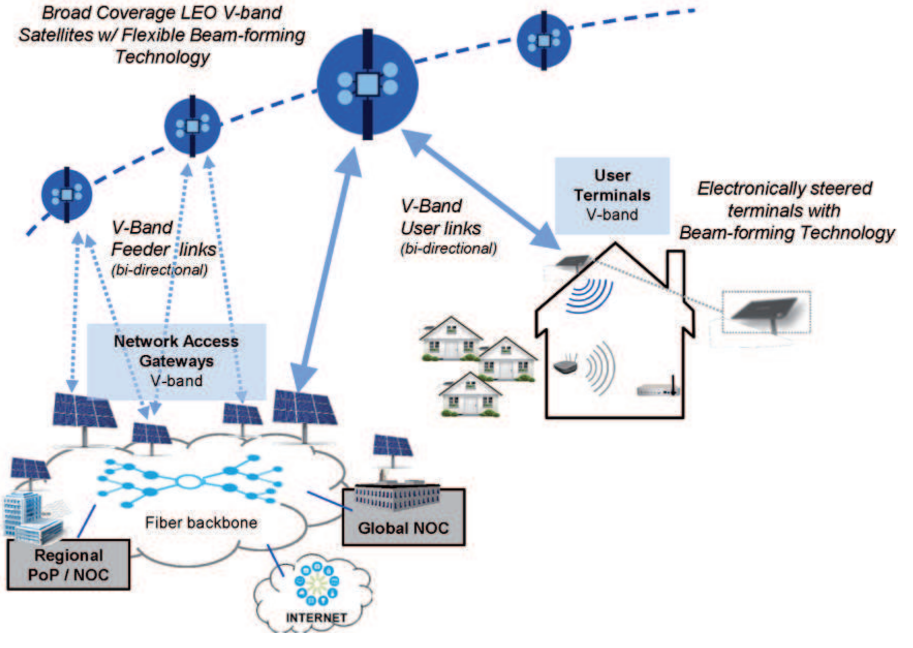

Figure 11.
Satellite solution of the Boeing company.

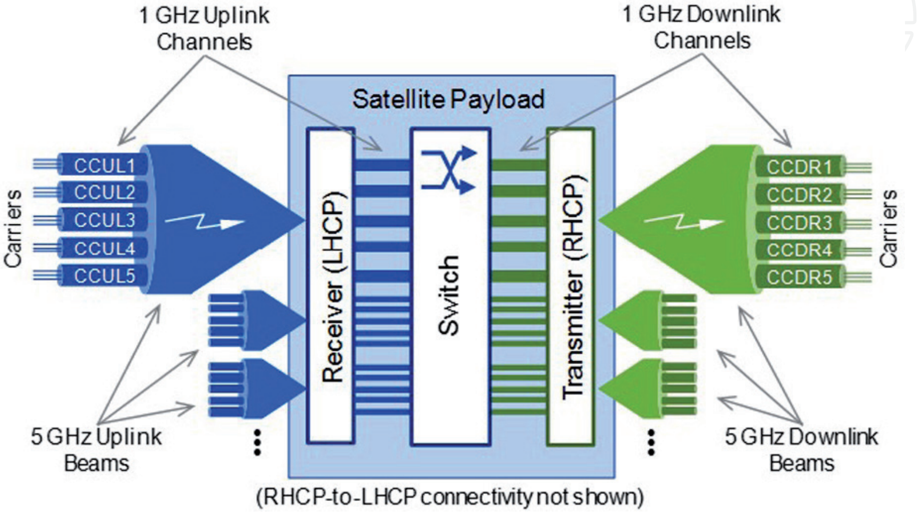

Figure 12.
Scheme of on-board processing payload.

processing so as to generate thousands of narrow-band beams to provide 5G network services through satellite segment on the Earth surface.

Each satellite up-link or down-link may consist of up to five channels of 1 GHz pass band resulting in a total pass band of 5 GHz depending on instant capacity required for a cell supported by a relevant satellite antenna beam. Any satellite UL-channel may be connected to any satellite DL-channel in compliance with used connection algorithm.

Boeing company estimation results show that usage of a satellite network for fixed satellite channels and its spectrum sharing with a 5G terrestrial network in the frequency band 37.5–40.0 GHz would be feasible under the following conditions:

- the frequency band 37.5–40.0 GHz is used only for signal reception in FSS network downlink;
- spectrum sharing between 5G satellite segment and 5G terrestrial segment is feasible due to high satellite elevation angles;
- applying of space-time selection beam-forming methods for terminal antennas of satellite networks and 5G equipment in the aim to achieve higher data rate.

The power flux density (PFD) limits approved by ITU [11, 12] would provide protection for 5G network terrestrial segment from interference caused by FSS satellite network downlinks subject to meeting the requirement of minimal reducing of 5G terrestrial network signal level to 0.2–0.6 dBW.

Boeing simulation results also show that in the assumed spectrum sharing scenario the increasing of 5G base station power would result in enlarging a number of satellite receivers affected by interference from 5G users. Hence, it is required to adopt a (>50 dBW) level of mitigating the interference from 5G networks between FSS earth station receivers and transmitting mobile and base stations of 5G terrestrial segment.

The results of Boeing statistical simulation and quantitative estimation of interference levels show that:

- satellite earth stations may be in a higher degree directly affected by 5G base stations interferences;
- EIRP values for 5G terrestrial segment should be limited to 62–65 dBW, so as to facilitate interference-free shared operation of 5G satellite and terrestrial segments of FSS system to provide for achieving the required data transfer rates in 5G networks.

Therefore, the joint deployment of satellite and terrestrial segments of 5G network is subject to particular conditions related to joint use of spectrum in V-band.

As confirmation, possibility of successfully utilization integrated satellite segment into 3GPP 5G testbed networks was the last demonstration of Surrey University achievements in 5G satellite network development [13].

Three use cases were demonstrated over a live satellite network via Avanti's GEO HYLAS 4 satellite and using iDirect's 5G-enabled Intelligent Gateway (IGW) satellite ground infrastructure that to 5G testbed core network of the University of Surrey to 5G UE terminals. All the 5G testbed use cases used this integrated 5G satellite system for the live satellite connectivity.

The use-case for 5G moving platform was demonstrated over SES's O3b MEO satellite system, using real terminals and 5G core network.

6. Conclusion

The need to provide the coverage of large areas of developed countries with 5G networks and the creation of 5G satellite segment of integrate 5G system become relevant issues of development and standardization of 5G networks at the second stage of building these networks in the period 2020–2025, playing the pivotal role in forging Digital economy.

3GPP efforts allowed to obtain many different use cases of 5G satellite segment applications, architecture solutions on bent-pipe, and on-board processing technologies, which would implement in development of future satellite systems.

The leading international organizations in the field of telecommunications as ITU, 3GPP, 5G PPP joined their efforts with consortiums and satellite manufacturers in conducting the researches related to the elaboration of 5G within the radio frequency ranges that have been allotted to satellite radio service to 5G on WRC-19, especially in S-, Ka- and V-bands.

One of the most important issues of 5G satellite segment future development may refer to shared spectrum usage in the frequency bands allocated to 5G satellite and terrestrial segments on the primary basis. Also urgent is the issue of intersystem electromagnetic compatibility of aboard equipment and earth stations with base stations and user devices of 5G terrestrial segment.

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References

[1] The European Space Agency Will Promote Satellite 5G Internet. Available from: http://mediasat.info/2017/06/23/esa-satellite-for-5g/

[2] CEPT ECC Report "Satellite Solutions for 5G". Approved: May 18, 2018

[3] 3GPP TR 22.822. 3rd Generation Partnership Project; Technical Specification Group Services and System Aspects; Study on Using Satellite Access in 5G; Stage 1 (Release 16)

[4] 3GPP TR 38.913. 3rd Generation Partnership Project; Technical Specification Group Radio Access Network; Study on Scenarios and Requirements for Next Generation Access Technologies; (Release 15)

[5] Recommendation ITU-R M.2083. IMT Vision-"Framework and overall objectives of the future development of IMT for 2020 and beyond". Accessed: September 2015

[6] 3GPP TR 22.737. 3rd Generation Partnership Project; Technical Specification Group Services and System Aspects; Study on architecture aspects for using satellite access in 5G (Release 16)

[7] Khan F. Mobile Internet from the Heavens. Richardson, Texas, USA: Samsung Electronics; 2015

[8] Eneberg J. Satellite Role in 5G, Inmarsat; 2017

[9] 3GPP TR 38.104. 3rd Generation Partnership Project; Technical Specification Group Radio Access Network; NG-RAN; Architecture description (Release 15)

[10] 3GPP TR 38.821. 3rd Generation Partnership Project; Technical Specification Group Radio Access Network; Solutions for NR to support non-terrestrial networks (NTN) (Release 16)

[11] Boeing Seeks Permission to Launch Satellite Constellation in Same V-Band Spectrum as 5G Systems. Available from: https://www.fiercewireless.com/tech/boeing-seeks-permission-to-launch-satellite-constellation-same-v-band-spectrum-as-5g-systems/

[12] Boeing Company. Application for Authority to Launch and Operate a Non-Geostationary Low Earth Orbit Satellite Systemin the Fixed Satellite Service. FCC, [Accessed: June 22, 2016]

[13] SaT5G Project Demonstrates 5G over Satellite and Holds Industry Briefing at University of Surrey. Available from: https://www.sat5g-project.eu/sat5g-industry-day-27-november