Benefits and constraints associated with 5G satellite networks

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***Abstract*—This document provides an overview of integration scenarios of satellite in 5th Generation Mobile system. It highlights the benefits and constraints associated with the different scenarios for Mobile Network Operators (MNO), vertical stakeholders and industry stakeholders. It then provide a status of Standardization activities on satellite in 3GPP.**

Keywords—Satellite, 5G, integration scenarios

1 Introduction

Mid December 2019 in Sitges/Spain, 3GPP [10] decided to start the normative activities of the features supporting the integration of satellite in 5G system, as part of the release 17 (June 2020 – Sept 2021):

- Approval of a new Work Item on "Solutions for NR to support non-terrestrial networks (NTN)" [1]. It will develop technical specifications to support especially Transparent payload-based LEO (Low Earth Orbit) & GEO (Geostationary Earth Orbit) scenarios addressing UE (User Equipment) with GNSS (Global Navigation Satellite System) capability. In this context, transparent payload means that the payload doesn't embark any 5G system functions. NR refers to New Radio (5G radio interface).
- Approval of a new Work Item on "Integration of satellite systems in the 5G architecture" [2]. It will develop technical specifications to support especially Mobility Management, identification of satellite access and its QoS (Quality of Service) impacts, regulatory requirements as well as satellite backhaul.

These work items have been supported by a wide range of organizations from both the satellite and mobile industry as well as professional and governmental stakeholders.

This followed a number of study activities as part of Rel-15 and Rel-16 on channel modeling and identification of solutions to address key issues associated with the support of satellite by 5G system.

This paves the way to the definition of a global standard for satellite networks operating at LEO, MEO or GEO orbits, at any frequency band, with any terminal type (with omni or directive antenna) and providing any kind of service (Fixed, Mobile and Broadcast).

Future 3GPP releases may add features to improve the 5G based satellite network's throughput, radio link availability and to provide new capabilities such as support of IAB (Integrated Access and Backhaul [9]), UE without GNSS or inter satellite links.

This paper aims at analyzing the possible benefits and constraints for the different stakeholders of 5G satellite networks.

2 Satellite roles in 5G system

With disruptive requirements such as the increase of capacity, peak and sustained data rates, latency, or number of devices supported, the advent of the 5G system should create a wealth of opportunities for the telecommunication industry in a context where the digitization of the economy and of the media sector creates a strong pressure on the corresponding actors. Along with this disruption, terrestrial cellular actors have acknowledged that a combination of access technologies shall be deployed in the 5G heterogeneous network to answer to the challenging service requirements (QoS, coverage, availability, reliability, scalability …).

Unlike previous generation, 5th Gen requires a flexible technology framework able to support and combine (hand-over, multi connectivity, roaming) multiple access technologies that best responds to the ever increasing requirements of the consumer markets (Throughput), Machine-Type-Communication (massive connectivity) but also able to address critical service requirements from vertical markets (coverage, reliability, availability, response time).

This context is a unique opportunity for the SatCom (Satellite Communication systems) industry to expand its ecosystem by establishing itself in the global communications ecosystem and to benefit from a significant market renewal. The higher the integration, the more roles satellite networks can take in 5G system.

The vision on non-terrestrial networks for 5G shared between NGMN alliance (Next Generation Mobile Network, https://www.ngmn.org/) and ESOA (European and middle east Satellite Operator Association, https://www.esoa.net/) is provided in clause 5 "Conclusions" of the position paper attached to [3] and summarized below:

"Non-Terrestrial network solutions can contribute to the deployment of 5G services for the provision of coverage, capacity, reliability and availability as a complement to cellular networks. Satellite can be particularly valuable in extending 5G services to rural and extremely rural areas. This added value will be maximized via seamless integration of satellite networks within 5G, enabled by the development of 3GPP standards supporting satellite access & backhaul solutions as part of Rel-17 and beyond"

Satellite networks integrated in 5G will enable Mobile Network Operators and vertical stakeholders to better address markets which are currently difficult to serve and hence address the main challenges:

- Extending service coverage [5] in currently un-served areas where the deployment of cellular networks is not economically viable because the ARPU (Average Revenue Per User) density is insufficient.
    - Address population living outside of areas covered by mobile broadband networks (750 Million people [6] [7])
    - Ensure service continuity for users (anyone willing to benefit from 100% coverage in outdoor condition)
    - Provide connectivity to IoT (Internet of Things) devices to serve the needs in transport, logistics, utilities and mining industry (e.g. surveillance of remote infrastructures), public safety [8] as well as agriculture
- Providing connectivity service to population in remote places
    - isolated villages (more than 50 km long backhaul links), islands
    - moving platforms in areas with discontinuous service coverage (vessels, aircraft, trains and even buses).

3 INTEGRATION SCENARIOS OF SATELLITE IN 5G SYSTEM

The integration of satellite networks in the 5G system may be implemented through different scenarios each having its own benefits and constraints for the Mobile Network Operators, the end-users and the European Industry stakeholders.

3.1 Integration at Data Network level - #1

This scenario refers to legacy satellite networks interconnected to the data network. Such satellite network can be used as transport network for the connectivity between the radio access network and the core network of a 5G system. Interactions between the transport network and the 5G system can be established at network management level. The use of the satellite network in 5G system is illustrated in figure 1.

FIGURE 1: INTEGRATION AT DATA NETWORK LEVEL - #1

3.2 Integration at Core Network level - #2

This scenario refers to the legacy satellite networks (non 3GPP defined system) that are connected to a 5G core network in order to provide 5G services to users. This requires to implement some Inter Working Function (IWF) in the satellite network to provide the 3GPP defined NG interface (N1, N2 & N3 interface points). The reference architecture of the satellite communication system connected to the 5G core network is illustrated below:

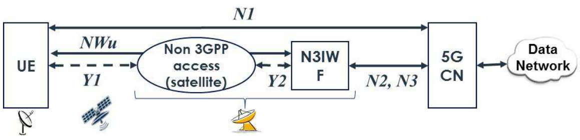

FIGURE 2: INTEGRATION AT CORE NETWORK LEVEL - #2

3.3 Integration at Radio Access Network level - #3

This scenario refers to 3GPP defined Satellite network (e.g. New Radio/Next Generation Radio Access Network based) that are supported by a 5G core network just as any 3GPP defined radio access technology and use the 3GPP radio interface based on OFDM (Orthogonal Frequency Division Multiplexing). One should distinguish between two categories of Satellite networks as defined in [4]:

- **Direct network connection (direct access):** one mode of network connection, where there is no relay User Equipment between a UE and the 5G network
- **Indirect network connection (indirect access):** one mode of network connection, where there is a relay User Equipment between a UE and the 5G network.

Applied to satellite context, the first category refers to satellite network directly servicing mass market or professional end-user devices (e.g. handset or IoT), while the second category corresponds to a satellite network providing connectivity to an intermediate network node which can be mounted for example on a building or a moving platform.

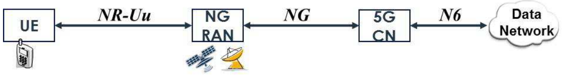

FIGURE 3: INTEGRATION AT RADIO ACCESS NETWORK LEVEL - #3 (PROVIDING DIRECT CONNECTIVITY TO UE)

In figure 3, the UE access the 5G network via a 3GPP defined satellite access technology supported by the 5G core network.

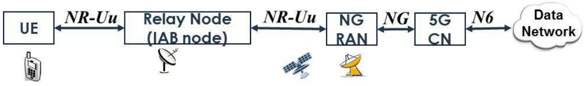

FIGURE 4: INTEGRATION AT RADIO ACCESS NETWORK LEVEL - #3 (PROVIDING INDIRECT CONNECTIVITY TO UE)

In figure 4, the UE is served by a 3GPP defined local access point based on NG-RAN (Next Generation Radio Access Network) and New Radio Interface (NR-Uu) and embedded in the relay node. The satellite network provides connectivity between the relay node and the 5G core network. The satellite network may be non 3GPP defined (e.g. DVB in [11]) or 3GPP defined (e.g. IAB).

As part of the normative efforts at 3GPP on satellite, the regulations of ITU-R (International Telecommunication Union - Radiocommunication Sector) that prevent mutual interference between cellular networks operating in Mobile Service allocated bands and satellite networks operating in satellite service allocated bands are taken into account. Moreover, we assume in this paper, that the satellite networks operate in frequency allocated exclusively to satellite services.

4 BENEFITS AND CONSTRAINTS FOR INTEGRATION SCENARIOS OF SATELLITE IN 5G

The development of satellite networks based on the same technology framework as 5G, will allow

- Better integration of the Satellite RAT (Radio Access Technology) in the overall 5G end to end network to provide global service continuity through handover or to increase the throughput and/or reliability for users through multi connectivity;
- OPEX (Operational Expenditure) reduction through simpler network management, operation and maintenance of the satellite network as well as application development;
- CAPEX (Capitale Expenditure) reduction related to standardization of equipment and

devices around 3GPP standards leading to the economy of scale, large product diversity, multiple vendor interoperability;

- New revenue generation thanks to new services for the 5G eco-systems stakeholders.

As seen in the table 1, the higher the integration of satellite in 5G the larger the benefits for the MNOs, the end-users and the Industry stakeholders.

5 Standardization status on satellite in 3GPP

In the table 2 are listed all past and current 3GPP standardization activities related to the integration of satellite. In bold characters, are highlighted the on-going activities in both RAN and SA context.

The RAN2 led Work Item on "Solutions for NR to support non-terrestrial networks (NTN)" covers satellite networks featuring

- Transparent payload architecture
- GEO or any circular orbiting NGSO constellation (LEO and MEO) and implicit compatibility to support HAPS (High Altitude Platform Station) and ATG (Air To Ground) scenarios
- Earth moving or Earth fixed cells

It assumes UE with GNSS capability, fixed tracking areas and Frequency Division Duplex mode. It is defining solutions to address issues due to long propagation delays, large Doppler effects, and moving cells in NTN. This will require main enhancements at:

- Physical layer
  - Timing relationship enhancements
  - Enhancements on UL time and frequency synchronization
  - HARQ: Enabling / disabling of HARQ feedback
- Access layer
  - User plane: Random access procedure, UL scheduling, DRX when HARQ disabled or turned off, extension of timer/value range for status reporting and sequence numbers
  - Control plane: assistance for cell selection/reselection, assistance to trigger hand-over and measurement, NTN-TN service continuity, applicability of LCS to NTN
- Radio access network architecture
  - Feeder link switch over, network identities handling, registration update and paging handling, cell relation handling

The SA2 led Work Item on "Integration of satellite systems in the 5G architecture" will address the following key issues:

- Mobility Management with large coverage areas.
- Mobility Management with moving coverage areas.
- Delay in satellite.
- QoS with satellite access.
- QoS with satellite backhaul.
- RAN mobility with NGSO regenerative-based satellite access.
- Regulatory services with super-national satellite ground station

Furthermore, a subsequent item has been approved that will study Narrow-Band Internet of Things (NB-IoT) / enhanced Machine Type Communication (eMTC) support for Non-Terrestrial Networks (NTN) will address the following key issues:

- Random access procedure/signals
- Mechanisms for time/frequency adjustment including Timing Advance, and UL frequency compensation indication
- Timing offset related to scheduling and HARQ-ACK feedback
- HARQ operation, timers (e.g. SR, DRX, etc.), idle mode and connected mode mobility
- RLF-based for NB-IoT, Handover-based for eMTC, System information enhancements
- Tracking area enhancements

TABLE 1: BENEFITS AND CONSTRAINTS ASSOCIATED WITH THE DIFFERENT INTEGRATION SCENARIOS OF SATELLITE NETWORKS IN 5G

SatCom integration scenarios in 5G		**#1: Data network level**	**#2: Core Network level**	**#3 : Radio Access Network level**
Satellite technology		Transport networks (legacy & proprietary).	Access Network (legacy & proprietary)	3GPP defined radio access technology based on 5G New Radio interface
End-users (Note 1)	**Benefits**	Transparent to end-users	Possible support of service continuity and network resilience through combination of satellite and cellular access technologies.	A unique User Equipment (5G mass market including smart phones or professional) providing access to 5G services anywhere on the planet.
	Constraints	Transparent to end-users .	Need to purchase specific Satellite User Equipment to benefit from 5G services.	Just a subscription issue with the operator of the satellite network (same as any cellular network).
MNOs	**Benefits**	Connectivity (backhauling, trunking) to cells in remote locations or on board moving platforms Edge delivery of content.	Same as Scenario #1, and Support of 5G PLMN standardized subscriber, mobility, security and slicing management.	Same as Scenario #2, and Direct connectivity to user equipment for seamless 5G service extension in areas beyond terrestrial coverage. Common internal skills and equipment suppliers for both satellite and terrestrial technologies. Large supply of satellite network solutions and competitive pricing thanks to standardization.
	Constraints	Specific Service Level Agreement to ensure that satellite network radio resources supports the traffic generated by the 5G system. No control of the satellite network radio resources	Specific Interworking Interface. Specific expertise needed to set-up, operate and maintain the satellite network	Just a roaming agreement issue with the operator of the satellite network (same as any cellular network).
Industry (Note 2)	**Benefits**	Re-use of legacy satellite network with minimum R&D effort on the network management system	Re-use of legacy satellite network with R&D effort on the network management system and the interworking interface with core network	A global market and a unique technology framework for the satellite network solutions whatever orbit, frequency band, terminal types (smart phones, Very Small Aperture Terminal etc..), services Open architecture that creates market opportunity for Small and Medium Enterprises.
	Constraints	High risks on the market acceptance in mid/long term because not able to sustain the cost reduction of bandwidth	A fragmented market for the satellite network solutions with higher risks to amortize R&D effort Feature is the main differentiator	R&D effort for terrestrial NG-RAN & 5-CN (5G Core Network) products to support satellite features. High competition from all the 5G eco-system industry stakeholders. Volume based economy where price is the main differentiator.
Note 1: End-users refer to consumers as well as professionals from vertical markets such as public safety, transport, logistics, utilities, agriculture, etc. Note 2: Industry refer to prime as well as network equipment and technology vendors at space and ground segment level.				

TABLE 2: 3GPP SATELLITE/NTN STANDARDISATION ACTIVITIES

Rel	Item ref	Lead WG	Title	3GPP doc	Completion	Rapporteurs
15	SI ”FS_NR_nonterr_nw on NR”	RAN	Study on New Radio (NR) to support Non Terrestrial Networks (Release 15)	TR 38.811	June 2018	N. Chuberre - Thales
	SI ”FS_5GSAT”	SA1	Study on using Satellite Access in 5G; Stage 1 (Release 16)	TR 22.822	June 2018	C. Michel – Thales
16	SI ”FS_NR_NTN_solutions”	RAN3	Solutions for NR to support non-terrestrial networks (NTN) (Release 16)	TR 38.821	Dec 2019	N. Chuberre - Thales
	WI ”5GSAT”	SA1	Service requirements for the 5G system; Stage 1 (Release 16)	CR to TS 22.261	Dec 2018	C. Michel – Thales
	SI ”FS_5GSAT_ARCH”	SA2	Study on architecture aspects for using satellite access in 5G (Release 16)	TR 23.737	Jun 2020	C. Michel - Thales
	SI ”FS_5G_SAT_MO”	SA5	Study on management and orchestration aspects of integrated satellite components in a 5G network	TR 28.808	Dec 2020	C. Michel – Thales
17	WI ”NR_NTN_solutions”	RAN2	Solutions for NR to support non-terrestrial networks (NTN)	CR to TS 38.X	Sept 2021	N. Chuberre - Thales
	WI ”5GSAT_ARCH”	SA2	Integration of satellite systems in the 5G architecture	CR to TS 23.X	Mar 2021	J.Y. Fine - Thales
	SI “FS_LTE_NBIOT_eMTC_NTN”	RAN1	Study on Narrow-Band Internet of Things (NB-IoT) / enhanced Machine Type Communication (eMTC) support for Non-Terrestrial Networks (NTN)	TR 36.763	Sept 2021	G. Charbit - MediaTek; S. El Moumouhi - Eutelsat

6 CONCLUSION

To satisfy the overall telecommunication market needs, the 5th Generation network (5G) requires a blend of network technologies and, therefore, a seamless and harmonized combination of access technologies including satellite. 3GPP is paving the way for the development of such network of networks where satellite will be seamlessly integrated.

The roll-out of Satellite friendly network and user equipment products based on the upcoming 3GPP NR-NTN standard are expected to start in 2022-23 time frame (18 months after publication of the Rel-17 NR-NTN standard completion) and therefore, the design of future satellites and related systems should already consider the support of this 5G NTN technology.

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REFERENCES

[1] 3GPP RP-201256, New Work Item on "Solutions for NR to support non-terrestrial networks (NTN)", Thales, submitted at 3GPP RAN#88-e, June 2020 (revision of approved WI at 3GPP RAN#86 in Sitges/Spain, Decembre 2019)

[2] 3GPP SP-191369, New Work Item on "Integration of satellite systems in the 5G architecture", Thales, submitted at 3GPP SA#86 in Sitges/Spain, Decembre 2019

[3] 3GPP RP-193153, position paper on "Non-Terrestrial Networks", NGMN alliance, submitted at 3GPP RAN#86 in Sitges/Spain, Decembre 2019

[4] 3GPP TS 22.261 "Service requirements for the 5G system"

[5] 3GPP RP-192833 "Consolidated needs for satellite coverage extension of 5G terrestrial networks", Novamint, Thales, submitted at 3GPP RAN#86 in Sitges/Spain, Decembre 2019

[6] "The State of Mobile Internet Connectivity 2019", GSMA, July 2019, www.gsma.com

[7] 3GPP SP-191245 "NTN for the digital inclusion of the less favoured ones", Thales, submitted at 3GPP SA#86 in Sitges/Spain, Decembre 2019

[8] 3GPP RP-192925 "5G NR Broadband satellite coverage is safety!", Ministère français de l'intérieur , submitted at 3GPP RAN#86 in Sitges/Spain, Decembre 2019

[9] 3GPP TR 38.874 "NR; Study on integrated access and backhaul"

[10] www.3gpp.org

[11] www.dvb.org