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3GPP nonterrestrial networks: A concise review and look ahead

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Summary

The purpose of this report is to present an overview of 3GPP processes with emphasis on recent nonterrestrial, especially satellite communications (SATCOM), activities that have been initialized by 3GPP. The focus is more on describing timely 3GPP activities, spiced up with some VTT's viewpoints, rather than being a detailed technology review. In essence, the SATCOM complements terrestrial communication networks in the areas that are completely uncovered or insufficiently served for target digital services. As a result, 3GPP has recently initiated several study items on evaluating possible impacts and solutions for a stand-alone solution and more heavily integrated version combined with upcoming terrestrial 5G networks. In opposite to previous 1G-4G cellular standards, the 5G standard portfolio will provide strong heterogeneity support from many perspectives, including services, network technologies, and traffic characteristics. As the 3GPP processes can be quite difficult to understand for a previously inexperienced 3GPP party, we also provide a concise summary of main general issues which help to understand the underlying standardization procedures. Moreover, the provided specification map in Section 5 helps to understand current 3GPP standardization status and main outcomes particularly related on SATCOM. While 3GPP is currently mostly interested in integrating satellite access into terrestrial networks, also high and low altitude platforms are expected to be important for the 3GPP terrestrial network in the near future. Unlike in the previous cellular technology generations, in 5G there are no competing standard bodies. Therefore, understanding of 3GPP processes becomes even more important over many vertical industries.

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Glossary

3GPP	3rd generation partnership project
5G	5th generation
AMSS	Aeronautical mobile satellite services
ASN.1	Abstract syntax notation one
CT	Core network and terminals
DVB-S/SH	Digital video broadcasting - satellite services to handhelds
eMBMS	Enhanced multimedia broadcast and multicast system
ESA	European space agency
ETSI	European telecommunications standards institute
GEO	geostationary earth orbit
gNB	Next generation node B
HAP	High-altitude platform
HARQ	Hybrid automatic repeat request
HEO	Highly-eccentric orbiting
ISL	Intersatellite link
ITU	International telecommunication union
LEO	Low earth orbit
LMSS	Land mobile satellite services
M2M	Machine to machine
MEO	Medium earth orbit
MMSS	Maritime mobile satellite services
mMTC	Massive machine type communications
MNO	Mobile network operator
NB-IoT	Narrowband internet of things
NTN	Nonterrestrial network
OBP	On-board processor
QoS	Quality of service
RAN	Radio access network
RAT	Radio access technology
SA	Service and system aspects
SATCOM	Satellite communication
SI	Study item
SSO	Standard setting organization
TR	Technical report
TS	Technical specification
TSG	Technical specification group
TWTA	Travelling wave tube amplifier
UE	User equipment
UAV	Unmanned aerial vehicle
UMB	Ultra mobile broadband
WG	Working group
WI	Work item
VSAT	Very small aperture terminal

1. Introduction

In the past, mobile cellular networks have been largely backhauled using terrestrial networks. However, especially for mobile or moving entities such as trains, planes, and ships there is unused potential of employing satellite communications (SATCOM) techniques to support seamless digital services with high mobility and hard to reach locations. Therefore, 3GPP has initiated plans to include significant contributions related to SATCOM in Release 16 which is scheduled to be ready by the end of 2019 or early 2020 (functional freeze). All 3GPP documents referred in this report can be found from (3GPP 2018d) using the provided search engine by 3GPP. We also touch on the concept called nonterrestrial networks (NTNs) which include, in addition to satellites, also airborne vehicles such as high altitude platforms and unmanned aircraft systems which are still in a rather initial development phase within 3GPP.

The purpose of this report is to present an overview of 3GPP processes with emphasis on recent SATCOM activities that have been initialized by 3GPP. The focus is, therefore, more on describing timely 3GPP activities, spiced up with some VTT's viewpoints, rather than being a detailed technology review. In essence, the SATCOM complements terrestrial communication networks in the areas that are completely uncovered or insufficiently served for target digital services. As a result, 3GPP has recently initiated several study items on evaluating possible impacts and solutions for a stand-alone solution and more heavily integrated version combined with upcoming terrestrial 5G networks. In opposite to previous 1G-4G cellular standards, the 5G standard portfolio will provide strong heterogeneity support from many perspectives, including services, network technologies, and traffic characteristics. As the 3GPP processes can be quite difficult to understand for a person previously inexperienced in 3GPP, we also provide a concise summary of main general issues which help to understand the underlying standardization procedures.

Some review studies at VTT have been made on SATCOM and 3GPP standardization in the past. The authors are aware of already few years old reports (Rautiola 2016) on SATCOM without 3GPP emphasis and (Lasanen 2016) on 5G standardization without SATCOM emphasis. This report aims at fulfilling the cap between these reports, i.e. evaluating the updated status on newly initiated 3GPP SATCOM activities within the 5G standardization development. Some recent examples of VTT's work published in international forums can be found from (Höyhtyä 2017a, Höyhtyä 2017b, Mazzali 2018).

The organization of this report is as follows. In Section 2, a brief summary is presented on general 3GPP procedures. Some interesting background information is then provided in Section 3 related to recent 5G SATCOM activities. The anticipated use cases on the SATCOM technologies are outlined in Section 4. Then Section 5 goes a bit deeper into 3GPP processes and documents particularly related to SATCOM. Finally, Section 6 presents some ideas of future challenges followed by the conclusions in Section 7.

2. A concise and timely outlook on general 3GPP procedures

In this section, we provide a brief outlook on general 3GPP procedures. In essence, it is important to understand the general procedures how 3GPP operates before going into details on some more specific topic.

3GPP was formed in 1998 at a time ETSI started to collaborate towards 3rd generation cellular networks using W-CDMA technology (Cascaccia 2017). Another group was 3GPP2 promoting related CDMA2000 technology. Both approaches were supported by International Telecommunication Union (ITU). The competition continued in the next 4th generation where 3GPP with LTE technology started to dominate the UMB technology of 3GPP2. Unlike in the previous generations, in 5G there are no competing standard bodies. Therefore, understanding of 3GPP processes becomes even more important over many vertical industries.

Figure 1 provides an overview of the 3GPP organization (3GPP 2018c). In short summary, there are three technical specification groups (TSGs), namely radio access network (RAN), service and system aspects (SA), and core network and terminals (CT). Each TSG involves multiple working groups (WGs) as shown in Figure 1.

Figure 2 then provides an overview of recent 3GPP specification releases. At the moment Release 15 is (functionally) frozen and Release 16 is in progress. The status of Release 17 is now set to 'open' in (3GPP 2018f) but the detailed schedule has not been decided yet and expected to be available by Q1/2019. There have been several delay extensions for original frozen dates in several releases as recently reported by 3GPP (3GPP 2018f) and outlined in Figure 2. Different stages of releases describe the maturity level of the releases and are defined as (3GPP 2018f):

- Stage 1 refers to the service description from a service-user's point of view.
- Stage 2 is a logical analysis, devising an abstract architecture of functional elements and the information flows amongst them across reference points between functional entities.
- Stage 3 is the concrete implementation of the functionality and of the protocols appearing at physical interfaces between physical elements onto which the functional elements have been mapped.

Project co-ordination group (PCG)		
TSG RAN Radio access network	TSG SA Service/system aspects	TSG CT Core network/terminals
RAN WG1 RAN Layer 1	SA WG1 Services	CT WG1 Core Layer 3
RAN WG2 RAN Layers 2-3	SA WG2 Architecture	CT WG2 Capability (Closed)
RAN WG3 Interface protocols	SA WG3 Security	CT WG3 External networks
RAN WG4 Radio performance	SA WG4 Codec	CT WG4 Supplementary protocols
RAN WG5 Conformance testing	SA WG5 Telecom management	CT WG5 Open ser. access (Closed)
RAN WG6 Legacy RAN	SA WG6 Mission-critical apps	CT WG6 Smart card

Figure 1. Structure of 3GPP organization including 3 TSGs and 16 active WGs.

After the specification is properly stable, it is frozen, i.e. a release can have no further additional functions added. However, detailed protocol specifications (stage 3) may not yet be complete. That is, a frozen technical specification is one which can have no further new or modified functionality change requests, other than to align earlier stages with later stages or for essential correction of errors. Also other extensions such as abstract syntax notation one (ASN.1) interface descriptions typically takes place after stage 3 within three months. Summary of release specific technical topics can be conveniently found from (3GPP 2018i, 3GPP 2018j) and not included here.

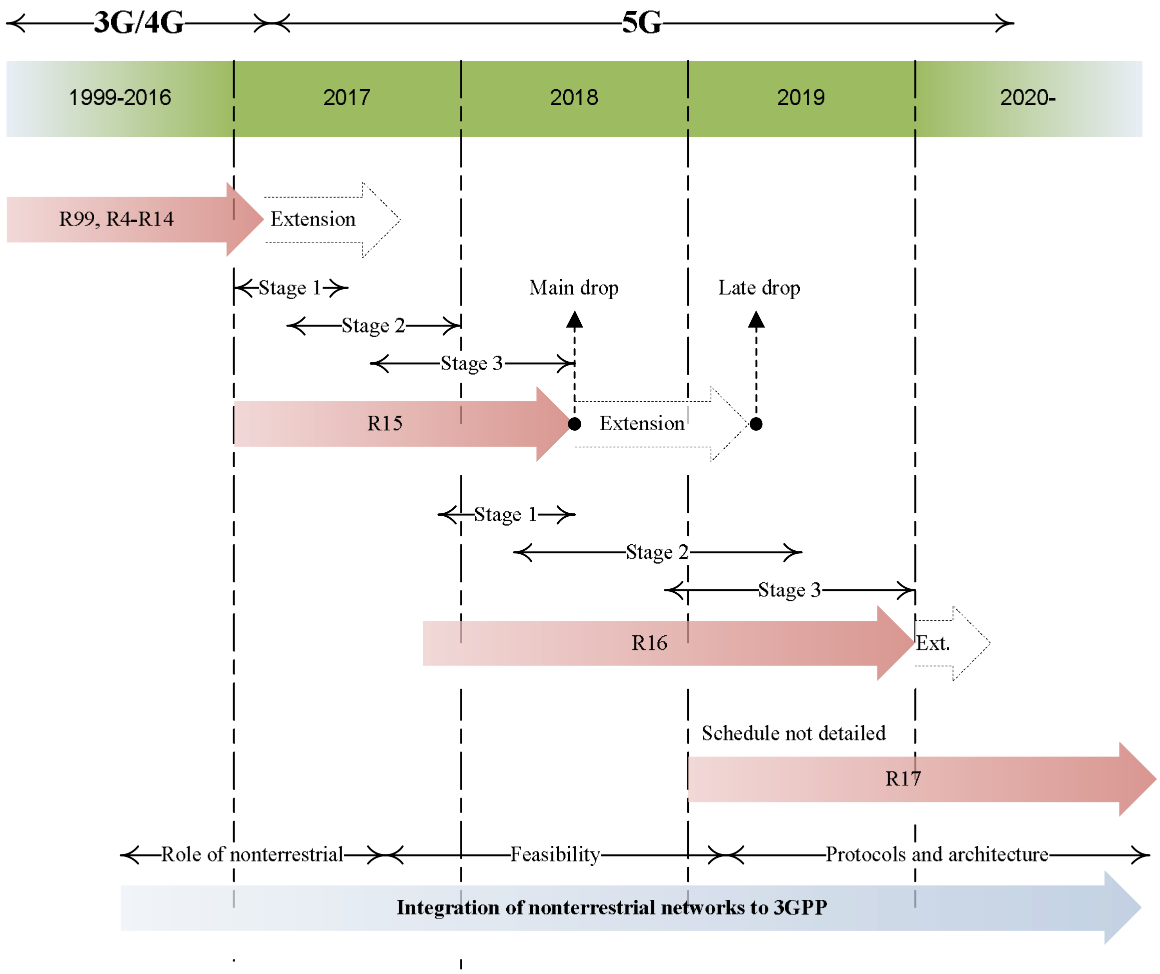

Figure 2. Recent 3GPP releases and their updated timetable as reported in (3GPP 2018f, 3GPP 2018h). A rough plan to integrate nonterrestrial networks is also adopted from (3GPP 2018a).

3GPP develops technical specifications, which are transposed into standards by regional standards setting organizations such as ETSI for Europe. 3GPP specifications are published up to four times in a year in TSG meetings (3GPP 2018b). There can be different document update actions, including i) document brought under change control (i.e. >80% ready), ii) change requests, iii) upgraded to a release specification. Regarding the 3GPP documentation, the following practises have been adopted, see more from (TR21.801 2018, Meredith 2002). The leader of a given WG from Figure 1 initiates the specification using the numbering style x.y.z where x is the release field (record major functional changes to overall system), y is the technical field (record technical changes to given functionality), and z is editorial field (record editorial changes). Version x.0.0 is a approved version of the specification of release x. It can then be modified using the change control procedure, i.e. the WG can update the specification via change requests (CRs) to the TSG. Detailed guidelines of creating CRs are given in (3GPP

2018g). After the specification is frozen, they can be published by regional standard organizations such as ETSI.

A very nice description of overall 3GPP specification procedure is given in (Cascaccia 2017). The main 5 steps are outlined in Figure 3 including the following items:

- project proposal (PP): new technical features initiated by individual 3GPP members, typically initiative visionary work is done outside 3GPP
- study item (SI): TSG-approved project proposal that becomes a study item of a given WG. The output of SI is a technical report (TR) that is a feasibility study by nature.
- work item (WI): After the TRs from SI are approved, SI becomes a WI which starts the actual development work. The contributions lead to new technical specifications (TSs) or modifications of existing TSs.

Figure 3 further highlights some cooperation opportunities at different phases between involved companies and research institutes. Regarding the decision process in 3GPP, the decisions which contributions are accepted are made iteratively and contributions are rarely accepted directly. Any member can reject a contribution at any time and final selections are made via negotiation between 3GPP members. More information about 3GPP working procedures are also available in (3GPP 2016).

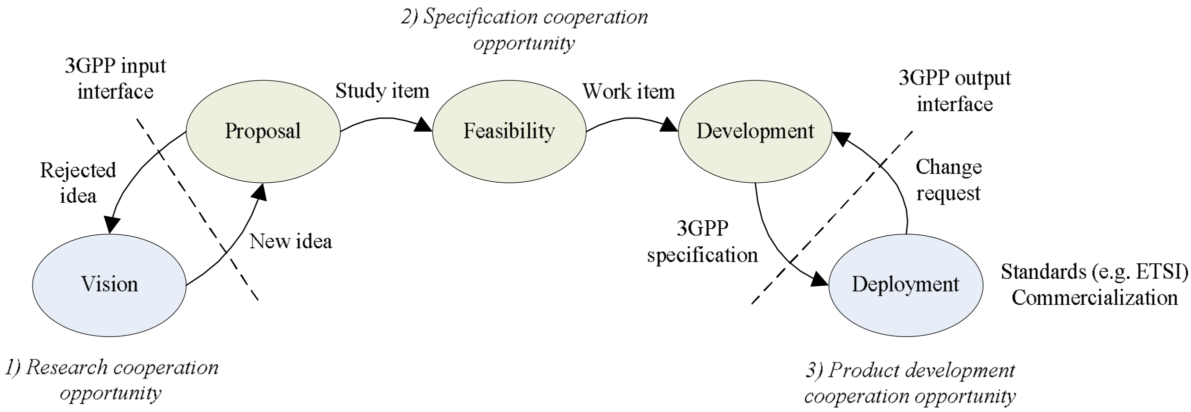

Figure 3. 3GPP 5-step working procedures, interfaces, and three distinctive cooperation opportunities for companies and research institutes.

3. Status and background of nonterrestrial networks

The standardization activities of satellite communications have been largely focused on digital video broadcasting including the DVB-S/S2 and DVB-SH standards that have been published by European Telecommunications Standard Institute (ETSI 2014). Some developments have also taken place regarding hybrid satellite-terrestrial networks by International Telecommunication Union (ITU-R 2011). Recently, 3GPP initiated studies on possible role of satellites in terrestrial mobile radio communications. In essence, the newest 3GPP releases under 5G development provide a promising opportunity to integrate previously independent terrestrial and satellite networks. This activity was initially started already in Release 14 in the form of a requirement use scenario study. In this report, we focus solely on 3GPP activities.

A general airborne communication architecture is shown in Figure 4 which incorporates several layers, including terrestrial networks, low altitude platforms, high altitude platforms, and satellite platforms similar to (Cao 2018).

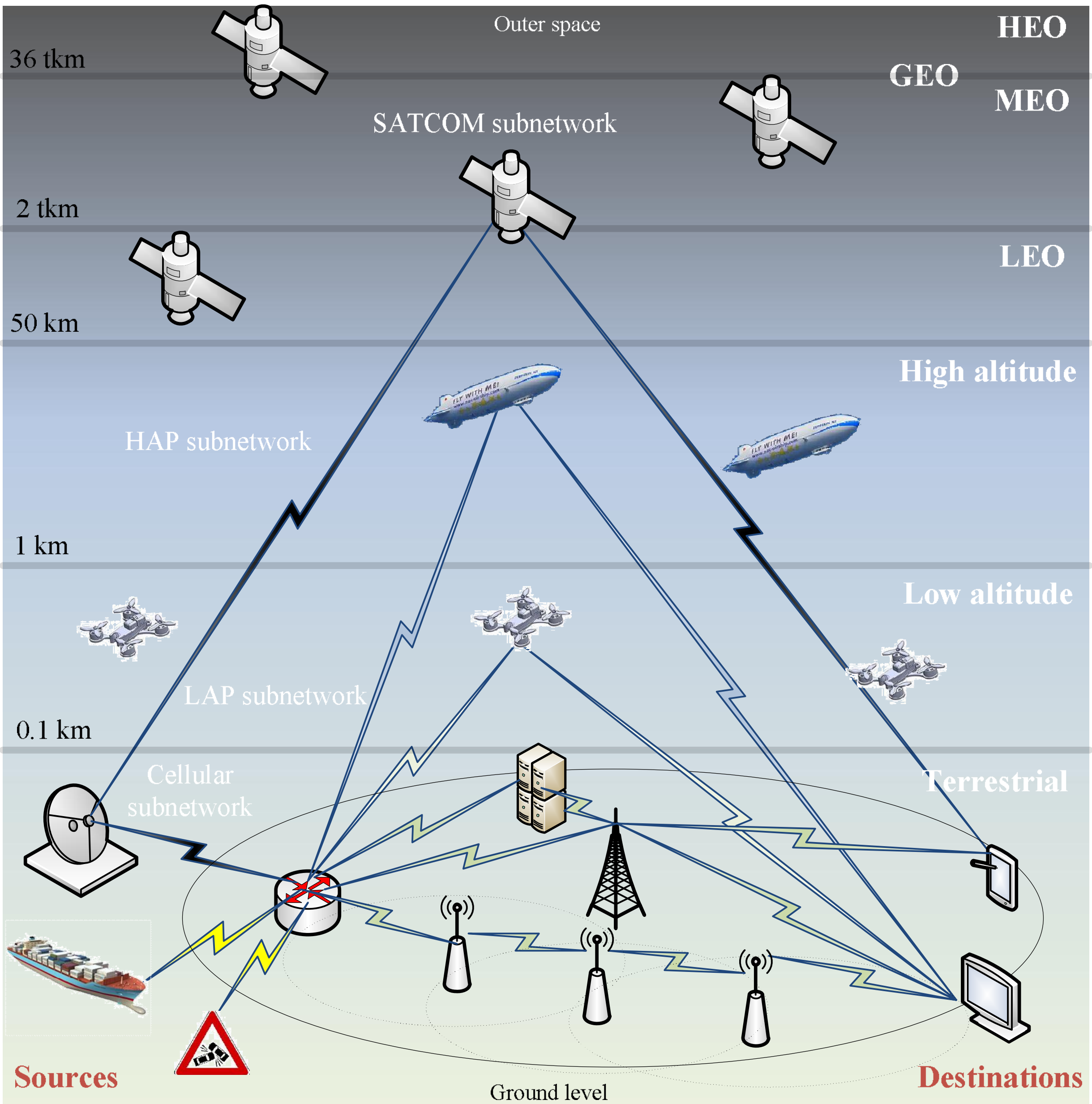

Figure 4. Overall structure of integrated terrestrial-nonterrestrial airborne networks. Altitudes in km are only indicative maximum values for particular subnetworks.

While 3GPP is currently mostly interested in integrating satellite and HAPs into the terrestrial network, the role of LAPs is expected to be important in the near future as well. The links can be ground-airborne, airborne-ground, or airborne-airborne. The integration essentially involves of protocol stacks of all involved heterogeneous technologies. The advantages of nonterrestrial networks in 5G systems are well summarized in (TR38.811 2018): i) extend terrestrial 5G in hard-to-reach or underserved areas, improve service continuity for mobile users and moving service platforms, and iii) improve better service scalability via robust multicasting.

3.1 Understanding terminology

The following SATCOM terminology and abbreviations are applied (cf. TS22.261, TR38.811, TR23.737):

- **Satellite**: a space-borne vehicle embarking a bent pipe payload or a regenerative payload telecommunication transmitter, placed into low-Earth orbit (LEO) typically at an altitude between 300 km to 2 000 km, medium-Earth orbit (MEO) typically at an altitude between 8000 to 20000 k m, or geostationary satellite Earth orbit (GEO) at 35 786 km altitude.
- **Satellite access:** direct connectivity between the UE and the satellite.
- **5G satellite access network**: 5G access network using at least one satellite.
- **Satellite NG-RAN:** a NG-RAN which uses NR in providing satellite access to UEs.
- **Geostationary Earth orbit (GEO):** Circular orbit at 35,786 kilometres above the Earth's equator and following the direction of the Earth's rotation. An object in such an orbit has an orbital period equal to the Earth's rotational period and thus appears motionless, at a fixed position in the sky, to ground observers.
- **Bentpipe payload**: payload that changes the frequency carrier of the uplink RF signal, filters and amplifies it before transmitting it on the downlink
- **Low Earth orbit (LEO):** Orbit around the around Earth with an altitude between 500 kilometres (orbital period of about 88 minutes), and 2,000 kilometres (orbital period of about 127 minutes).
- **Medium Earth orbit (MEO):** region of space around the Earth above low Earth orbit and below geostationary Earth Orbit.
- **Nonterrestrial networks (NTN)**: Networks, or segments of networks, using an airborne or space-borne vehicle to embark a transmission equipment relay node or base station.
- **On-board processing:** digital processing carried out on uplink RF signals aboard a satellite or an aerial.
- **Highly-eccentric orbiting (HEO)**: satellites, with a range of operational altitudes (the orbit of such satellites being designed for the spacecraft to be exploited when the vehicle is closer to its apogee - the higher part of the orbit -) between 7,000 km and more than 45,000 km. The inclination angle is selected so as to compensate, completely or partially, the relative motion of Earth with respect to the orbital plane, allowing the satellite to cover successively different parts of Northern land masses (e.g. Western Europe, North America, and Northern Asia).
- **Transparent payloads:** the electromagnetic wave that are transmitted from Earth surface are converted by a satellite receive antenna into an electric signal which is channel filtered and amplified by low-noise amplifier (LNA). The signal is then frequency converted. A high power amplifier (HPA) delivers finally the signal to a transmitting antenna generating a re conditioned electromagnetic wave towards the Earth surface where receive station are located.
- **Regenerative payloads:** an On-board processor (OBP), is inserted between the LNA and the HPA. This OBP allows to convert the air interface between the uplink (from Earth to satellite) and the down link (from satellite to Earth). It allows to correct bits or packet in errors before retransmitting them, or to route packet between beams. Ultimately any network function can be implemented, as the expense of power and

mass, thanks to an OBP (including gNB CU's or DU's, or any function attached to a CN).

- **Inter-satellite links (ISL)**: can also interconnect regenerative satellite payloads. Through ISL's satellites can be interconnected through a dedicated mesh-network.

3.2 Satellite radio communication

3.2.1 Overview of technologies

Currently the leading satellite communication systems are Iridium, Inmarsat and Thuraya. Among these, Iridium is the only one using a constellation of low-earth orbit (LEO) satellites (66 satellites) while the other two rely on two or three geo-synchronous (GEO) satellites. As a recent field test indicates the services that these systems provide are just voice calls and SMS. For data transmission Iridium offers a very modest speed of 2.4 kbps, Inmarsat supports up to 240/384 kbps Tx/Rx speed and Thuraya may provide 444/404 kbps down/up speed, and with transmission delays of more than 500 ms. Furthermore, none of these systems can support roaming; the UEs may only connect to their dedicated satellites (Rowland 2017). In this case, the field tests were done in Australia, where satellite radio coverage is better than in most places. Some recently launched high throughput GEO satellites, such as ViaSat and EchoStar can theoretically provide 100 - 300 Gbps overall capacity. The principles of satellite orbits is illustrated in Figure 5.

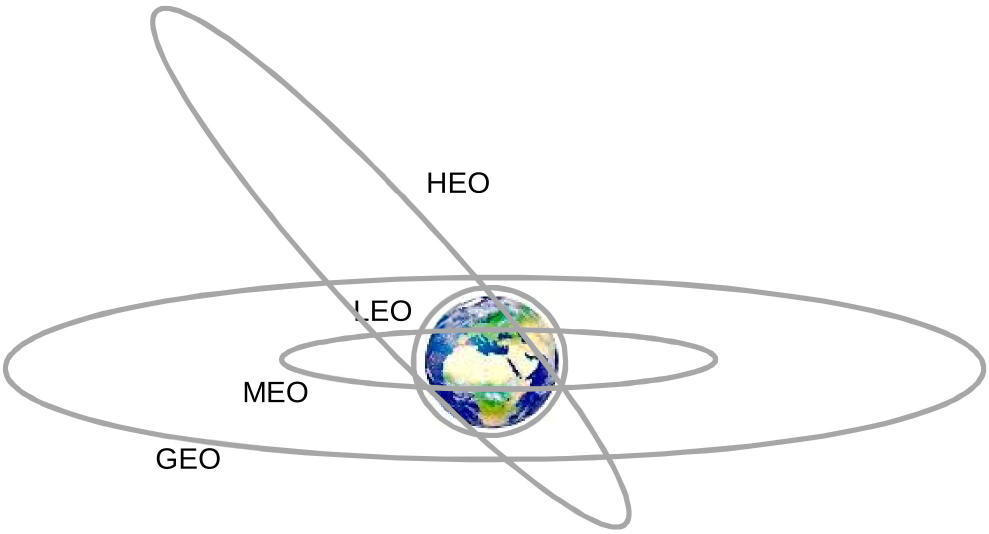

Figure 5: Illustration of satellite orbits.

However, there are several new LEO satellite projects, which seriously aim at offering broadband internet access. Presently LeoSat, OneWeb, SpaceX and Telesat are progressing with their work and the first pathfinder satellites are already orbiting. These networks are expected to reach full operational capacity in the early 2020s. They may offer user speeds from 0.5 Gbps to 5.2 Gbps. Unfortunately the LEO systems require launching hundreds or even thousands of new satellites. At the same time, it is difficult to produce small and technically advanced low-cost antennas, which these systems inevitably need. In addition, implementing the LEO satellite systems will cost billions; the current estimations vary between 3.5 to 5 billion dollars. These issues can become critical obstacles to their success (Mohney 2018).

The European Space Agency (ESA) now actively wants to promote 5G based satellite communication. ESA considers that the promises and expectancies of the 5G environment cannot be fulfilled economically with expensive terrestrial deployments. Still it looks that ESA has also expected that 5G will support a broad set of technologies, which may include MF-TDMA and DVB-S2X transmission (Corici et al. 2016). Anyways, ESA has quite recently, in October 2018, set up a collaboration to support Europe’s 5G markets. ESA and the 5G Infrastructure Association (5G IA) published their joint intent to work together to enable new and innovative 5G solutions. ESA and the main stakeholders in the European Space Industry published in the Paris Airshow 2017 another joint statement, which aims at setting up “Satellite for 5G Initiative” (ESA 2018a). In these letters the concrete proposals are trial projects and definitions of design principles. Setting up a specific LEO satellite constellation for 5G may not yet be under work.

Satellite on-board hardware is practically impossible to be fixed or replaced after launch, although software updates are feasible. Therefore, the satellite air interface should be compatible with 5G from the beginning or it should be modifiable with software. A good survey on satellite integration is found e.g. from (Kapovits 2018).

3.2.2 Example of VTT’s recent contribution to the state-of-the-art

Some recent examples of VTT’s work published in international forums can be found from (Höyhtyä 2017a, Höyhtyä 2017b, Mazzali 2018). In the following, we discuss (Mazzali 2018) in more detail. VTT was a prime for the ESA project Novel Ground Components Prototype beyond DVB-S2 for Broadband Satellite Networks (NOVEL, Contract No. 4000110120/14/NL/NR), see Figure 6 (Mazzali 2018).

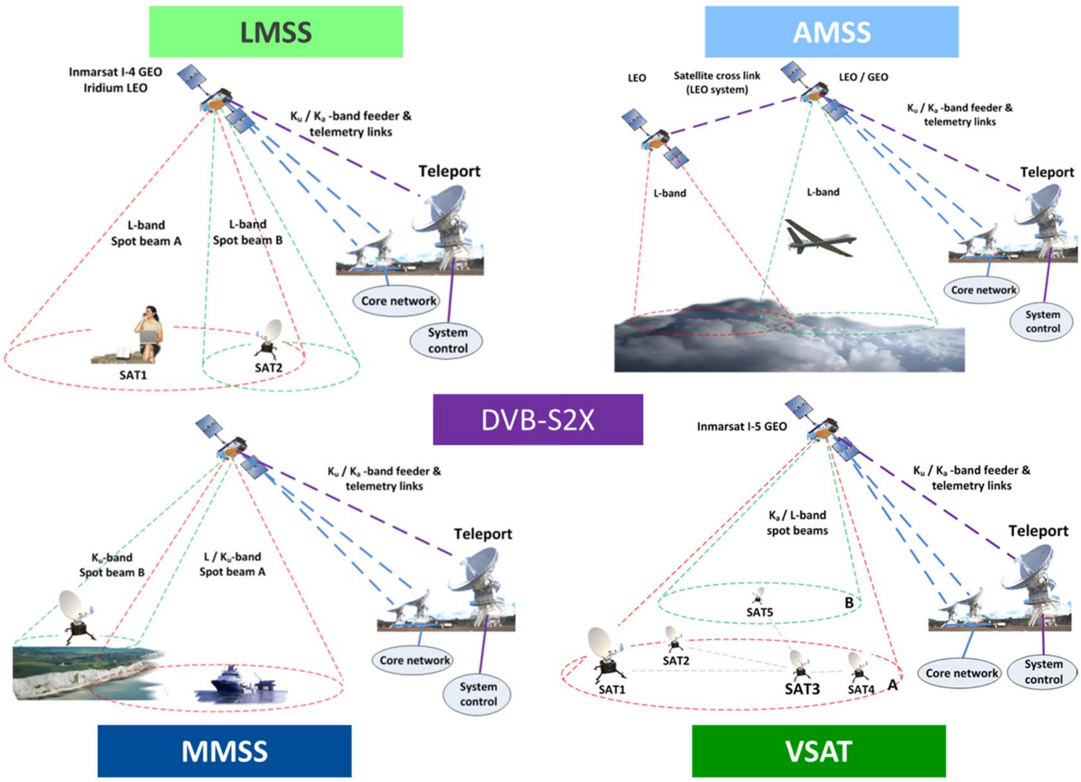

Figure 6. The DVB-S2X is a technology enabler for the VSAT and LMSS, MMSS and AMSS, modified from (Mazalli 2018) by adding AMSS.

The DVB-S2 and its extension S2X form the cornerstone for satellite communication standards forming the state-of-the-art of broadband satellite waveforms. The outcome of the NOVEL was that the DVB-S2X can be a common technology enabler not only for very small aperture terminal (VSAT) but also for land mobile (LMSS), maritime mobile (MMSS) and aeronautical mobile satellite services (AMSS). From technical point of view, a special attention was given to signal predistortion and to develop, implement and verify a robust synchronization at very low signal-to-noise ratio (SNR). A HW testbed incorporating the selected PHY techniques with DVB-S2X framing was devised, and the functionality of HW testbed was validated by comparing the measured performance with the SW simulations. As a highlight of the results, the test system can operate down to -6 dB SNR and timing drift up to 100 ppm can be tolerated. These are attractive findings for commercial equipment and (low earth orbit) LEO satellite scenarios.

According to the NOVEL project, the typical DVB-S2X channel models are presented in Figure 7. In the case of AMSS, the fading can be neglected, and the LOS can be assumed with the proper Doppler. In LMSS and MMSS cases, both slow shadowing fading and fast multipath fading have to be modelled. However, high satellite elevation angle and directivity antennas may allow to use 1-tap Ricean channel.

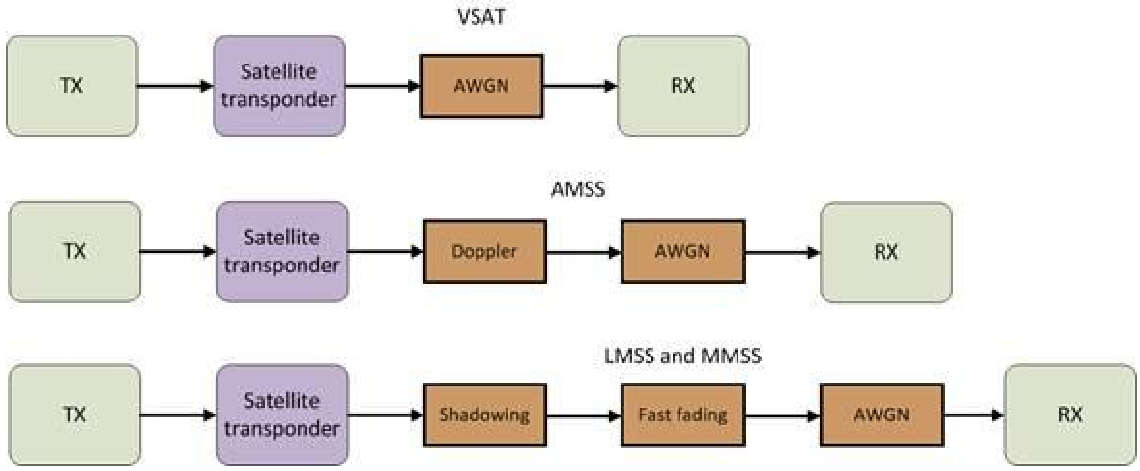

Figure 7. DVB-S2X channel models .

Beyond the propagation channel effects, we need to take into account the TX/RX distortions and nonlinear satellite transponder as presented in Figure 8. In more detail, IMUX/OMUX filters introduce linear distortions and group delay. Nonlinear distortions are caused by the travelling wave tube amplifier (TWTA), and frequency offset is due to an imperfect frequency conversion. Low cost components will increase distortions. The countermeasure techniques include an adaptive equalizer to compensate the linear distortion. The frequency error and group delay are corrected by the synchronization chain in the receiver. The nonlinear distortion requires a dedicated predistortion algorithm at the transmitter.

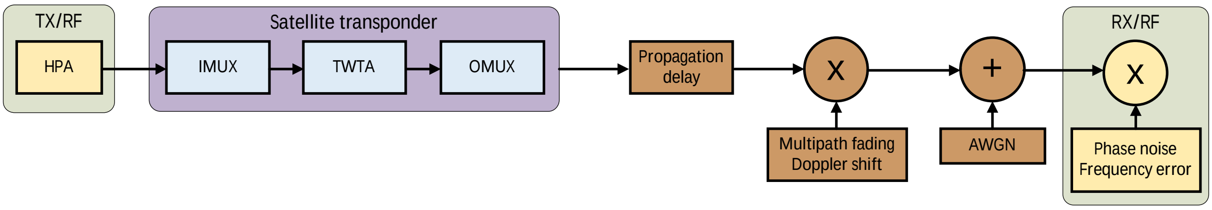

Figure 8. TX/RX distortions and nonlinear satellite transponder.

3.3 High and low altitude platforms

Beyond satellites, there is also interest within 3GPP to simultaneously utilize the high altitude platforms (HAPs) which operate between 8 and 50 km altitudes as a lower delay/Doppler shift option to SATCOM (Cao 2018). These technologies are distinctively featured with high network heterogeneity and topology changes with specific height-dependent propagation models. As a result, their integration to existing terrestrial networks and SATCOM is far from being trivial.

Although the development of HAPs have been made already in the 1990s, there have been no significant commercialization of the technology mainly due to reliability and cost reasons (Cao 2018). Recent activities, most notably from Google, have promoted to again the possibility of using HAP as completion of the gaps remaining from satellite and terrestrial networks. Those gaps involve better channel conditions and fast response to locally changing traffic demands. In general, HAPs may consist of aircrafts or airships that operate 17-22 km above ground surface. During 2018, 3GPP has established new SIs to advance using HAPs in addition to satellites in future releases of 3GPP.

Recently, 3GPP has initiated a new study item for Release 17, called FS_EAV, Study on enhancement for unmanned aerial vehicles (UAVs). It represent a serious interest towards integrated airborne networks described in Figure 4. A good survey on state-of-the-art UAVs can be found from (Hayat 2016).

4. Overview and analysis of 3GPP SATCOM use cases

The main benefits of satellite-based systems are the wide coverage and ubiquity, which can be important after disasters such as Earthquakes or floods. Also high scalability is a benefit in the sense that they are eligible for broadcasting or multicasting. Additionally, the satellite services are getting cheaper than they were so that in some cases they may even produce cost savings. The main critical weakness is the transmission delay, which can be up to 250 ms even in the coming high throughput satellite systems while 5G has set latency of 1 ms as a target. Therefore, satellite connections remain ineligible for the most latency sensitive applications.

3GPP defines three major groups of use cases for NTN in 5G system. Firstly, NTN can rollout 5G service in unserved or underserved areas such as isolated or remote areas, aircrafts or vessels at sea, and also rural areas where terrestrial networks can be too costly to build. Secondly, NTN should reinforce the 5G service reliability by providing service continuity for M2M devices, or for passengers on board vehicles, aircraft, trains and buses and for critical communications. Thirdly, enabling 5G network scalability by providing multicast or broadcast resources for data delivery towards the edge of the network or user's terminal (TR38.811 2018).

Furthermore, 3GPP analyses twelve different use cases for satellite access in 5G. The use cases are examples only; there are many more cases, which could be discussed as well. Nevertheless, these cases show the strong potential that the satellites bring to improve the 5G service level (TR22.822 2018). Below we present short summaries of the use cases specified in (TR22.822 2018). Most of the requirements that derive from these cases are not quite new or unique; still implementing 5G systems to enable these services may require essential changes to the 5G network functions.

4.1 Roaming between terrestrial and satellite networks

This use case is about a shipping company, which wants to track and trace its containers equipped with 5G UEs through routes, which are not completely under terrestrial coverage. The containers may travel at sea inside or on board ships, and on land in trains or as truckload. Still there is a satellite operator that can offer 5G service throughout the route and which has roaming agreements with terrestrial system operators. When no line of sight to satellites is available, the UEs can utilize relay UEs or some of the UEs inside containers can connect as a remote UE.

Requirements

This use case requires that the 5G system provide connectivity with a 5G satellite access network, enables roaming between the satellite access network and terrestrial access networks and that the 5G system supports network reselection policy.

Verdict

This use case does not require extremely short delays or wide bandwidth, so it is quite feasible with existing 5G technology.

4.2 Broadcast and multicast with a satellite overlay

Mobile network operators (MNO) may cooperate with a satellite network system to enhance their service, which includes distribution of television channels or video streaming. 3GPP's Release 14 specified many advances for television services which eMBMS (enhanced multimedia broadcast and multicast system over LTE) provides. UEs may be in the radio coverage of the terrestrial and the satellite network simultaneously, or solely under the satellite or solely under the terrestrial system.

Requirements

UEs should support satellite access and they should be able to send and receive in parallel via a satellite access network and a terrestrial access network. The 5G system should also be able to optimise the delivery of content when using the 5G satellite access network.

Verdict

The basic radio technology should be adequate for wideband video transmission and reception, which is not a new requirement for 5G. Call control and mobility management functions may need changes.

4.3 Internet of things with a satellite network

LEO satellites should extend the radio coverage for IoT as well. In this example, a land vehicle with wireless sensors on board moves in an area where 5G terrestrial networks cannot provide 100% continuous coverage although that is strictly required.

Requirements

UEs that support mMTC and/or NB-IoT services in 5G networks should also support those services through a satellite access network. Accordingly, a 5G system supporting mMTC and/or NB-IoT services and satellite access should support mMTC and/or NB-IoT services on the 5G satellite access. A 5G system should also allow optimal selection between a satellite and a terrestrial access network.

Verdict

This use case sets high expectations to UEs energy capabilities, which in many of the IoT devices can be very limited. It also requires a satellite system constellation orbiting in LEO.

4.4 Temporary use of a satellite component

Terrestrial RAT is partly or completely lost due to an earthquake, a hurricane, a war or something as exceptional and temporary. The satellite component can still provide at least limited service to mission critical users. Still only specific set of users may get a minimum set of services.

Requirements

UEs and the 5G system should support at least one 5G satellite RAT.

Verdict

These requirements may become regulatory requirements, in some countries at least. Currently, 3GPP RAT is not typical in satellites.

4.5 Optimal routing or steering over a satellite

Some UEs may constantly run applications, which set strict real-time requirements while they occasionally must also support software updates for large systems. An example is a monitoring system of a remote manufacturing process where immediate control actions may abruptly become necessary, also when the communication channel is saturated. In such case, the terrestrial networks should handle the latency-constrained applications while the satellite link would process everything else.

Requirements

The 5G system should be able to optimise the connectivity of UE through the satellite or terrestrial access network in accordance with the required QoS. The UEs should be capable of dual connectivity with a satellite access and a terrestrial access network. The 5G system should be capable to establish independently uplink and downlink connectivity through satellite and terrestrial access networks.

Verdict

This use case can require essential changes to 3GPP Non-Access-Stratum, in other words the call control and mobility management protocols.

4.6 Satellite trans-border service continuity

MNOs in different countries may use satellite services that partially overlap radio coverage while UEs may have access to more than one satellite system through roaming agreements. UE can connect to a satellite system, although a terrestrial network is in reach.

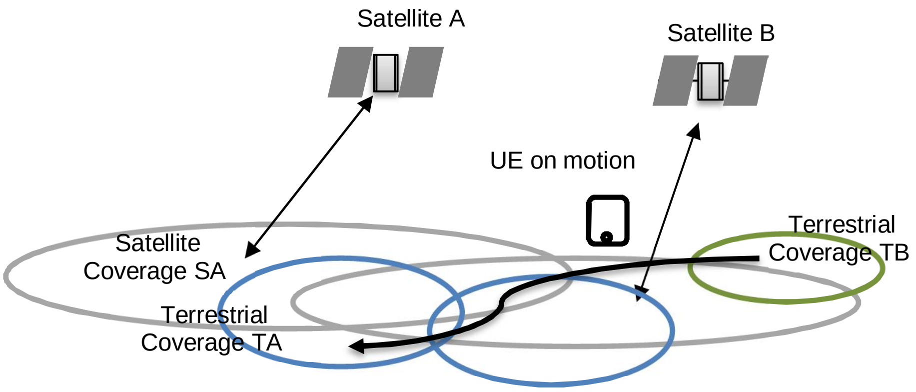

Figure 9. Multiple terrestrial networks that include satellite access, the networks may reside in different countries, modified from (TR22.822 2018).

Requirements

Mobility management should take into account the satellite access networks. Satellite access networks should support network sharing and support MNOs of different countries attached to the same 5G satellite network.

Verdict

Networks should cope with varying regulatory requirements, support roaming between 5G satellite network and 5G terrestrial network, as well as extension of the 5G terrestrial network with QoS capability.

4.7 Global satellite overlay

For some users and applications, even very short variances of transmission delays can be critical, for instance in High Frequency Trading. Transmission latencies e.g. between Tokyo and Paris may affect to prices at the stock exchanges.

Figure 10. Globally connections should be quick, reliable, resilient, and secure.

Furthermore, these applications require extreme reliability and security in addition to otherwise high QoS. Satellite route can sometimes be quicker than fibre connections, at least if a constellation of LEO satellites and a meshed architecture in communication is available.

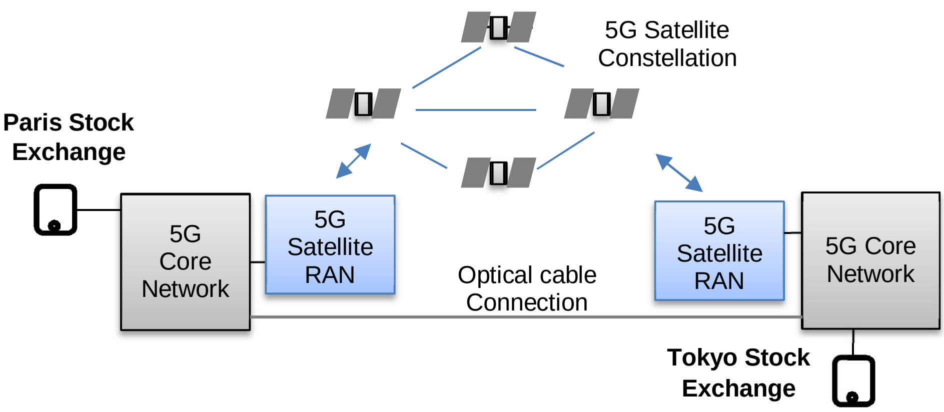

Figure 11. Alternative transmission paths may bring profits in high frequency trading.

The operator should always have access to a number of routes including satellite-based and terrestrial with advanced real-time performance monitoring facilities. The user may utilize the satellite overlay network depending on the measured delays and the current network load, to get the highest end-to-end QoS and optimal routes for each path.

Requirements

The 5G systems with global satellite overlay access should be able to select the communication link providing the UEs with the suitable quality with respect to latency jitter and required bit rates. The 5G satellite system designers should consider supporting meshed connectivity between satellites.

Verdict

Utilizing a mesh architecture between the satellites to provide faster connections is a new approach, which may promote discussion. Solutions can be costly, but very important for several wealthy customers, such as bankers and international companies. It can become necessary to control that all users experience the same latency or else some traders may get unfair benefit.

4.8 Indirect connection through a 5G satellite access network

In order to serve users that are located in areas with no connectivity to any 5G terrestrial access networks, a satellite enabled UE could serve as a relay UE. Examples of such users are travelers in airplanes (hundreds), on cruise vessels (thousands) or the very few hikers or dwellers in remote areas. The relay UE would provide indirect connectivity between associated remote UEs and the 5G core network through the 5G satellite access. The relay UEs could be located in different countries, or on a moving platform (aircraft, ship) which moves from a country to another during a connectivity session. Subscribers of remote UEs attached to the relay UEs could expect similar connectivity services as if they were located within direct reach of a 5G terrestrial access.

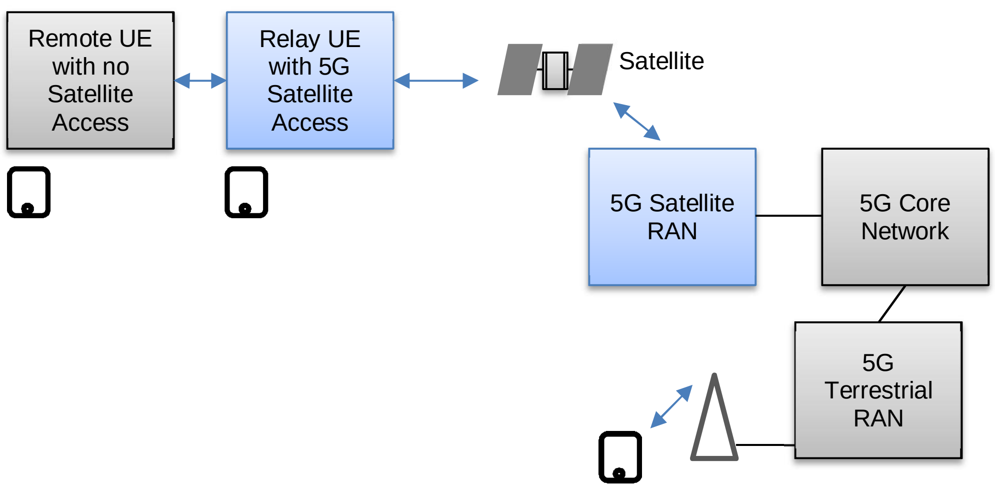

Figure 12: Interconnection of UE to a 5G network through a satellite and relay enabled UE, modified from (TR22.822 2018).

This use case impact to several issues for further study (FFS) within the 3GPP WG. Roaming functions and charging policies do not properly handle the case where a Relay UE moves between countries while a UE is attached to the Relay UE. The Relay UE could be in view of more than one 5G system simultaneously; conditions for this case should be decided. A Relay UE with satellite access may not provide the same QoS as a terrestrial connection for the attached UEs. It is also FFS how the security mechanisms can offer the same security performance for the remote UEs as they offer for any other UEs.

Requirements

A 5G system with satellite access should support Relay UE's with 5G satellite access, roaming of Relay UEs and the remote UEs connected to the relay and service continuity when the relays and the connected UEs move between 5G RANs.

Verdict

Technology that enables this case exist, but 3GPP still needs to work with the roaming, charging and security functions, which currently are not properly supporting worldwide networks.

It looks that a relay UE should offer almost the same service level as a terrestrial access network, which sets hard requirements for the Relay UEs.

4.9 5G fixed backhaul between NR and the 5G core

Instead of building a cable connection of about 5 km or more between a core network and a distant NR gNB, the operator may use satellite backhaul to the remote cell tower. In this case, a gNB typically has less than 200 potential users, although occasionally traffic may be busier.

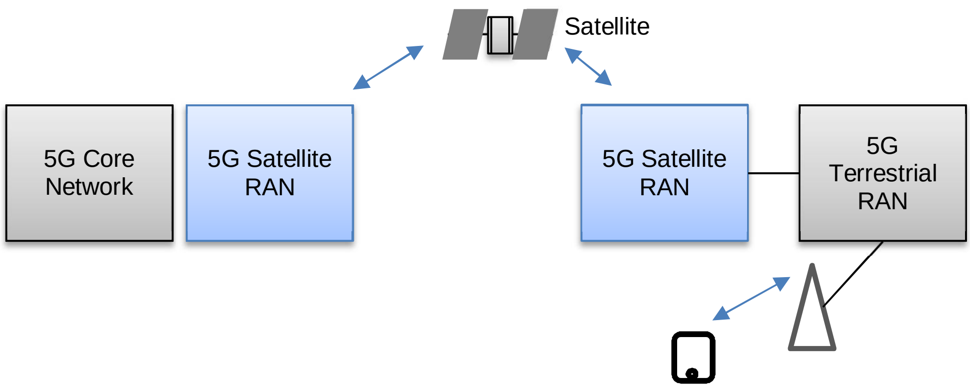

Figure 13. A fixed satellite backhaul for remote terrestrial cells.

The satellite backhaul generates propagation delay, mitigating that is possible by selecting links that utilise LEO constellations.

Requirements

The 5G system shall support the use of satellite links between the radio access network and core network and within the core network, by enhancing the 3GPP system to handle the latencies introduced by satellite backhaul.

Verdict

Satellite backhaul may bring savings in this case, if users accept the latencies, which are not as 5G promises but can still be better than in typical 4G systems.

4.10 5G moving platform backhaul

This example presents a high-speed train travelling through densely populated areas, where mobile networks can sometimes be overloaded, and through a 200 km track without any terrestrial 5G coverage at all. The train operator wants to offer entertainment content as unicast/multicast/broadcast over the terrestrial base stations and/or base stations on the train. The uplink connection is not so important. Frequently used content can be stored in the train operator's local infrastructure and updated when needed. When the train passes the area without terrestrial network, only satellite connectivity is available. UEs entitled to general internet services can use both access networks, combined or singly.

Requirements

The 5G system shall support the use of satellite links between the radio access network and core network and within the core network, by enhancing the 3GPP system to handle the latencies introduced by satellite backhaul.

Verdict

Satellite backhaul could really enhance service in this case.

4.11 5G to premises

In a remote small village in the foothills of a mountain, radio coverage of terrestrial access network is not quite satisfactory. Satellite component is available, it can be used to broadcast, and multicast media contents, and it is possible to cache frequently used contents in a local home/office gateway. Unicast can still use the cellular route, particularly for the applications that need short latencies. For improving radio coverage at the difficult geographical positions, the operator builds local gateways.

Requirements

Broadcast/multicast service through a 5G satellite component must be present. 5G system must handle the latencies, which the satellite links introduce. UEs must be capable to dual mode of operation, through satellites and terrestrial systems simultaneously. The 5G system should allow optimally distribute traffic over both satellite and terrestrial access networks.

Verdict

This case sets interesting requirements to both UEs and the 5G network systems, as handling various latencies and UEs in dual mode may not be quite simple.

4.12 Satellite connection of remote service centre to offshore wind farm

A wind farm uses 5G for the power plant's internal communication. This network connects to an on-shore remote service centre via a 5G satellite connection.

Remote monitoring and non-time-critical control of power plant's operations need moderate data volume with low transmission latency. Sensor data is analysed at the remote service centre and that requires high uplink data volume with no restriction on communication latency. Video surveillance for on-demand maintenance may require high uplink data volume and low satellite communication latency. Provision of support information from remote service centre to on-site personnel demand high downlink data volume.

Requirements

The 5G satellite link must support high uplink data rates, high downlink data rates, interfaces for QoS monitoring of the 5G satellite connection and selection of the satellite access depending on the QoS requirements. Reliability, or communication service availability, should be at least 99, 99%

Verdict

This use case sets requirements that are almost as strict as the requirements set for autonomous or remotely controlled ships. Satellites in LEO constellation were mentioned; still it seems that other constellations could be utilized in some cases.

4.13 Key requirements for 5G satellite communication

An important use case which 3GPP did not analyse is that of autonomous ships. However, the Wind Farm Case is close to that, as it sets strict requirements for latencies and the uplink connection also. If the 5G system can satisfy those expectations, 5G connectivity can become a solid option for autonomous ships that sail on the high seas.

The 5G satellite access network's architecture should rely on bent-pipe satellites or regenerative satellites with on-board processing capabilities. Some of the existing satellite networks could be suitable for 5G system extensions as bent-pipes. However, the current satellite network operators have not shown much interest to co-operate with mobile network operators. A regenerative satellite should support 5G's NR, which the prevailing systems cannot do. However, offering full-scale on-board processing for a 5G system would also require considerable power resources that only large and expensive satellites can provide. This could be a problem, if huge constellations of LEO satellites are used.

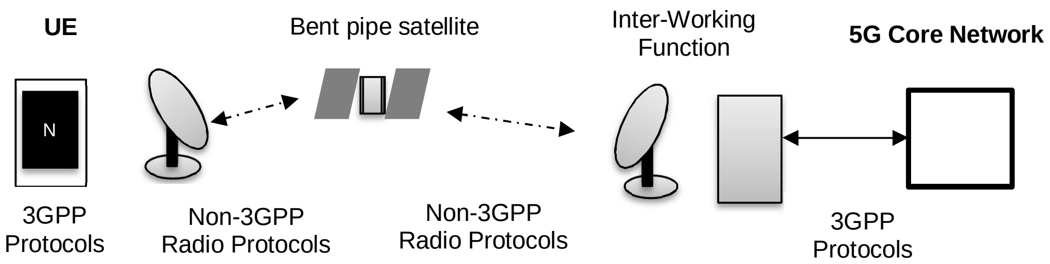

Figure 14. Satellite access network with a non-3GPP section. If NR replaces the non-3GPP protocols, satellite could connect directly to handheld 5G UEs, modified from (TR22.822 2018).

3GPP's short analysis of the use cases for satellite connections shows that essential changes to 3GPP's NAS (Non-Access-Stratum) protocol become necessary (TR22.822 2018, TS 24.301 2018). Unfortunately, some of these issues relate to legislation and regulations, which differ between countries. Adapting the 5G protocols to the different regulations is probably difficult and time-consuming. Therefore, we can expect that in the 5G systems the satellite links first support the multimedia and broadcasting services much as the existing satellite systems do.

Other difficult requirements deriving from the analysed use cases are the 5G expectations of short delays, high uplink capacity and support of low-energy systems, such as IoT. Implementing these features requires advances in technology and big investments. Probably the market expectations dictate how quickly these services realize. In any case, utilization of satellites truly improves 5G services and finally the satellite links become vital part of the 5G system.

5. Main existing SATCOM-related 3GPP specifications and change requests

In this section, we outline the most important WGs and their contributions within 3GPP that are dealing with SATCOM technologies. The provided information is collected from a large number of sources which can be found on 3GPP portal (3GPP 2018d).

Currently, the most active WGs on SATCOM are RAN1 (Layer 1), RAN3 (Interfaces), SA1 (Services), and SA2 (Architecture). Table 2 outlines the found SIs and WIs for the respective WGs, including their announced completion status. Table 3 then outlines the conducted technical reports on SATCOM and the specifications they have influenced so far. Finally, Table 4 includes some recent interesting CRs on SATCOM related proposals.

Table 1. Summary of SIs and WIs for satellite access in 3GPP

Item type (SI/WI)	Title (Acronym)	WG	Status*
SI	Study on architecture aspects for using satellite access in 5G (FS_5GSAT_ARCH)	SA2	15%
SI	Study on solutions for NR to support Non Terrestrial Network (FS_NR_NTN_SOLUTIONS)	RAN3	0%
SI	Study on NR to support non-terrestrial networks (FS_NR_NONTERR_NW)	RAN1	100%
SI	Study on using satellite access in 5G (FS_5GSAT)	SA1	100%
WI	Integration of satellite access in 5G (5G_SAT)	SA1	95%

*Work done in % on 12/2018. See statuses from: http://www.3gpp.org/DynaReport/GanttChart-Level-2.htm#bm

Table 2. 3GPP technical reports and related specifications on SATCOM

Technical report ID	Impacted specification	Title	WG	Status*
TR 23.737	N/A	Study on architecture aspects for using satellite access in 5G	SA2	Draft
TR 38.811	N/A	Study on NR to support non-terrestrial networks	RP/RAN1	UCC
TR 22.822	TS 22.261/R16	Study on using satellite access in 5G	SA1	UCC
TR 38.821	N/A	Solutions for NR to support non-terrestrial networks	RAN3	Draft
TR 22.829	N/A	Enhancement for UAVs		
TR 22.819	N/A	Feasibility study on maritime communication services over 3GPP system	SA1	UCC

*Status 12/2018; can be draft, under state control (UCC), or withdrawn, see https://portal.3gpp.org

Table 3. Some recent change requests for technical specifications and reports

Change request ID	Target specification	Title	WG	Status*
CR255	TS22.261/R16	Performance requirements for 5G satellite access	SA1	Approved
CR256	TS22.261/R16	Mutiple access requirements related to 5G satellite access	SA1	Approved
CR257	TS22.261/R16	Connectivity aspects of 5G satellite access	SA1	Approved
CR258	TS22.261/R16	Efficient delivery of content using 5G satellite access network	SA1	Approved
CR259	TS22.261/R16	Efficient user plane aspects of 5G satellite access	SA1	Approved
CR260	TS22.261/R16	Mobility management related requirements for 5G satellite access	SA1	Approved
CR261	TS22.261/R16	NG-RAN sharing for 5G satellite access network	SA1	Approved
CR262	TS22.261/R16	QoS control aspects of 5G satellite access	SA1	Approved
CR263	TS22.261/R16	Regulatory and charging aspects related to 5G satellite access	SA1	Approved

CR264	TS22.261/R16	Satellite links between radio access network and core network	SA1	Approved
CR265	TS22.261/R16	Broadcast and multicast via satellite access networks	SA1	Approved
**pCR	TR23.737/R16	Key Issue on multi connectivity with satellite access	SA2	Approved
pCR	TR23.737/R16	New solution - addition of new RAT type satellite	SA2	Approved
pCR	TR23.737/R16	Key Issue: RAN mobility with NGSO regenerative-based satellite access	SA2	Approved
pCR	TR23.737/R16	Solution for mobility management in the 5GS with satellite access	SA2	Approved
pCR	TR23.737/R16	Key issue on QoS Feedback from satellite backhaul	SA2	Approved
pCR	TR23.737/R16	Key Issue on QoS with satellite access	SA2	Approved
pCR	TR23.737/R16	Key Issue on Delay in a 5G System with satellite access	SA2	Approved
pCR	TR23.737/R16	Key issue on Mobility Management with mobile satellite access coverage areas	SA2	Approved
pCR	TR23.737/R16	Key issue on Mobility management with large satellite access coverage areas	SA2	Approved
pCR	TR23.737/R16	Satellite Reference Integration Scenarios	SA2	Approved
pCR	TR23.737/R16	23.737: Reference Satellite Integration Architectures for FS_5GSAT_ARCH TR	SA2	Approved
pCR	TR23.737/R16	Satellite system characteristics to be included in FS_5GSAT_ARCH TR	SA2	Approved
pCR	TR23.737/R16	TR Skeleton for study on architecture aspects for using satellite access in 5G	SA2	Approved
pCR	TR23.737/R16	Integration of satellite in the Next Generation system architecture	SA2	Approved
pCR	TR38.811/R15	Non-Terrestrial Networks: Adding uRLCC related use cases	RAN1	Approved
pCR	TR38.811/R15	Non-Terrestrial Networks: Considerations on NR impacts	RAN1	Approved
pCR	TR38.811/R15	Propagation delay and Doppler in Non-Terrestrial Networks	RAN1	Approved
pCR	TR38.811/R15	Non-Terrestrial Network Deployment scenarios	RAN1	Approved
pCR	TR38.811/R15	Non-Terrestrial Network overview	RAN1	Approved
pCR	TR38.821/R16	Applicability of Xn to Satellites	RAN3	Agreed
pCR	TR38.821/R16	Transporting F1 over Satellite Radio Interface	RAN3	Agreed
pCR	TR38.821/R16	NTN architecture with transparent satellite	RAN3	Agreed
pCR	TR38.821/R16	NTN architecture with regenerative satellite	RAN3	Agreed

*Status 12/2018; can be noted, reissued, withdrawn, endorsed, postponed, merged, revised, not pursued, rejected, approved, agreed, see details from http://www.3gpp.org/specifications/change-requests; **pCR denotes pseudo change request for draft TRs which ID is not available.

In order to provide further insight about the status of preparing SATCOM related activities, we present a block diagram of the active WGs and related documents in Figure 15 based on the previously presented tables. In essence, SATCOM is now a strong component of the 5G requirement specification TS 22.261 with version V16.5.0. The work has conducted by SA1 and based on earlier technical report TR 22.822. These requirements further influenced the study in TR 38.811 by RP/RAN1 to evaluate more closely the feasibility and challenges of the integrated SATCOM and 5G NR concept. SA2 is conducting a study on 5G-SAT system architecture issues. In addition to documents in Figure 15, very recently also CT4 has initiated discussions on 5G SATCOM issues considering satellite specific technical issues to be considered in 5G core specification in power point presentation, see (3GPP 2018e).

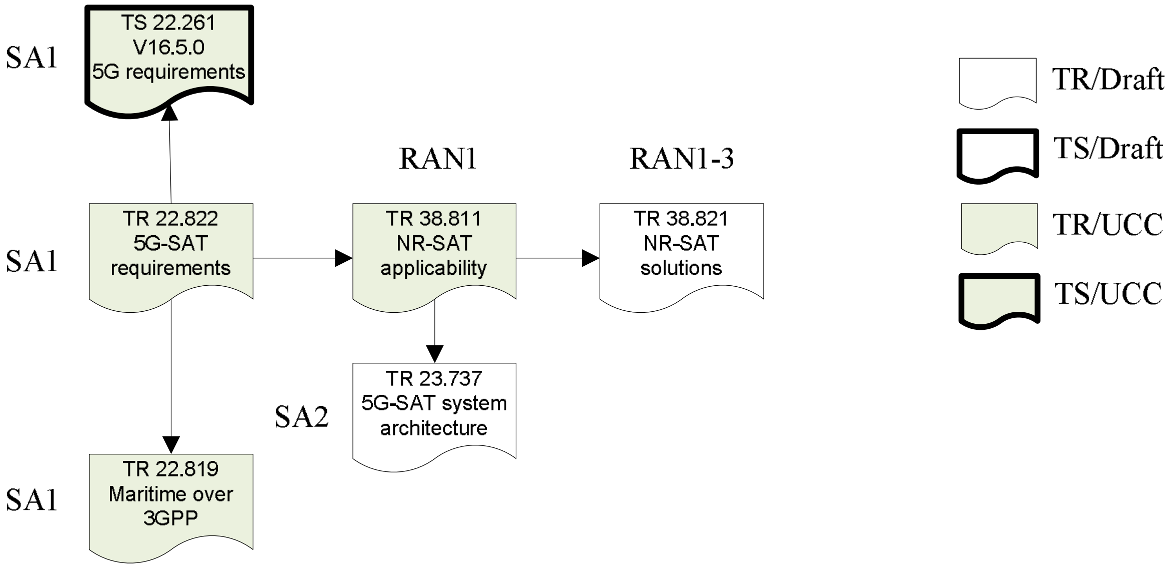

Figure 15. Diagram of currently active WGs and main specification documents.

We have further picked the most interesting highlights from these 5 documents presented in Figure 15 as follows:

- TR 22.822
  - Provides 12 use cases for 3 service categories of 5G SATCOM, namely service continuity, service ubiquity, and service scalability
  - Recommends functional requirements for each use cases, including e.g. latency issues
- TS 22.261
  - Adapts most important 5G SATCOM requirements as part of overall 5G system requirements.
  - Includes 11 CRs from 5GSAT WG
- TR 38.811
  - Provides the first comprehensive technical study on feasibility of 5G NR for 3GPP non-terrestrial networks.
  - Evaluation includes e.g. Doppler shifts, delays, antenna patterns, and channel models. E.g. the one-way delay can be up to 270 ms for GEO systems while as low as about 2 ms for a HAP system.
  - Recognized key impact areas on 5G NR to support non-terrestrial operation are related to: propagation channels, frequency planning, power limitations, network cell pattern modelling, delay characteristics, mobility of users and infrastructure, service continuity, and radio resource management with minimal response time
- TR 38.821
  - Only a preliminary version V0.3.0 was available at 12/2018.

  - Work in this report will be a continuation of TR 38.811 to further consolidate the recognized impacts mainly on Layers 1-3.

- TR 23.737
  - Only a preliminary version V0.3.0 was available at 12/2018.
  - Considers the system architecture issues including roaming between terrestrial and satellite networks and fixed backhaul to 5G core network.

- TR 22.819
  - Considers maritime communication services as one of 3GPP vertical applications.
  - Proposes use case on satellite access to support maritime communication services over 5G system

6. Future SATCOM challenges and research opportunities

The integration of nonterrestrial technologies to terrestrial ones has been considered already for some time in the past. However, recent progress in both technology and standardization bodies has led to increased interest in many parties. One of the most important challenges in integration of SATCOM technologies to terrestrial is to be able to reuse the existing technologies as much as possible. However, since terrestrial and nonterrestrial networks possess very different characteristics, finding those common interfaces with a low effort is challenging. In addition to this report, good sources for recently recognized challenges are found from (Guidotti 2018, Cao 2018, TR38.811 2018).

Research recommendations to advance integrated satellite-terrestrial communications presented in the latest literature include satellite-terrestrial architecture, integrated signalling in satellite communications, and on-board processing (Sharma 2018). Research is also needed to enable use of higher frequency bands and spectrum sharing e.g. in 5G pioneer bands between several satellite and terrestrial systems. In addition, development of autonomous and remote-controlled vessels, cars, and other mobile systems demands new capabilities from integrated systems including high throughput to uplink direction.

Developing integrated satellite-terrestrial architecture is utterly important in advancing the 5G system capable to provide the new enhanced services reliably and efficiently. Among the challenges arising in that work are supporting parallel and transparent access of the users to both broadband and broadcast resources, smart management of the sophisticated network resources as well as the user content. Furthermore, the 5G users obviously expect service continuity that provides seamless service delivery when roaming between terrestrial and satellite backhauled cells. Achieving that may require new type of mobility management protocols for supporting vertical handovers, transmission protocols that can handle the varying latencies, low-cost 5G devices capable to satellite-terrestrial dual mode operation as well as innovative business models that can satisfy the interests of the satellite and terrestrial network operators.

Yet another challenge comes from the 5G expectation of supporting the M2M systems through the integrated satellite-terrestrial architecture. Especially the satellite's IoT design can be challenging, as it should enable secure, reliable and energy-efficient communication with large number of low-power M2M systems. Moreover, the IoT scenarios should tolerate the varying latencies in the satellite communication and manage with the redesigned routing protocols. In addition, the various scenarios of the integrated architecture and efficient utilization of the higher than 10 GHz frequencies probably need investigation in terms of optimal carrier, bandwidth and power.

Signalling in satellite communications should synchronise with 5G signalling, and the signalling should handle ultra-dense cells, handovers, mobility management, backhauling and data-cell discovery. These functionalities become more complicated when an integrated satellite-terrestrial network is in question and the convenient 3GPP protocols require upgrading. Signalling must enable controlling of high-mobility users through procedures, which activate several network functionalities such as broadcast and synchronisation. Satellites may need to cache certain user information and its associated latency or channel conditions, which further complicates the mission. These challenges reflect to dimensioning the physical layer frames, as well as the non-access stratum.

In the current satellite broadcasting systems, the bent-pipe architecture is typical and no on-board processing occurs, partly due to cooling problems in the higher orbits. However, on-board processing could enhance system flexibility, and configurability, enable mesh connectivity and higher throughput together with better link efficiency. Still it requires extra hardware, more energy and heavier transponder. The complexity of on-board processing is also a threat to reliability and security, which both are critical in communications. There is a strong need for low cost and reliable processing techniques to advance on-board processing in satellites.

Table 4 summarizes the main design constraints of nonterrestrial networks partly adopted from (Guidotti 2018, Cao 2018, TR38.811 2018).

Table 4. Distinctive design constraints for nonterrestrial networks for further study.

Design constraint	**Remarks**
Propagation channel	Multipath delay/fading model and Doppler spectrum are unique compared to terrestrial networks. Time dispersion can be ignored for some system scenarios.
Frequency planning	High bandwidths are possible in the Ka band and in the higher bands such as Q/V and W bands. Interference avoidance with frequency re-use. Spectrum sharing techniques enable use of the same band by satellite and terrestrial systems.
Power efficiency	Maximize throughput and service availability under deep fading. Use of power-efficient waveforms robust to nonlinear distortion.
Network topology	Medium access control, especially random access, is challenging with dynamically changing network topology. Inter-satellite links may be needed for large constellations.
Delay	GEO system leads up to 270 ms e2e delays restricting its use for low latency applications. HAPS can achieve around 10 ms delays. Difficult to use high-delay HARQ techniques typical for terrestrial networks to support high reliability.
Mobility	GEO system is typically quasi static with respect to UEs while HAPS lead to more significant Doppler shifts and Doppler variation rates. Support of high speed UEs can be complicated. E.g. for 1000 km/h UE speeds and Ka band, the Doppler shift can be as high as 720 kHz.
Service continuity	Handover triggering between terrestrial and nonterrestrial networks can be complicated.
Resource management	Delay of resource management decisions and required control data must be minimized.
Integrated software-defined network design	Fault-tolerant dynamic non-terrestrial/terrestrial network design capable of softwarization and virtualization of networks resources and functions

7. Conclusions

In general, the focus of this review was more on describing timely 3GPP activities, spiced up with some VTT's viewpoints, rather than being a detailed technology review. Unlike in the previous cellular technology generations, in 5G there are no competing standard bodies. Therefore, understanding of 3GPP processes becomes even more important over many vertical industries. It is evident that 3GPP is now seriously working towards 5G system, which utilises satellite communications to provide advanced services. Satellites can widen telecommunication network's coverage, advance its ubiquity, and in some cases, reduce the operator's costs. The progress with recent satellite systems has brought transmission rates and QoS in satellite communication very close to what terrestrial networks can offer. Still the inevitably longer transmission delay can be problematic for some specific applications but this may not be an important issue for many other potential users. Using lower altitude platforms could partly solve the issue, and initial steps towards this direction have recently been taken in Release 16 and 17 preparation work. In any case, the differences in latency between the satellite and the terrestrial transmission path require upgrades to 3GPP specifications on many levels. The provided specification map in Section 5 helps to understand current 3GPP standardization status and outcomes particularly related on SATCOM.

There is also much work to do in integrating the 3GPP's terrestrial network architecture with satellite network architecture. In addition to the technological challenges of serving properly the moving users that roam fast or slow, and around the world, there are issues that concern regulation and legislation that differ between countries. The existing 3GPP specifications expect that a network operator takes response of a network in one country while a case where a user may connect to several networks is out of their scope. Solving these issues may take many years, but probably it will eventually be realized. A severe obstacle for quick utilisation of satellite communication in 5G is that implementing a LEO satellite constellation is expensive. Launching hundreds or thousands of new satellites and building their facilities may cost several billions of euros. Currently there are several huge projects aiming to satellite internet, but very few of these are focusing to 5G. Another problem related to this is that user's devices that connect to LEO satellites also need complex antennas, which still are costly.

In spite of the aforementioned challenges, the future of nonterrestrial networks looks now more promising. It will be interesting to see how the upcoming 3GPP activities will accelerate the progress. The main purpose of this report is to help on understanding the overall status of 3GPP towards this objective.

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