

Reference Models of Satellite Segment Integration for NTN 5G

Valery Tikhvinskiy^{1,2}, Yevgeniya Daineko¹, Altay Aitmagambetov¹, Aigul Kulakayeva¹, and Bagdat Kozhakhmetova¹

¹International Information Technology University, Manas St. 43/1, Almaty, 050000, Kazakhstan

²Radio Research and Development Institute, 105064, Moscow, Russia

Abstract

Currently, international communications organizations are carrying out a large amount of research on the use of satellite communications in the unified telecommunications of a new generation, related to the 5G and 6G generations.

These studies were initiated by the SaT5G project, which is part of EU Horizon 2020 Research Program (FP-8). The concept of the SaT5G project was to develop cost-effective "plug and play" solutions for 5G satellite communications, which can enable telecom operators and service providers to accelerate the deployment of 5G in all geographical regions and at the same time create new and growing market opportunities for stakeholders in the satellite communications industry. This article analyzes the research results of several international organizations for standardization and development of telecommunications as ITU-R, 3GPP, and ETSI, and their applicability for the construction of satellite segment in the non-terrestrial network (NTN) in 5G integrated network.

Keywords

3GPP; 5G integrated network; ISL; LEO; NTN; reference model

1. Introduction

Reference models of 5G satellite segment proposed in Technical Specifications of 3G Partnerships Project (3GPP) differ in the following parameters [1-3]:

- satellite grouping orbits used to create a 5G satellite segment;
- type 5G satellite segment access equipment used on board the communication satellite;
- type of signal processing on board the communication satellite;
- type of interfaces and protocols used for inter-satellite communication lines (ISL) of 5G satellite segment transport network;
- the number of satellite gateways connecting the non-terrestrial network (NTN) in 5G integrated network with the public access data network.

Reference models of space data processing and transmission systems of the 5G satellite segment can be created on:

- satellites in low Earth orbit (LEO);
- satellites with medium Earth orbit (MEO);
- satellites with geostationary Earth orbit (GEO);
- satellites in high elliptical orbits (HEO).

Reference models of space data processing and transmission systems can use three payload types on board of communications satellites:

Proceedings of the 7th International Conference on Digital Technologies in Education, Science and Industry (DTESI 2022), October 20–21, 2022, Almaty, Kazakhstan

EMAIL: vtiir@mail.ru (Valery Tikhvinskiy); y.daineko@iitu.edu.kz (Yevgeniya Daineko); a.aitmagambetov@iitu.edu.kz (Altay Aitmagambetov); a.kulakayeva@iitu.edu.kz (Aigul Kulakayeva); kozhahmetova.ba@gmail.com (Bagdat Kozhakhmetova)

ORCID: 0000-0002-3443-5171 (Valery Tikhvinskiy); 0000-0001-6581-2622 (Yevgeniya Daineko); 0000-0002-7808-5273 (Altay Aitmagambetov); 0000-0002-0143-085X (Aigul Kulakayeva); 0000-0002-9566-3629 (Bagdat Kozhakhmetova)



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CEUR Workshop Proceedings (CEUR-WS.org)

- Regenerative payload;
- Transparent payload (Bent pipe payload);
- Payload with on-board processing.

Reference models of 5G satellite segment satellite data processing and transmission systems can use various types of inter-satellite channels (ISL) in the case of using a constellation of satellites (for example LEO). At the same time, the reference model must necessarily be built using a regenerative payload on board satellites.

Constellations of LEO and MEO satellites can be used to provide services in both the northern and southern hemispheres. In some cases, the constellation may even provide global coverage, including polar regions. In the latter case, this requires an appropriate inclination of the orbit, a sufficient number of generated beams and inter-satellite communication based on ISL transport channels.

Thus, reference models of 5G satellite data processing and transmission systems should take into account the following features:

1. ISL inter-satellite channels can operate in the radio frequency or optical bands.
2. According to the structure, ISL inter-satellite channels can have a one-hop or over multihop procedure for transmitting service and space data of the 5G satellite segment in the constellation of satellites.
3. ISL inter-satellite channels can be built using Integrated Access and Backhaul (IAB) technology based on the interfaces and protocols of the 3GPP Partner Project used in 5G mobile networks, or they can use a non-standardized 3GPP structure of interfaces and protocols.

2. Analysis of standardization of the 5G satellite segment by the 3GPP and ITU-R Partner Project

The process of standardization of the results of work on the use of satellite communications in unified telecommunications of the new generation is shown in Figure 1 [4-5].

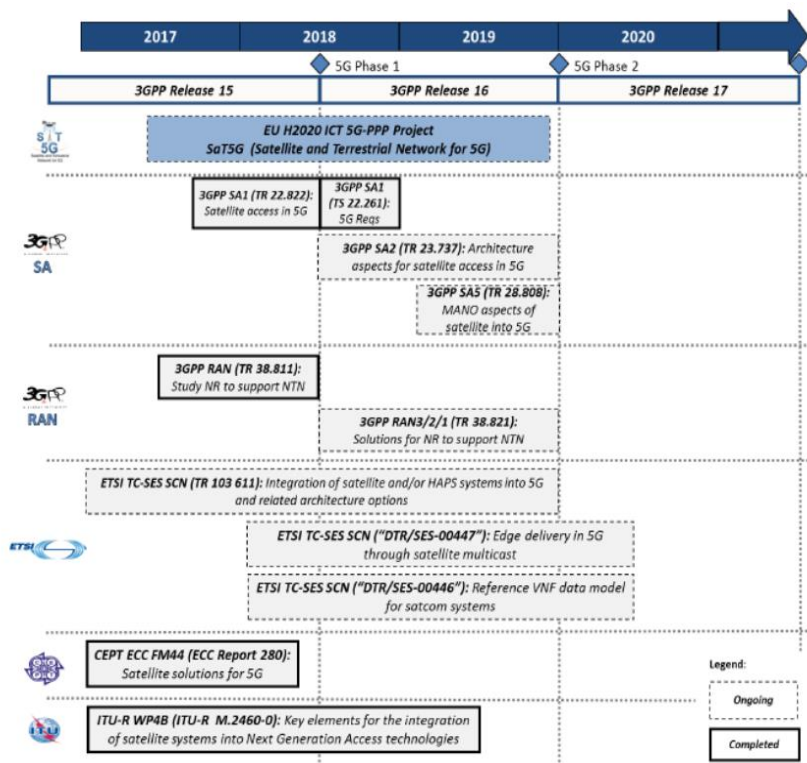


Figure 1: The process of international standardization of satellite communications in unified telecommunications of the new generation [5]

Carrying out work in the ITU-R Radio Sector. According to ITU-R Resolution 69, the report M.2460-0 (07/2019) "Key elements for the integration of satellite systems into next-generation access technologies" was prepared as part of the work related to the 4th Research Commission (RC4 or SG4) [6].

The ITU-R M.2460-0 (07/2019) report examines the role of satellite systems in Next Generation Access Technologies (NGAT) or STIN (Satellite Terrestrial Integrated Network) in the terminology of the 3GPP Partner Project, which will be a highly developed, ubiquitous, seamlessly integrated heterogeneous "network of networks" or "system of systems" [6].

Both GEO geostationary satellite networks and LEO non-geostationary satellite systems, MEO provide networking capabilities with NGAT/STIN technology.

In addition to the target study M.2460-0 (07/2019), the ITU-R Sector also prepared two Recommendations used in the study of the satellite segment of 5G networks to assess the parameters and capabilities of the radio access equipment used [7,8]:

- Recommendation ITU-R P.681-10, "Data on the propagation of radio waves necessary for the design of ground-space mobile communication systems" (12/2017).
- Recommendation ITU-R P.618-13, "Propagation data and forecasting methods necessary for the design of telecommunication systems Earth-space" (12/2017).

2.1. Activities of the target working groups on the Radio Access Network (RAN) and system Aspects (SA) of the 3GPP Partner Project to create a 5G satellite segment

Technical Specification Development Groups on non-terrestrial infrastructure of 5G networks (Non-Terrestrial Networks, NTN) were created by 3GPP in 2017 and are still continuing their work.

According to the definition of 3GPP, satellite part of non-terrestrial networks are understood as networks or segments of communication networks using on-board or satellite radio-electronic means to create a relay node with radio transmitting equipment or a base station of a mobile communication network [1-3].

3GPP classification of Non-Terrestrial Networks is shown in Figure 2.

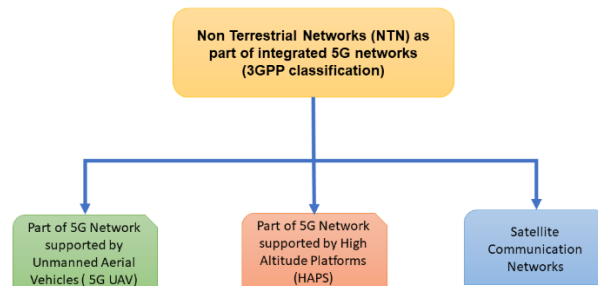


Figure 2: Classification applied by the 3GPP for non-terrestrial networks

Thus, in addition to satellite communication networks, non-terrestrial networks of 5G integrated network include communication networks based on high-altitude platforms (HAPS) and communication networks based on low-flying unmanned aerial vehicles (UAV) platforms.

Table 1 [5] lists all areas of research on the non-terrestrial infrastructure of 5G NTN, including the use of a satellite segment of the 5G integrated network, from Release 15 to Release 17 of 3GPP.

As can be seen from Table 1, each working question of 3GPP research is associated with a leading group (i.e., groups R for RAN aspects and groups S for system aspects), and the date indicates the time limit at which the research was completed or should be completed. The final work on the Technical Specifications of the 3GPP Release-17 is scheduled to be completed in the second quarter of 2022.

We will conduct a brief analysis of Technical Reports and Specifications related to NTN (satellite and platform segment of 5G networks) prepared by 3GPP.

Technical Report TR 38.811 [2] defines deployment scenarios for non-terrestrial (satellite) networks and corresponding system parameters (for example, architecture, altitude, satellite constellation orbit, etc.), adapts 3GPP channel models for NTN, describes deployment scenarios, identifies key areas of impact on NR interface.

Technical Report TR 38.821 [1] investigated a set of necessary functions/adaptations that ensure the operation of the NR 5G radio interface in NTN with priority of satellite access to the 5G network. Related solutions were identified, the performance of the NR 5G radio interface was evaluated in selected deployment scenarios (access to LEO satellites, access to GEO satellites) through modeling at the channel and system level, solutions related to NR, levels 2 and 3 of the network system architecture, as well as solutions for the RAN network architecture and the corresponding interface protocols.

Table 1
Research questions on non-terrestrial infrastructure of 5G networks

Number Release	Working group number	The issue under study	Date of completion of the study
Release 15	R1	Study on NR to support Non-Terrestrial Networks	June 2018
Release 16	R2	Study on solutions for NR to support Non-Terrestrial Networks	December 2019
	S1	Integration of satellite access in 5G	June 2018
	S2	Study on architecture aspects for using satellite access in 5G	June 2020
	S5	Study on management and orchestration aspects with integrated satellite components in a 5G network	June 2020
Release 17	R1	Study on NB-IoT/eMTC support for Non-Terrestrial Networks	June 2021
	S2	Integration of satellite components in the 5G architecture	September 2020
	R2	Solutions for NR to support Non-Terrestrial Networks	December 2021

Technical Report TR 22.822 "Research on the use of access to satellite capabilities in 5G. Stage 1" (Release 16) [3] reviewed the business cases of the satellite segment of the 5G network, the main of which is the Internet of Things. The report defines the requirements for cross-border connection scenarios, as well as the main characteristics of the satellite segment of the 5G network: classes of orbits, geometry of coverage areas and signal delays during propagation, network architecture of the satellite segment of the 5G network.

In addition, the report examines the continuity of service between the ground-based NGRAN and the satellite component NG-RAN based on NTN, owned by the same operator or used by agreement between the operators. The report also identifies service delivery options when considering the integration of 5G NTN-based access components into a 5G system and, as a result, new services and requirements (i.e. installations, configurations, maintenance and regulation) are found.

The Technical Specification TS 22.261 "Requirements for servicing new services and new generation markets" [9] substantiates the requirements for the 5G network to be able to provide services using the satellite access segment. The specification contains service and operational requirements for UE subscriber devices, NG-RAN radio access network and 5G Core base network.

Technical Report TR 23.737 [10] defines the areas of influence of satellite integration of non-terrestrial NTN networks into the 5G system when considering use cases TR 22.822 [3], finds solutions for adjusting the 5G system for impact areas for three use cases (i.e. roaming between the terrestrial and NTN 5G segment, between the fixed 5G transport network between NG-RAN based on NTN and 5G Core, as well as solving problems related to the interaction of the NG-RAN network and the 5G Core network.

Technical Report TR 28.808 [11] has identified the main key issues related to business roles, service and network management, as well as 5G network orchestration with integrated satellite components, and is exploring appropriate solutions. These technical solutions are aimed at minimizing both the impact and complexity of satellite integration into existing business models, as well as in the management and orchestration aspects of existing 5G networks.

Thus, the analysis of the main research results of 3GPP and ITU-R on the use of satellite communications in unified telecommunications of the new generation 5G and 6G showed that their efforts are aimed at forming flexible reference models of the satellite segment of NTN, allowing the use of various types of satellites payload based on both implementations of the NR-RAN radio access network interfaces of 5G networks, as well as other interfaces not standardized by 3GPP.

The main principle of building a new generation of 5G and 6G networks will be the use of an integrated network architecture that allows the integration of satellite networks to create non-terrestrial networks as part of an integrated 5G network.

3. Analysis of reference models of the architecture of the satellite segment of the 5G network

Consider a reference model of a space data processing and transmission system using a transparent payload and elements of NG-RAN architecture.

This reference model assumes the following features of its implementation (Figure 3.):

- The satellite payload implements frequency conversion and amplification of radio frequency signals both in the communication line up and in the communication line down. The model, in fact, corresponds to an analog repeater of satellite signals of previous generations.
- The onboard radio equipment of the satellite repeats the signals transmitted in the NR-G radio interface from the feeder line (between the NTN gateway and the satellite) to the service line (between the satellite and the UE) and vice versa.
- The satellite radio interface (SRI) on the feeder line is NR-Uu. In other words, the satellite does not terminate the communication line from the subscriber terminal for the NR-Uu physical interface.
- The NTN GW gateway supports all the necessary functions for forwarding the NR-Uu interface signal to the public data network via the gNB base station of the 5G network on the ground.
- The gNB base station of the 5G network interacts with the 5G Core reference network via the NG logical interface and further via the N6 interface with the public data network.
- Various satellites with transparent payloads can be connected via the NTN GW gateway to the same gNB base station of the 5G network on earth.

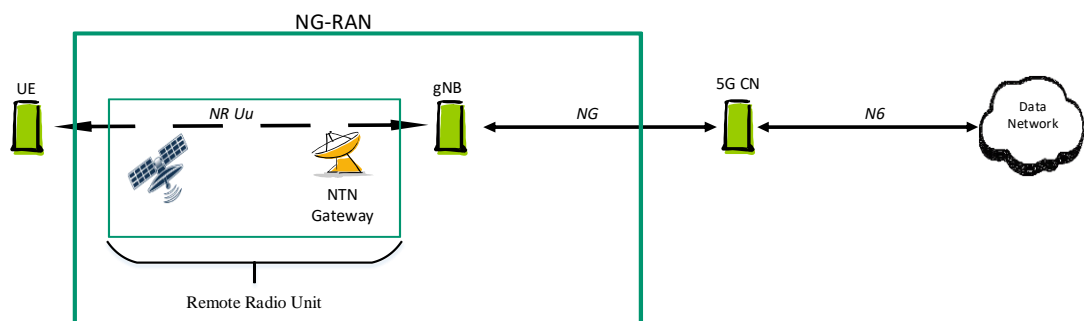



Figure 3: Reference model when using transparent LEO payload for NG-RAN radio interface

The reference model architecture for the satellite segment of 5G integrated network and the transparent payload on the LEO satellite, implementing the NG Uu physical interface standardized by 3GPP in the service and feeder channels is shown in Figure 4. This figure also shows user data streams (session PDUs) and service data streams that provide QoS through the Radio Bearers radio channel management service and formed tunnels in the User Plane (UP) for NG-U logical interface. The

connection of UE to the 5G network via the RAN is carried out on the basis of the technical requirements of 3GPP. The UP protocol stack is shown in Figure 5.

Figure 5 the sign  shows HF processing of incoming and outgoing signals and frequency switching.

As can be seen from Figure 4. User data is transmitted between the UE subscriber terminal of the 5G network and the 5G Core reference network, in accordance with the algorithms for 5G protocols, but through the NTN GW ground gateway without changing the structure of the 5G protocols.

The control plane (CP) protocol stack for the 5G satellite segment reference network with transparent payload is shown in Figure 6.

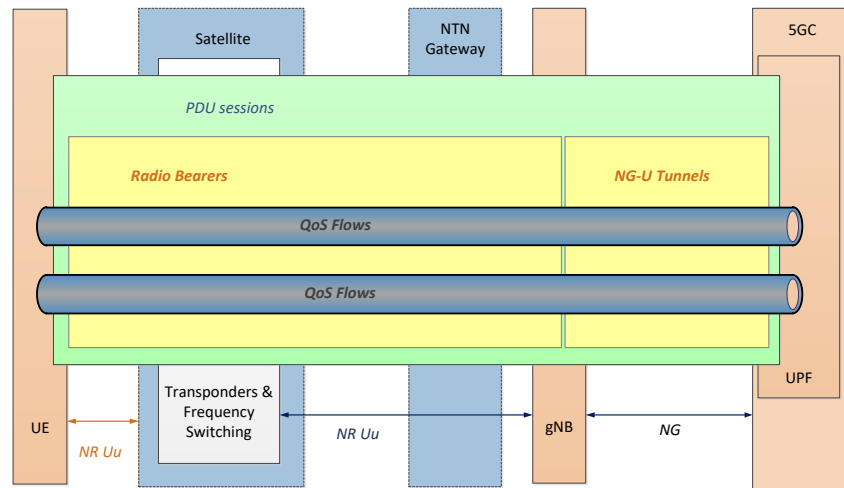


Figure 4: Architecture of a 5G reference network with a physical NR Uu interface and a LEO satellite with a transparent payload

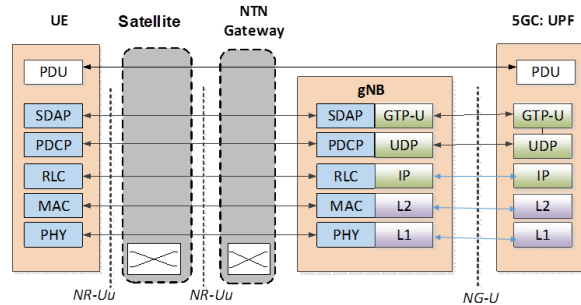


Figure 5: Protocol stack in the user plane for the reference network of the 5G satellite segment with a transparent payload

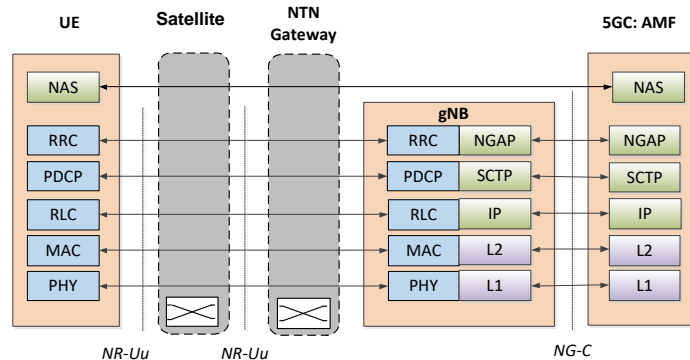



Figure 6: Protocol stack in the CP for a reference model of a 5G satellite segment network with a transparent payload

Figure 6 shows  HF processing of incoming and outgoing signals and frequency switching.

Analysis of the UP and CP protocol stacks for the 5G satellite segment with a transparent payload shows that there is no need to modify the NG-RAN architecture to support satellite access when using a transparent payload. The timers of the NR-Uu physical radio interface between UE and LEO satellite may have to be expanded, compared to 5G terrestrial network, in order to cope with the long signal delay in the feeder line and service line. In the context of the LEO scenario with inter-satellite lines ISL, the delay in question should include at least the delay of SRI logical interface feeder line between the NTN GW gateway and LEO satellite and in one or more ISL lines.

The CP and UP protocols terminate on the Ground in the public data network (DN). As for CP, this reference model does not create any special problems in its use, except for the need to adapt to a much longer signal transit time back and forth over the physical radio interface of the Uu. This problem can be solved by implementing a reference model. Analysis of User Plane for the reference model shows that, with the exception of problems with signal delay due to a longer receive-transmit time for packets in the UP, UP protocol itself does not require changes. However, a longer delay on the physical Uu interface will require more buffering for UP packets in the gNB base station of the 5G network.

4. Reference model of a system for processing and transmitting space data using a regenerative payload for the LEO constellation of satellites

This reference model assumes the following features of its implementation (Figure 7):

- LEO satellite constellation is used to provide continuous customer service.
- On board the LEO communication satellite, the payload of the communication satellite implements the regeneration of signals received from Earth via the NR-Uu physical radio interface.
- The NR-Uu interface is used in the service channel - the channel between the UE subscriber terminal of the 5G network and the LEO satellite on which a fully functional gNB base station is implemented in the form of a regenerative payload through which access to the data transmission network is organized.
- The satellite radio interface (SRI) is implemented on the feeder channel - the channel between the NTN GW gateway and the LEO satellite on top of which the NG over SRI (Satellite Radio Interface) standardized 3GPP is organized.
- The transport channel between NTN GW and the satellite is based on the SRI interface, from the NTN GW gateway to the 5G Core network, the logical interface NG standardized by 3GPP is used.
- The 5G Core network interacts via the N6 logical interface with the public data network.

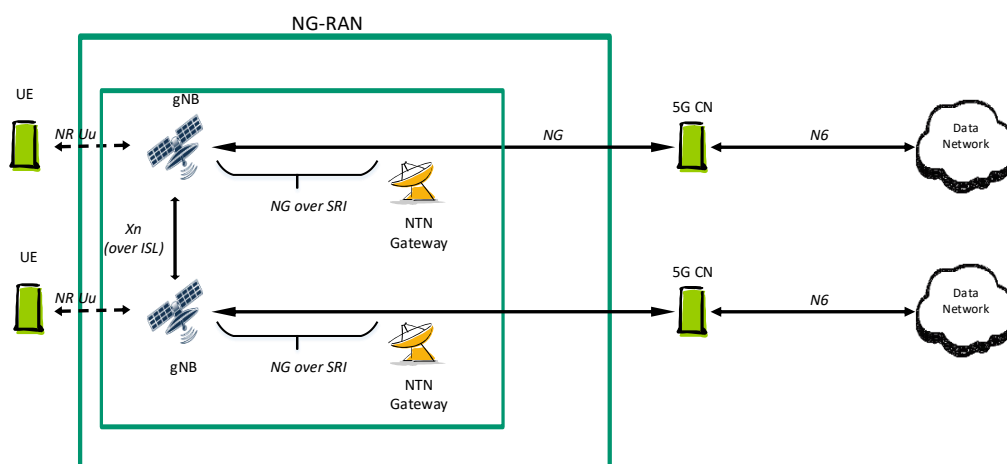


Figure 7: Reference model when using the regenerative payload of the LEO satellite constellation

Inter-satellite interaction in the LEO constellation of satellites is implemented on the basis of the Xn over SSL logical interface used in the 5G terrestrial mobile network [4]. Considering that when using a regenerative payload, a gNB base station is deployed on board the satellite, it can be used as an integrated access and transit IAB (Integrated Access and Backhaul) node in the transport network [13] connecting the LEO satellites constellation of 5G network.

Standardization of IAB technology began in 2017 and was adopted in 3GPP TS 38.401 [4] in 2020 as part of Release 16. IAB technology will support a very flexible deployment of the satellite segment of the 5G network, allowing the onboard nodes (gNB base stations) of NG RAN to function as repeaters for other LEO satellite constellation network nodes, in addition to their functioning as a regular gNB access node for ground UE. The LEO satellite constellation transport network will contain usual IAB nodes and an IAB donor. A regular IAB node is an NG-RAN node that supports wireless access for UE and wirelessly transmits access traffic [14-15]. The IAB donor is NG-RAN node, which provides an interface between the UE and 5G Core network and the functionality of a wireless repeater of ISL connections for conventional IAB nodes.

From the scheme of the reference model in Figure 7 [1] it can be seen that the UE subscriber terminal, serviced by the gNB base station on board the satellite, can access the 5G Core network via ISL inter-satellite communication lines via the Xn over ISM logical interface, which LEO satellites are connected to the constellation. gNB base stations on board different constellation satellites can be connected via NG over SRI and Xn over ISM logical interfaces to the same 5G Core reference network on Earth. If more than one gNB base station is placed on the LEO satellite, the same SPI logical interface will transport the aggregate user data via the NG logical interface.

The architecture for the reference model of the satellite segment of the 5G network with a regenerative payload on the LEO satellite implementing the gNB base station on board the communication satellite is shown in Figure 8.

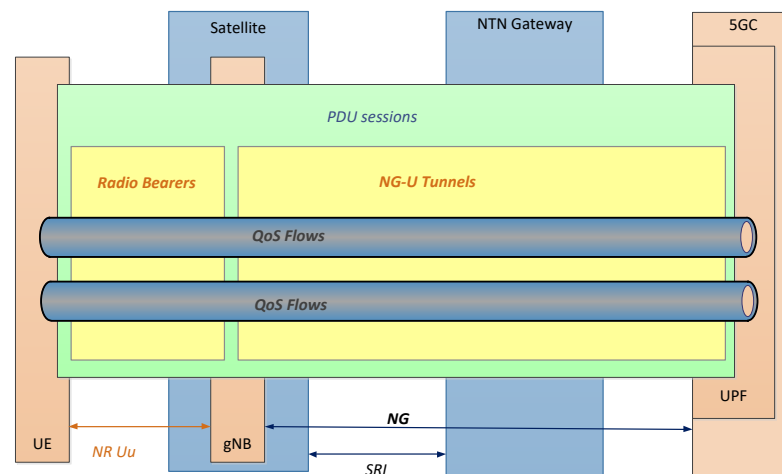



Figure 8: Architecture for the reference model of the satellite segment of the 5G network with a regenerative payload on the LEO satellite

Figure 8 also shows user data streams (session PDUs) and service data streams that provide QoS through the Radio Bearers radio channel management service, as well as formed tunnels in the user plane for the NG-U logical interface in the service channel and for the NG over SRI logical interface in the feeder channel connecting the satellite to the NTN GW ground gateway.

The protocol stack of the UP for the PDU session in the reference model of the satellite segment of the 5G network with a regenerative payload is shown in Figure 9 [1].

Figure 9 shows by the note that the protocol stack of the SRI satellite radio interface is used to transport data (PDU sessions) in User plane between the LEO satellite and the NTN gateway. PDU session data is transported via GTP-U tunnels, as usual, between the 5G Core reference network and the gNB base station located on the satellite, but through the NTN GW gateway.

The CP control plane protocol stack for the 5G satellite segment reference network with transparent payload is shown in Figure 10 [1].

Figure 10 by the note  shows the protocol layer stack on the SPI logical interface between the LEO satellite and the ground gateway of the NTN GW network. It can also be seen that the data of the NG-AP protocol is transported over the SCTP protocol between the gNB base station located on the LEO satellite and the 5G Core reference network, as usual, through the NTN gateway. Control plane data using the NAS protocol is also transmitted via the NG-AP protocol between 5G Core and the onboard gNB base station via the NTN GW gateway.

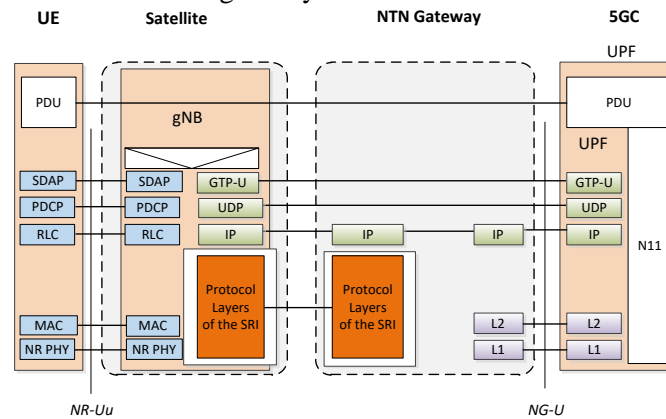


Figure 9: Protocol stack in the user plane for the reference network of the 5G satellite segment with regenerative payload

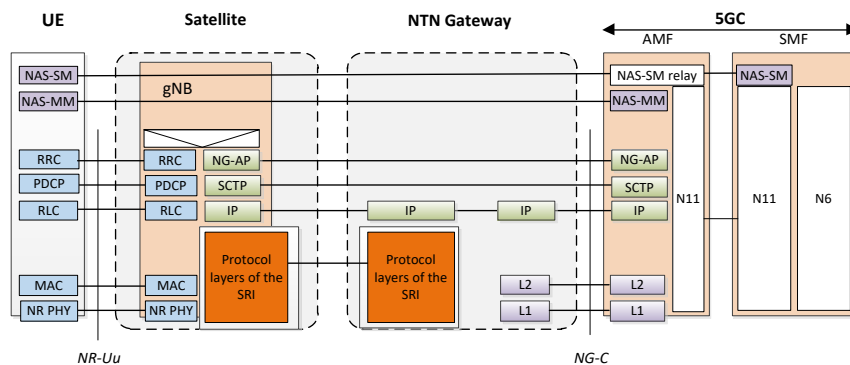


Figure 10: Protocol stack in the SR control plane for a reference model of a 5G satellite segment network with a regenerative payload

The NG application protocol timers between the LEO satellite and the AMF module of 5G Core network may have to be expanded to compensate for the long delay in the feeder line. In the reference model for a constellation of LEO satellites with ISL transport links, the delay in question should cover the delay at least in the SRI logical interface feeder line between the NTN GW gateway and the LEO satellite and in one or more ISL inter-satellite communication lines.

There are several options for transforming and implementing NG RAN architecture in the architecture of satellite segment in 5G integrated network. It depends on whether the satellite uses a payload with Bent-pipe technology (with transparent satellite transponders-repeaters without information processing on board) or a payload with signal processing on board.

Figure 11 (a-d) [16] shows the architecture of the 5G satellite segment, which is planned to be based on technology with transparent satellite transponders-repeaters without on-board information processing (Bent-pipe) without placing gNB or its elements on board satellites and in which only amplification and frequency conversion of signals is carried out on board the satellite while maintaining the type of 5G signal modulation used.

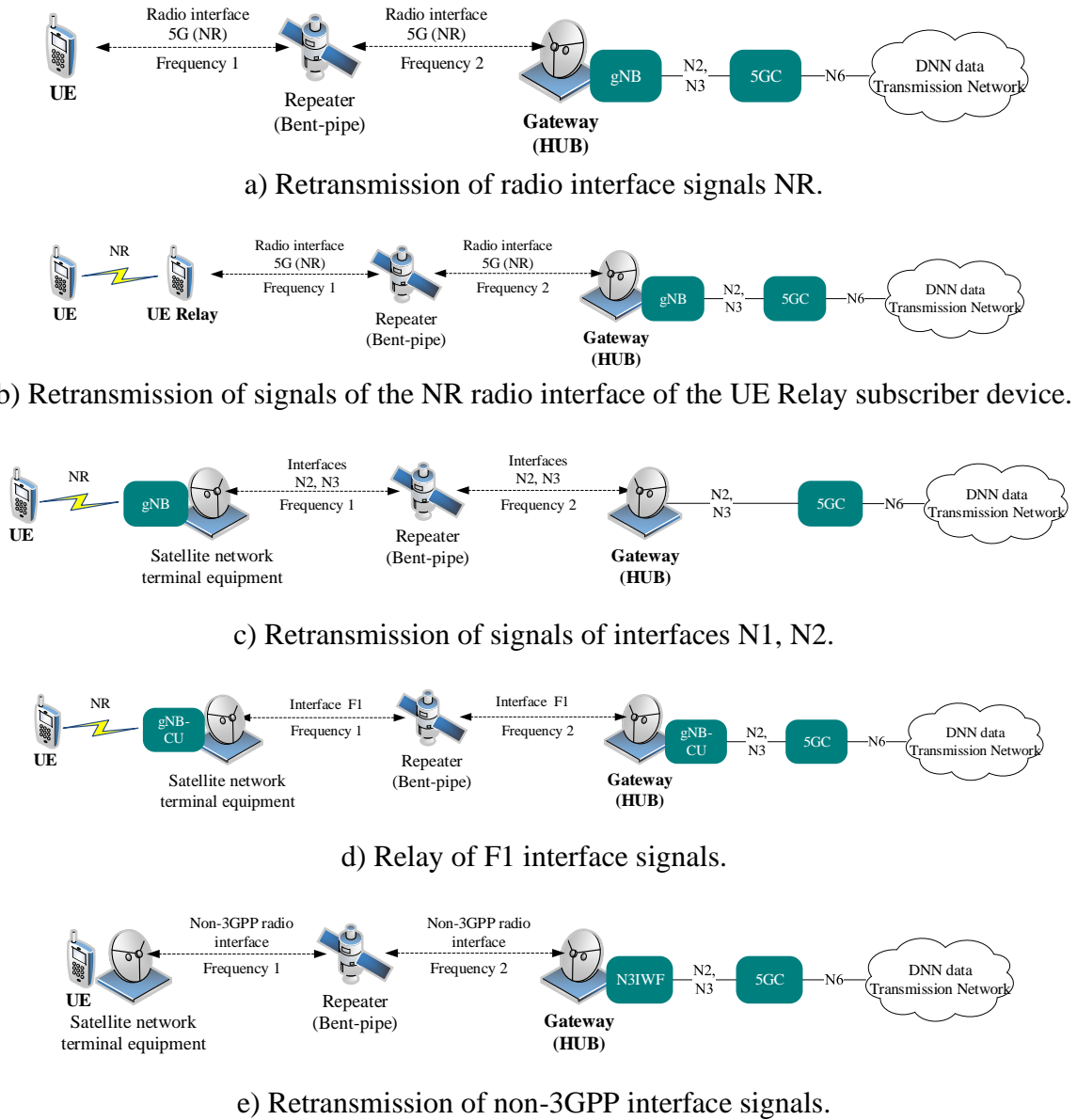


Figure 11 a-d: 5G satellite segment architecture based on Bent-pipe technology [16]

Figure 12 shows the architecture of the 5G satellite segment, which is planned to be based on a regenerative payload with 5G signal processing technology on board (On-Board Processing), which implies the placement of all or part of the gNB base station equipment on board the satellite.

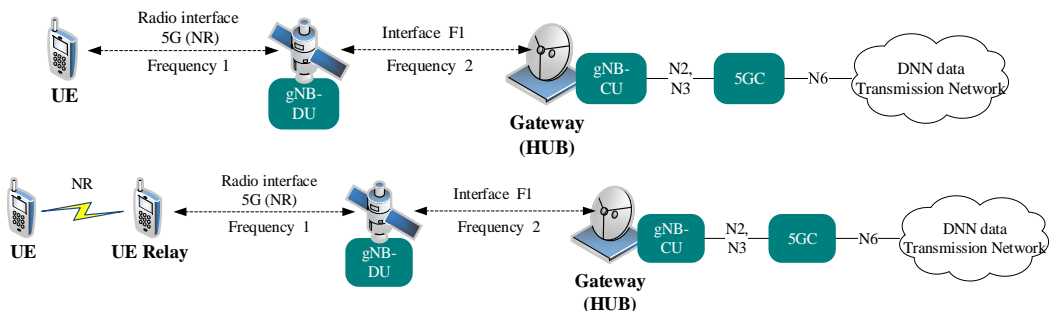


Figure 12: 5G satellite segment architecture based on On-Board Processing technology [16]

As shown in Figure 12, the architecture of the 5G satellite segment can use a ground relay (relay) node UE relay, which can amplify the signal of the UE subscriber devices before sending it on board. Mobile subscriber devices of the 5G satellite segment UE are represented by both wearable subscriber terminals and other mobile devices installed on cars, ships, airplanes, and so on. Currently, the capabilities of wearable subscriber terminals are limited to the use of L- and S-band bands, however, research is continuing to support subscriber terminals in higher frequency bands.

5. Conclusion

The analysis carried out by authors showed that the reference models of systems for processing and transmitting space data of satellite segment in 5G integrated network, which is part of 5G non-terrestrial networks, are divided according to the following parameters:

- orbits of the satellite grouping used to create the 5G satellite segment;
- type of equipment, interfaces and access protocols of the 5G satellite segment used on board the communication satellite (3GPP and non-3GPP);
- type of signal processing on board a communication satellite (direct relay, regenerative processing, processor processing);
- type of SRI interfaces and protocols used for inter-satellite communication lines ILC of 5G satellite segment transport network;
- the number of satellite gateways connecting 5G NTN network to the public data network.

In addition, the analysis performed in the article showed that 3GPP standardized several reference models which can use for systems development for processing and transmitting space data in the satellite segment of 5G integrated network, namely:

Reference model with transparent payload and satellite-repeater for NR-RAN interface;

Reference model with regenerative payload and distributed 5G gNB base station infrastructure for NR-RAN interface;

Reference model with regenerative payload and centralized infrastructure of 5G gNB base station on board for NR-RAN interfaces;

Reference model of LEO satellite constellation with 5G gNB distributed infrastructure on board for regional and global coverage;

Reference model of LEO satellites constellation for 5G satellite network segment with centralized infrastructure of gNB base stations on board for regional and global coverage.

6. Acknowledgements

This research was funded by the Science Committee of the Ministry of Education and Science of the Republic of Kazakhstan (grant no. AP08857146).

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