5GAA Automotive Association

Maximising the benefit of future satellite communications for automotive

5GAA Automotive Association
Technical Report

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Executive summary

Vision and objectives

This Technical Report (TR) outlines a clear vision for integrating a Non-Terrestrial Network (NTN) connectivity layer as a complement to Terrestrial Networks (TN), enhancing coverage and services for connected vehicles. This is driven by growing demand for ubiquitous connectivity and the need to address coverage gaps in existing terrestrial mobile networks.

NTN roadmap and timelines

The NTN roadmap presented in the document identifies three key phases of service deployment:

- Narrowband Data Rate Services (< 400 kbps): Expected from 2027 onwards, leveraging 3GPP Release 17 standards for applications like emergency assistance and safety information in remote areas.
- Wideband Data Rate Services (< 10 Mbps): Expected from 2029 onwards, enabled by 3GPP Release 17/18 standards for use cases such as HD map data collection and over-the-air software updates.
- Broadband Data Rate Services (> 10 Mbps): Expected from 2030 onwards, requiring higher frequency bands and more advanced user terminals to support applications like 4K video streaming and cloud gaming.

Automotive requirements and antenna parameters

This document proposes specific antenna parameters for automotive NTN user equipment, including noise figure, transmit power and antenna gain, optimizing performance and cost-effectiveness for automotive connectivity. These recommendations have been submitted to 3GPP for consideration in future standard releases.

Key recommendations

- Alignment of NTN services with global mobile standards (3GPP) enabling seamless interworking with terrestrial networks.
- Deployment of Low-Earth Orbit (LEO) satellite constellations operating in FR1 or S/L-band frequencies are a key success factor for early implementation of cost-effective NTN services particularly for narrowband and wideband use cases.
- Focus on optimizing user terminal parameters and costs in both FR1 and FR2 (to enable broadband use cases) ensuring widespread adoption of NTN services by automotive customers.

Conclusion

The integration of non-terrestrial connectivity presents a significant opportunity toward enhancing the capabilities and coverage of terrestrial mobile networks. By aligning with global standards, optimizing technical parameters of automotive user terminals, and securing appropriate spectrum, the automotive and telecommunications industries can work together to realize the vision of space-connected vehicles on our roads.

1. Introduction

Since its foundation in 2016, 5GAA has focused on the development of terrestrial mobile connectivity technologies and the necessary standards. In recent years satellite access technology has emerged as having the potential to improve connectivity services for the automotive industry. This is made possible through two major factors. On the one hand, the evolution (technical and economic) of launchers has enabled the deployment of satellite networks based on mega-constellation of hundreds, if not thousands, of Low-Earth Orbit satellites. On the other hand, the release of 3GPP features has enabled 5G-supported Non-Terrestrial Networks and led to the development, deployment and seamless integration of satellite components into mobile radio systems using terrestrial networks, thus providing global service continuity.

5GAA has thus decided to analyze how future Satellite Communications (SatComs), based on the newly defined 3GPP NTN standards, can be used for automotive applications.

The aim of this TR is to lay out a clear vision on the integration of a new (non-terrestrial) connectivity layer for connected vehicles into the already existing Terrestrial Networks. That near-time vision is built on the analysis and consensus of the automotive and telecommunication industries represented by 5GAA. It is thus understood as a guideline for decision-makers in regulation and policy bodies as well as underlying technology suppliers; what decisive steps need to be taken now in order to make the vision of space-connected vehicles a reality on our roads, starting in 2027 and with broad usage by 2030.

2. Motivation

There are five main reasons why Non-Terrestrial Networks are perceived as important from a 5GAA perspective:

1. Customers are asking for ubiquitous vehicle connectivity: A possible step-wise approach could be starting with narrow band applications like e-call, remote control functions for cars, or widely available telematics services. Later, new digital services like online shopping, 4K video streaming, AAA gaming, the emerging Metaverse, and autonomous driving applications are envisioned to drive demand for ubiquitous connectivity. Seamless mobility between Terrestrial and Non-Terrestrial Networks is a critical target to offer such connectivity to customers while keeping applications running without significant interruptions.

2. Existing market gaps: Terrestrial Networks still have smaller or larger coverage gaps, especially in low-populated remote or rural areas. Hence, coverage of 2G, 3G, 4G and 5G networks is sometime limited in such areas. NTNs can provide complementary coverage extension to TNs, especially in poorly covered areas.

3. Window of opportunity to influence upcoming 3GPP releases of 5G-Advanced and later 6G: First standards have already been defined in 3GPP Rel-17 to operate NTNs working together with TNs.

4. New space approaches enable LEO mega-constellations at comparable low cost. Several constellations consisting of thousands of LEO satellites are about to be launched and will enable broadband internet access to millions of customers or devices globally.

5. Digital services are disrupting traditional automotive business models. The revenue share by (always on) digital vehicle services will grow significantly and demands that the vehicle be connected at all times and everywhere. Original Equipment Makers (OEM) choosing not to explore new business opportunities – by focusing only on the necessary enablers – run the risk of going out of business.

3. Assessment on TN coverage: status quo

Cellular networks provided by terrestrial Mobile Network Operators (MNO) are unable to cover 100% of the global land mass simply due to economic reasons. MNOs traditionally built out terrestrial network coverage of different 3GPP generations where most people live (populated areas) or where movement of a significant number of people was attractive for business attractive (e.g. highways or major roads). This resulted in uncovered areas; typically very rural, remote or sparsely populated. Going to lower frequency bands than 900 MHz initially with GSM – the 600/700/800 MHz band deployments – improved rural and in some cases indoor penetration.

No coordinated analysis of the coverage situation has been performed as part of this 5GAA Work Item, but some crowd-based approaches are mentioned. However, the figures below offer a glimpse of the cellular coverage situation in several countries based on GSM Coverage Maps [9].

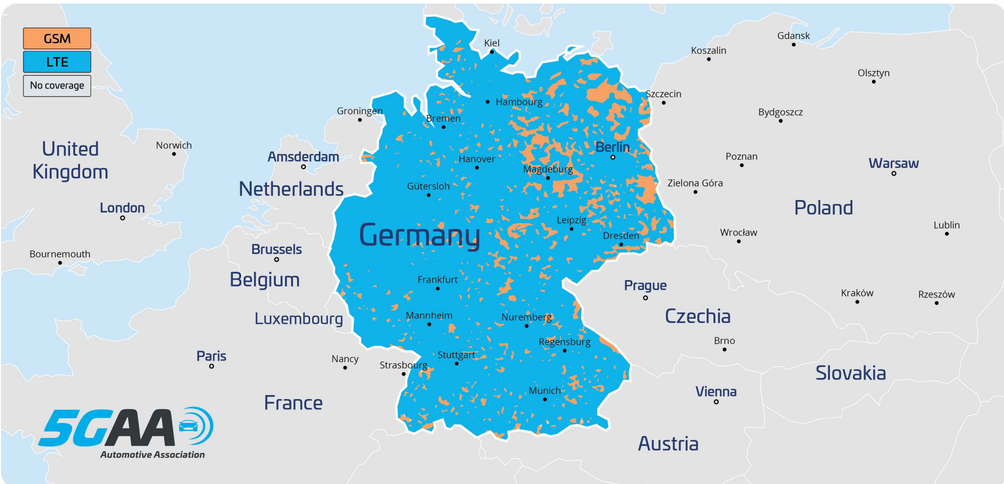


Figure 1 Coverage Map Germany

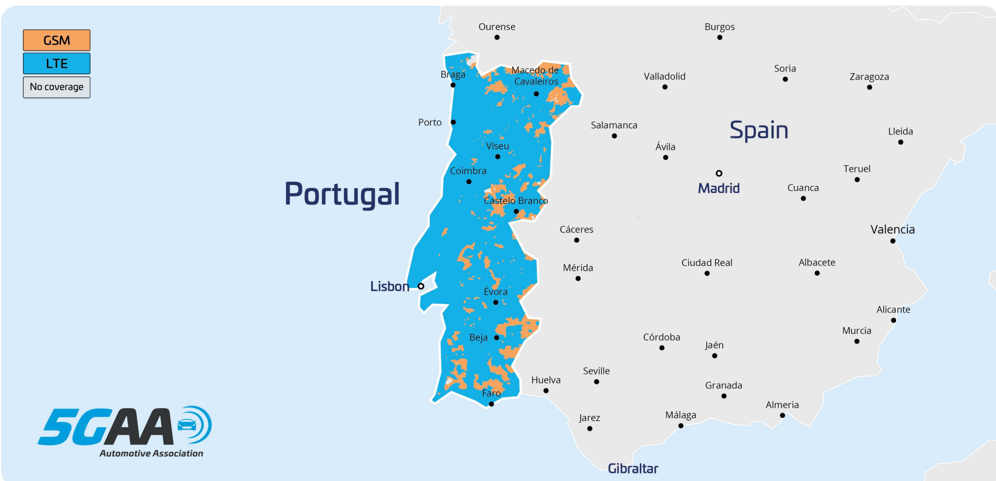


Figure 2 Coverage Map Portugal

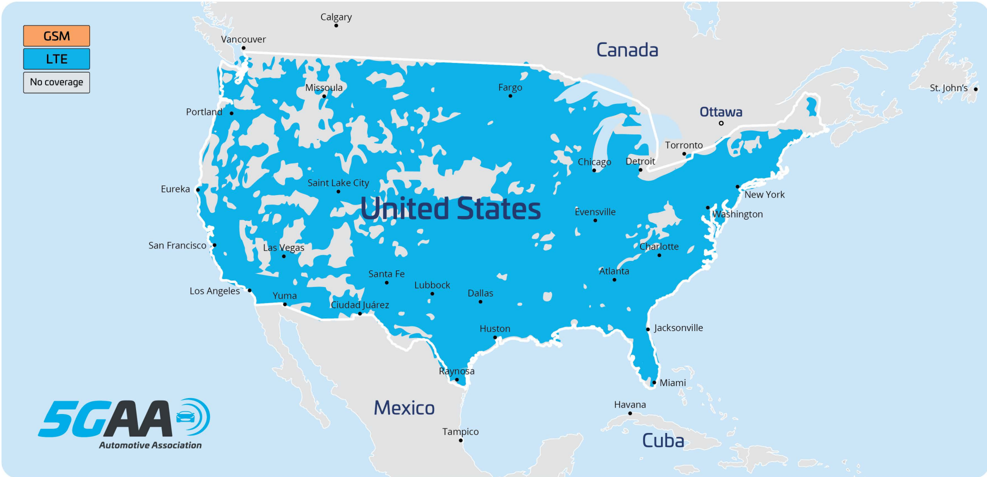


Figure 3 Coverage Map USA

As such, it can be seen that in countries with more low-populated or remote areas, such as Australia, Canada, and the USA, there are larger areas of uncovered territory. In smaller, more densely populated countries (e.g. France and Germany), there are very few uncovered areas (and GSM is at least available).

This situation led to the conclusion that cluster coverage needs to be grouped into three categories in order to assess whether NTN makes sense as a complement to terrestrial networks:

1. Small countries typically densely populated and well covered by TN networks (examples are FR, DE, etc.).
2. Small countries typically sparsely populated and only well covered by TN networks in certain regions or capitals and coastal areas (examples are some African countries).
3. Large countries typically densely populated in some areas (coasts) but sparsely populated and not well covered by TN networks in certain other regions (examples are Australia, Canada, USA, etc.).

The consequences of service-specific coverage loss must also be considered. If a car drives through a larger uncovered area of at least 1.5 km, it will not regain coverage quickly enough for a streaming service to continue uninterrupted (e.g. a coverage gap of several hundred meters).

Only synchronous applications need persistently a defined quality of service (QoS) requirements. Because it is known that the service quality is not always optimal, automotive OEMs and the Consumer Electronics industry have developed measures to minimize the effects of changing from good to poor network quality. For instance, some OEMs have multi-roaming contracts with terrestrial MNOs to maintain minimal service during coverage gaps (e.g. eCall). Furthermore, most applications are designed to cope with small coverage gaps (e.g. streaming services – audio and video – buffer data). For narrowband services, a higher latency is taken into account to resend messages enabling narrowband applications. Thus, the benefit of NTNs, as an extension to TNs, must be defined for every application.

4. Roadmap of use cases benefitting from NTN

4.1. Overview of use cases benefitting from NTN

5GAA is already applying roadmaps to promote discussion around V2X use cases. These roadmaps are usually structured according to various use case categories and show potential timelines for future deployment. This methodology is also used now in NTN.

In addition to the existing 5GAA use case categories, Intelligent Transportation Systems (ITS), Traffic Efficiency and Advanced Safety, Cyber Security, Digital Twin, and Info/Entertainment have been added. These categories are gaining more and more importance in the automotive domain.

The data rate requirement has been identified as a key differentiator in the roadmap classification. Therefore, the use cases have been classified according to their data rate requirements: narrowband (up to 400 kbps), wideband (up to 10 Mbps), and broadband (> 10 Mbps). It can be observed that geostationary satellites, based on 3GPP Rel-17, will be commercially available first, thus allowing ultra-narrowband data rates (up to 10 kbps) using 3GPP's NB-IoT technology. Later, LEO satellite constellations, based on 3GPP Rel-17 NR NTN, are expected to offer narrowband data rates (up to 400 kbps), and in further steps satellite constellations are expected to offer wideband (up to 10 Mbps) and broadband data rates (> 10 Mbps), also based on NR NTN (Rel-17 and -18).

In the following chapters, the various use case categories according to data rate will be discussed in more detail.

4.2. Service Level Requirements of use cases benefitting from NTN

4.2.1. Introduction

Initially 5GAA has published Service Level Requirements (SLR) for the identified C-V2X use cases and their associated user stories in three Technical Reports [1, 2, 3] focused on technology/solution-agnostic descriptions. These SLRs characterize and quantify the conditions that must be met for the successful execution of the use case. They involve properties of the connectivity service, as defined as in [1] (such as data rate, latency, reliability) and of the vehicle. As use cases depend heavily on connectivity and with the rise of NTNs it is now important to describe the benefit and contribution of NTN on these use cases in detail.

To date, no specific NTN use cases have been identified. The key benefit of NTN is rather to provide connectivity for the existing use cases in the following situations:

- In areas where the terrestrial networks have *permanent coverage gaps* (ubiquity).
- In situations where the terrestrial networks become *temporarily unavailable* due to outages and disaster situations (resilience).

NTN can be leveraged to provide space-enabled connectivity. NTNs are viewed as a complement to, rather than a replacement of, Terrestrial Networks. NTN provides connectivity where no terrestrial connectivity is available or increases the available data rate where terrestrial connectivity is limited. NTN requires a free line of sight between the terminal and the satellite and cannot provide connectivity in tunnels or other indoor locations.

In general, already existing SLRs from the 5GAA Technical Reports [1, 2, 3] can be used. Occasionally, if there are multiple options for the use case implementation and associated SLRs, only some of them may be accessible by NTN. When considering implementation of NTN for a given C-V2X use case, the following connectivity related SLRs need to be addressed:

- Information requested/generated – especially the data volume and required data rate via NTN, as this will determine the nature of the link service (narrow-, wide-, broadband) and may be a limiting factor for the transmission service.
- Service Level Latency – satellite constellations orbiting the Earth will introduce an inherent latency in addition to the network latency, depending on their orbit altitude, due to the link distances involved (3GPP TR 22.822 assumes a one-way E2E latency of 35 ms for LEO, 95 ms for MEO and 285 ms for GEO).
- Service Level Reliability – specifically the reliability of the connectivity links.
- Vehicle density – as it determines the number of potential users in the coverage area of a given satellite that compete for the connectivity resources, potentially leading to services being temporarily unavailable in some instances.

In the following chapters, some representative use cases are chosen to illustrate some typical requirements which apply for Terrestrial and Non-Terrestrial Networks.

4.2.2. Narrowband data rate use cases

A significant number of narrowband data rate examples in the 5GAA compilation of C-V2X use cases require the transmission of only small amounts of data, such as local hazard and traffic information messages, select vehicle data, or short commands. Clearly, these are all accessible by narrowband connectivity with data rates of up to 400 kbps in uplink, downlink, or both.

The following use cases belong in this category [1, 2, 3]:

- Emergency Call (incl. in disaster situations)
- Traffic Management in Disaster Situations
- Road and Safety Information in Remote Areas

- Local Hazard and Traffic Information
- Remote Access
- Vehicle Health Monitoring

In the following, selected use cases are discussed in more detail to show the benefit that NTN could bring.

Emergency Call (incl. in disaster situations)

The pan-European eCall is an emergency call generated either automatically via activation of in-vehicle sensors or manually by the vehicle occupants; when activated, it provides notification and relevant location information to the most appropriate Public Safety Answering Points (PSAP).

As part of this TR only Next Generation eCall (NG eCall)[1] is considered and works over packet-switched access networks (LTE/5G), based on Voice-over Internet Protocol (VoIP).

NG eCall or equivalent emergency service with an additional NTN component could provide the following added value:

- Extend the reach and coverage of NG eCall in areas where there is insufficient terrestrial coverage.
- Provide additional data transfer capacity via the NTN network to guarantee a minimum level of service or enhance it in case of emergency (e.g. additional data sources from the vehicle) or in general for added resilience in the terrestrial NG eCall functions.

Remote Access

Vehicle owners, fleet operators and authorized vehicle service providers want to monitor remotely the status of the vehicle also when the vehicle is parked, and they are not with the vehicle. Depending on the returned status they may want to send commands to alter the status – for instance locking the car when it has inadvertently been left unlocked, starting defrosting or air conditioning so that the climatic conditions inside are comfortable/safe at the desired departure time. Vehicle owners, operators or authorized vehicle service providers communicate with the car via the cloud/backend that manages all digital twin applications. This use case is mostly for the convenience of the driver/owner but could also help in detecting anomalies, such as interference or tampering (e.g. intended theft) with the vehicle (the status report could then be triggered by the car and could be sent to an authorized vehicle service provider). In many circumstances this use case needs to work also outside the coverage area of terrestrial networks – especially when anomaly detection or protection of the vehicle (i.e. locking the door) is needed, or in keyless car-sharing, when the vehicle is left in a remote location. Here, connectivity between the vehicle and the owner, operator or service provider is mission critical. NTN coverage could complement terrestrial coverage in these instances.

[1] NG eCall is not supported by NB-IoT via NTN

4.2.3. Wideband data rate use cases

In this section use cases that require wideband data connectivity with data rates from 0.4 to 10 Mbps are introduced. The following use cases belong in this category:

- Teleoperated Driving Support (objects)
- Data Collection and Sharing for HD Maps (objects)
- Hazard Information Collection and Sharing (suitable for AVs)
- OTA incl. Delta Update and Update Message
- Audio Streaming and Data File Access
- Help Assist, Concierge (incl. AR-video)

In the following, selected use cases are discussed in more detail to show the benefit that NTN could bring.

<u>Teleoperating Driving Support (objects)</u>

When a vehicle with autonomous capabilities faces an uncertain situation, Teleoperated Driving Support can for a short period of time assist the vehicle in overcoming a challenging driving task and resuming its normal mode of operation. This can be achieved in two ways:

- Where the remote driver takes over complete control of the vehicle and decides on acceleration, braking, steering, signage etc. while still being supported by the driver assistance functions of the vehicle.
- Where the remote driver advises the vehicle on the driving decisions to take while leaving control of steering and acceleration with the vehicle (the remote driver has the possibility to control the brakes).

In order for the remote driver to support the (autonomous) vehicle he/she needs to have sufficient information from the vehicle sensors – especially car sensor data (radar, lidar, ...), environment information (road conditions, traffic signs, traffic information, lane designations and geometry, ...), vehicle status and trajectory, and possibly also video streams from the vehicle cameras. Therefore, the data link from the vehicle to the remote driver needs to allow data rates of 4 Mbps if only interpreted sensor data in the form of objects is transmitted, and 32 Mbps [2] if video streams are needed to be sent. In contrast, for sending the driving instructions from the remote driver to the vehicle, 400 kbps will be sufficient.

Difficult driving situations – such as an autonomous truck getting stuck in a snowbank – can also occur in rural or remote locations where little or no terrestrial connectivity is available. Here, NTN connectivity can help by providing the necessary data link to allow the remote driver to resolve the challenge and return the vehicle to routine operating mode without the need to send a maintenance team to the remote location. NTN wideband services would be sufficient to provide the necessary connectivity if only objects are sent from the vehicle to the remote driver.

<u>Data Collection and Sharing for HD Maps (objects)</u>

HD maps are used as the basic source of information for autonomous vehicles, and they are a key factor in vehicle positioning, navigation, controlling, and safety. A map contains a large number of basic driving assistance information, such as the geometry of the road, location of road marking lines, a model of surrounding environment, etc. A high-precision map also contains rich semantic information, such as the location and type of traffic lights, the type of road markings, and in identifying upon which roads can be driven.

Autonomous vehicles obtain information on the surrounding environment from their own sensors or through other vehicles' sensor data, which is then compared with the HD map to identify the accurate position and speed of other vehicles, pedestrians, and unknown obstacles. This procedure can assist in safety and accurate route planning. Through this comparison the vehicle can also identify discrepancies between the HD map and the actual environment due to very recent changes such as road construction and detours or other incidents that alter the situation on the road permanently or at least for a significant period (hours and longer). The vehicle can notify the HD map provider of the discrepancy by either sending an updated full HD map of the location or by providing just the objects on which the original HD map differs from reality, which requires a significantly lower data rate. The HD map provider can then create an up-to-date map and distribute it to all vehicles in need of it – this update could also just contain modifications in the object layer of the map.

Typically, the sharing of the collected data and the updated HD maps is performed by terrestrial 5G networks. As this requires significant network resources, real-time service provision may see interruptions in areas of low or no terrestrial coverage, which could lead to impaired/inefficient operation of the autonomous/automated vehicles. 5G NTN promises to complement terrestrial coverage and to offer service continuity and ubiquity. If an update mode is implemented that uses only objects – both for sending identified discrepancies from the vehicle to the HD map provider and for transmitting map updates to the vehicles in the affected location, then NTN wideband services would perform adequately. Current practice foresees HD map updates in intervals of 30 minutes, ensured connectivity provided by TN, complemented by NTN, will enable in the future much more frequent and even very short-term updates (objects or full map), ensuring the most up-to-date environment information is available in the (autonomous) vehicles at all times.

Once sufficient edge computing capability is installed in satellites the updating of HD maps may even be performed in the satellite itself based on data collected and transmitted by vehicles and imagery obtained from suitable satellite instruments.

4.2.4. Broadband data rate use cases

In this section use cases that require broadband data connectivity with data rates over 10 Mbps are introduced. The following use cases belong in this category:

- Entertainment (e.g. HD Video Streaming, HD Video Calls/Conferencing, Cloud Gaming)
- Teleoperated Driving Support (Video Streaming)
- Data Collection and Sharing for HD Maps (full HD map)
- Remote Collection and Processing

In the following section, selected use cases describe the benefits that NTN could bring.

Entertainment (HD Video Streaming, HD Video Calls/Conferencing, Cloud Gaming)

In the era of connected vehicles, passengers expect a seamless in-car entertainment experience akin to the experience at home. Entertainment use cases like High-Definition (HD)/4K video streaming, HD video calls and conferencing, and cloud gaming are becoming increasingly popular services that demand high-speed connectivity.

For HD/4K video streaming, passengers want to enjoy their favorite movies and TV shows without interruptions, regardless of the vehicle's location. Similarly, HD video calls and conferencing are essential for maintaining productivity and ensuring effective communication with colleagues, clients, friends, and family members. Cloud gaming, on the other hand, requires a constant and reliable connection to deliver a smooth gaming experience with real-time interaction and high-quality graphics (e.g. if graphics are rendered remotely).

As terrestrial network coverage can be patchy, especially in rural or remote areas, leading to service disruptions, NTNs play an essential role. By leveraging satellite communication, NTN can provide the necessary coverage and bandwidth to support these demanding applications, ensuring a continuous connection even when terrestrial networks are unavailable. The difference between synchronous and asynchronous use cases is crucial in understanding the impact of coverage gaps. Synchronous services like HD video calls require a continuous real-time connection (conversational), meaning that even short coverage gaps can result in poor service (disruption/unavailable), affecting the call quality or causing disconnections. Asynchronous services, such as HD video streaming are more tolerant to interruptions thanks to buffering capabilities. These services can withstand larger coverage gaps, as preloaded content can be played during short coverage gaps. However, prolonged connectivity loss would eventually deplete the buffer, leading to service disruption which is a likely scenario in countries with huge coverage gaps (i.e. longer than the buffering time).

NTN's ability to complement terrestrial coverage is essential for providing a consistent and reliable broadband entertainment experience in vehicles.

Teleoperated Driving Support (Video Streaming)

This use case is equivalent to the above Teleoperating Driving Support case, except video streaming from the vehicle to the remote driver requires NTN transmission broadband services.

4.3. General perspective on evolvement of satellite constellations based on 3GPP principles

This section describes some deployment scenarios that might become reality. For the moment these scenarios have a European focus, i.e. focusing on possible constellation deployments serving continental Europe until, say, year 2030. Several developments are important to consider, as they will have a major impact on the whether certain satellite constellations and corresponding automotive services will be deployed or not.

Among others, these are:

- The availability of the required satellite spectrum and the number of parties that will have access to the spectrum.
- The geographical service coverage of narrowband data rates using existing satellite systems, likely using L- or S-band frequencies (i.e. FR1) and the IoT-NTN standard. Note that narrowband data rate services could also be offered by constellations using FR1 frequencies and NTN NR, or by using higher frequencies above 10 GHz (i.e. Ku- and Ka-band).
- Addition of new frequency bands (e.g., Ku-band) as 3GPP NTN bands.
- The acceptance of satellite-based solutions that will be able to work with existing equipment using terrestrial IMT spectrum or other new regulatory approaches.
- Funding availability for new satellite constellations, as deploying a constellation offering persistent connectivity will require large investments.
- The general appetite for servicing the automotive market.
- 3GPP standardization support for certain features which are deemed essential to the automotive industry.
- The availability of 3GPP-compliant automotive-grade chipsets and modules.

For the sake of discussion, "*narrowband data rate services*" are those services that can be fulfilled with a user data rate of maximum of 400 kbps and "*wideband and broadband data rate services*" will be those services requiring a higher data rate per user, as explained in Section 4.1.

The section below sketches possible deployments, distinguished between narrowband, wideband and broadband rate services (Figure 4). Note that there is only a loose relation between data rates and frequencies used: satellite constellations operating in higher frequencies (above 10 GHz) could equally provide lower data rate services.

Matrix of industry initiatives/areas of interest led by satellite network operators for the different deployment scenarios:

	Narrowband connectivity to IoT devices (NTN-IoT in FR1)		Narrowband/Broadband connectivity to handheld devices (NTN-NR in FR1)	Broadband connectivity to non-handheld devices (VSAT) (NTN-NR in above 10 GHz Band)	
Space Segment	**Re-use of existing GSO**	**NGSO**	**NGSO**	**GSO**	**NGSO**
Operators	EchoStar Viasat-Inmarsat TerreStar Solutions	Sateliot EchoStar OmniSpace Viasat-Inmarsat	EchoStar OmniSpace Viasat-Inmarsat SES	Intelsat Eutelsat-Oneweb Viasat-Inmarsat SES	Intelsat Eutelsat-Oneweb Viasat-Inmarsat SES
Timeline Indication	2023-2025	2024-2029	2026-2029		

Figure 4 Possible deployment scenarios as presented by GSOA to the TSG-RAN (Edinburgh, UK, RP-232732)

4.3.1. Narrowband data rate services

The future deployment for narrowband data rate services via satellite could be distinguished in three categories:

A. Satellite systems using existing satellite spectrum

Satellite constellations which are currently using the L- and S-band from GEO orbit could possibly satisfy a subset of the automotive use cases. However, the only 3GPP-compliant services which are currently offered are based on IoT NTN – providing only a limited data rate.

At the moment, no 3GPP NR NTN services using FR1 frequencies are offered commercially, and it is questionable whether this is an attractive offer for incumbents from GEO, considering their current installed user base and satellite system.

While there are various other commercial initiatives proposing 3GPP-compliant satellite services in L- and S-band, it is not likely that these parties will gain access to spectrum before 2027.

Realistically, only when incumbent L/S-band operators decide to implement a LEO constellation, which will offer 3GPP-compliant NR NTN services, a higher data rate service for automotive would be available before 2027.

Only after 2027, depending on the possible refarming of the European S-band licenses, other operators might emerge.

B. Satellite systems using terrestrial IMT spectrum as a complement to terrestrial networks

Recently, several satellite initiatives have started which complement terrestrial networks from space. In practice, for International Mobile Telecommunications (IMT) this means that terrestrial frequencies are used by satellites based on bilateral agreements with an MNO to provide additional coverage from space. This approach is applicable to 3GPP's Long-Term Evolution (LTE) as well as New Radio (NR) technologies.

The benefit of this approach is that the user terminals (UEs) are unmodified as they don't distinguish whether the communication emanates from a satellite or terrestrial network, and the necessary technical modifications are done solely on the Radio Access Network side (of the satellite provider). This opens a large market for using existing user terminals.

While this seems an attractive scenario, there are a few caveats:

- In Europe, the relevance of such a system is not evident considering the limited number of geographical areas without cellular connectivity.
- The frequency assignments of the different MNOs throughout Europe are quite diverse, and only allocated on a national basis to the TN MNOs, resulting in a patchwork of cellular networks throughout Europe, possibly leading to a complicated satellite solution intended as a complement. Regulatory conditions might enforce coverage gaps from satellites along country borders.
- Regulatory clarity is needed; the first studies are starting and will be intensified as part of WRC-27, but the outcome for Europe is not clear.

This type of complementary service seems more feasible in large countries (i.e. in North America and Oceania), as an extension to the terrestrial networks. Further, current systems that follow this approach do not use the full potential of the NTN features as defined in 3GPP Rel-17 and -18, possibly significantly limiting their performance.

C. Systems using higher frequencies than 10 GHz while offering narrowband data rate services

Narrowband data rates can also be offered by satellite systems using higher frequencies, above 10 GHz (i.e. in Ku- or Ka-band) using either:

- dedicated service offers with small Ku- or Ka-band antennas; currently offered over GEO satellites, but possibly not fulfilling all use cases in terms of latency (it may not be cost-efficient to offer narrowband data rate services only in such bands due to the high terminal costs),
- or as part of higher data rate services, leveraging already installed above-10 GHz antennas for higher data rate services based on NR NTN; with regards to the possible deployment of a higher data rate service, the reader is referred to the next section.

While Ku-band is currently not part of the 3GPP-defined NTN frequency bands, it might become part of future 3GPP Releases.

Finally, it should be noted that some of the use cases that can be satisfied with narrowband data rates but require voice services cannot be fulfilled with current NB-IoT NTN technology, as this technology does not support conversational services such as VoIP. This would need to be implemented using the LTE-M (eMTC) NTN variant.

4.3.2. Wideband and broadband data rate services

Some satellite solutions using terrestrial IMT spectrum from space could offer very high data rates, this will depend on space segment developments and available spectrum bandwidths. But most likely, wideband and broadband data rate services will need to use higher frequencies such as, Ku- and Ka-band. Note that currently only the Ka-band is an 3GPP standardized FR2-NTN band. Discussions are ongoing on new bands, for example Ku-band which could be included in future 3GPP releases.

In this Technical Report, satellite-based solutions which require a proprietary UE are not considered. Examples of such solutions are the first generations of OneWeb, Starlink, and Kuiper.

The following satellite deployments could be foreseen within a 2030 horizon.

A. Satellite systems using existing satellite spectrum

Current satellite systems in GEO can offer broadband services to vehicles, but with rather large flat panel antennas. Some GEO satellite systems could offer 5G NR NTN in Ku-band and Ka-band as soon as standardization of these bands in 3GPP is complete, as their satellites are “bent-pipe” and therefore only the ground infrastructure (*gNB*) and terminals (*UE*) needs to be changed.

This is also valid for some transparent Ku- and Ka-band LEO systems: 5G NR NTN could technically be offered soon, pending some standardization. Several new Ku- and Ka-band systems are planned which use regenerative payloads. Some of these initiatives will not support 5G compliant NTN technologies, or have other technical or commercial characteristics that make them unsuitable for the automotive industry.

Possibly, the European IRIS2 initiative will support 5G NTN's core services, but how accessible (and suitable) these will be for the automotive industry is not yet clear. The commercial component of IRIS2 might support 5G NTN services.

According to ITU Radio Regulations, new Non-Geo Stationary Orbit (NGSO) satellite constellations using frequencies that overlap with incumbent GSO satellites or other NGSO constellations will need to coordinate with these incumbent systems (to demonstrate that they do not interfere). While coordination between a limited number of systems is shown to be technically possible, the outcome of such a coordination process might limit the capacity or the geographic region in which these services are offered. Furthermore, the ITU Radio Regulations impose on most NGSO constellations using NTN-FR1 or NTN-FR2 frequency bands stringent milestones with regards to the number of deployed satellites over time. Some NGSO constellations may struggle to comply with those milestones, considering the limited launcher availability.

4.4 Vision of potential initial deployment of satellite connectivity in the automotive industry

In the last section, the potential deployment of 3GPP-based satellite connectivity was discussed. As shown in Figure 5, the initial deployment of satellite connectivity will probably happen in two major waves.

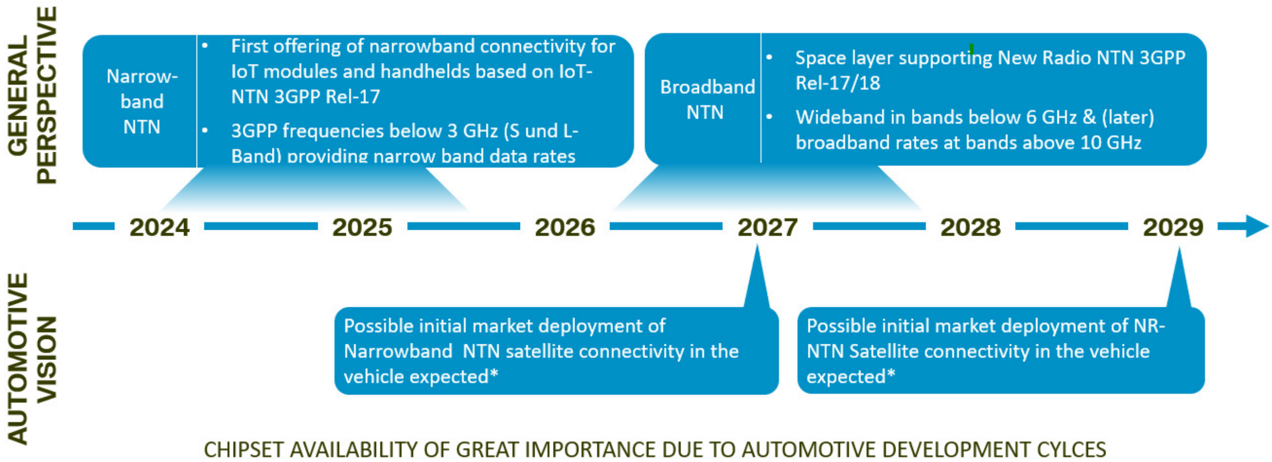


Figure 5 Vision towards automotive deployment of satellite connectivity

The first-wave *Narrowband NTN* can be expected in a time frame between 2024 and 2026, where first offerings of narrowband connectivity for IoT modules and handhelds based on IoT NTN 3GPP Release 17 should become available. Initial deployments use

3GPP frequencies below 3 GHz (S- and L-band providing narrowband data rates). In the automotive industry, the possible initial market deployment of narrowband NTN satellite connectivity is expected in around 2027. This delay is due to the long lead times for development of automotive grade chipsets.

The second wave *Broadband NTN* can be expected between 2026 and 2028, where the space layer will support NR NTN 3GPP Release 17/18. Wideband data rates can be offered in NTN-FR1 frequencies (S- and L-band) and broadband data rate services can be expected in NTN-FR2 frequencies (above 10 GHz).

Taking these assumptions into account, the various use cases benefitting from NTN can be integrated into an updated NTN roadmap as shown in Figure 6.

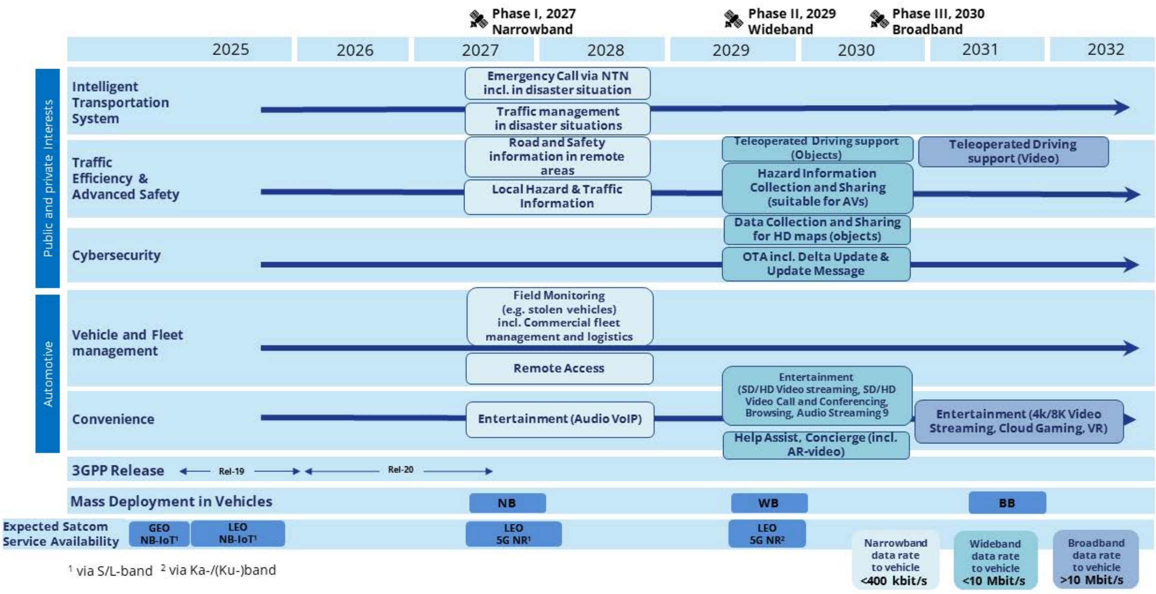


Figure 6 Updated NTN Roadmap

The NTN Roadmap clusters the various services vertically into two main types.

a. Services of public and private interest: with ITS services, Traffic Efficiency and Advanced Safety and Cyber Security services.

b. Automotive services: with Vehicle and Fleet Management and Convenience Services.

Horizontally, the NTN roadmap is structured along a time scale from 2024 until the 2030s. The deployment of 3GPP-based satellite connectivity provides the framework for various use cases according to their data rate and latency requirements.

In addition to the various stages of 3GPP technology, the applied spectrum and the orbit have an influence on when the various NTN services will be deployed in the future. For instance, data rates per user on the ground can be increased considerably by switching from GEO to LEO and increasing the number of satellites per constellation in parallel.

As a consequence, the deployment of NTN use cases is expected not to happen in two phases but rather in three phases. As explained above, Broadband NTN based on NR NTN will allow wideband and broadband data rate services. But while wideband use cases can be already supported by technologies working in the FR1 band, broadband data rate services need a much larger investment in terms of ground terminal equipment. The development of technologies like cost-efficient phase array antennas for FR 2 frequencies will take longer, and thus leads to a third phase of mass deployment beginning most likely in the 2030s.

5. Automotive requirements to be integrated into 3GPP Release 19

5.1 Mobility

5.1.1 What is already available in Rel-17 and -18

Until the advent of NTN in Rel-17, cellular networks consisted of cells deployed on the ground or buildings to provide terrestrial coverage, hence the name *Terrestrial Networks*. LTE networks are have grown significantly and today provide TN coverage worldwide, complemented by 5G NR networks in either Non-Standalone (NSA) or more recently in Stand-alone (SA) mode.

The typical frequencies being used for LTE and NR TN range[2] from 600 MHz in rural areas (providing wide-area coverage) to around 4 GHz in suburban or urban environments (providing high data rates and capacity). For NR, these frequencies are referred to as FR1 (up to 7.125 GHz). FR2 deployments in the frequency range 24.25 to 71 GHz are not yet widely available and might not play a major role in mobility for automotive use cases.

The aim of the development of NTN is to complement existing LTE and NR coverage in terms of coverage where TNs do not provide coverage at all.

The following description provides an overview of NTN mobility aspects as defined in 3GPP since Rel-17.

In NTN, there are various mobility scenarios that need to be considered (i.e. cell reselection, intra-satellite/inter-beam handover, inter-satellite handover, NTN to TN handover, and vice versa) to ensure seamless mobility, especially for automotive use cases. 3GPP specified in Rel-17 and -18 the NTN-related mobility procedures taking into account the orbital movement of the satellites – first time that the entire network moves rather than the UE, which may lead to frequent changes of serving nodes, and the NTN-specific characteristics (i.e. longer RTT values, etc.), due to the large range of cells (providing satellite coverage of around 600-1,200 km for LEO and 36,000 km for GEOs above ground).

3GPP Rel-17 – focused mainly on intra-NTN mobility scenarios – reuses and improves the legacy mobility procedures by leveraging the predictability of satellite movements and fully considers necessary NTN-specific factors. In fact, a new NTN specific System Information Block (SIB19) was introduced to carry serving cell's NTN payload ephemeris and, optionally, the neighboring cell's NTN payload ephemeris, as well as the associated epoch time to help the UE determine the satellite's real-time position. Based on the satellite ephemeris information, the UE can change to the NTN cell which can provide longer NTN service time and thus resulting in less frequent UE mobility.

In addition, in Rel-17 NTN, new parameters such as the time and location of the UE on the ground were introduced in measurement rules for cell reselection. Specifically,

[2] Range, i.e. distance to the application zone, velocity, positioning accuracy, interoperability needs

UEs in idle/inactive mode can perform location-based measurement initiation. This means the UE may choose not to perform "neighbor cell" measurement if the distance between the UE and the satellites "serving" the cell reference location is shorter than a defined threshold.

In terms of mobility in RRC_CONNECTED mode, 3GPP Rel-17 supports a time-based Conditional Handover (CHO) triggering condition, *condEventT1*, and location-based CHO triggering condition, *condEventD1*. Conditional Handover is a procedure where the potential target cells of the UE are pre-configured, which is highly efficient for a handover procedure with the deterministic movement of the satellite in NTN.

In a *condEventT1* case, the UE is allowed to execute the handover during a certain time interval, while for the *condEventD1* ("Distance between UE and a reference location *referenceLocation1* becomes larger than configured threshold *Thresh1* and distance between UE and a reference location *referenceLocation2* of conditional reconfiguration candidate becomes shorter than configured threshold *Thresh2*;"), the UE location, relative to the target and source cells, is taken into consideration for the handover decision, providing a flexible yet robust handover mechanism optimized for NTN.

3GPP Rel-18 provides mobility and service continuity enhancements, focused mainly on optimizing the NTN-TN and vice versa, allowing it to change between terrestrial and satellite networks. Specifically, in terms of enhancing NTN-TN cell reselection, the NTN may broadcast the cell information of NR TN and E-UTRA TN coverage areas in SIB25. This is supported for Earth-Fixed, quasi-Earth-Fixed and Earth-Moving Cells (EMC) provided by the beams of a satellite. The coverage information consists of a list of geographical TN areas, with associated frequency information also indicated. It should be noted that an RRC_IDLE/RRC_INACTIVE UE can skip TN measurement when there is no TN coverage and the related parameters provided (mainly to save UE energy). In addition, in Rel-18, SIB19 can be broadcast optionally in NR TN cells to provide satellite assistance information for NTN neighbor cells for smooth interworking instead of relying purely on PLMN selection based TN to NTN mobility.

Some further enhancements of NTN-to-NTN mobility are also part of Rel-18. Specifically, for cell reselection with EMCs, the reference location and distance threshold parameters of the serving cell are provided for the UE to estimate when the serving cell stops providing coverage at the present UE location. In fact, for cell (re)selection in an Earth-moving system, location-based measurement initiation is supported, while time-based measurement initiation is used to address feeder-link switch cases, where due to its movement the satellite needs to switch the feeder link providing the connection to the ground segment.

In terms of mobility in RRC_CONNECTED mode, RACH-less handover is supported in 3GPP Rel-18, while a new event for CHO (*condEventD2*) for the EMC case has been introduced that comprises a reference location and distance threshold for source and target cell. In addition, Rel-18 supports satellite switching with re-sync for both hard and soft satellite handover in the quasi-Earth-Fixed scenario with the same Synchronization Signal Block (SSB) frequency and the same gNB. Via this enhanced satellite switch with re-sync procedure, Layer3 mobility (which implies a real cell change based handover) is avoided for UEs in the cell, by maintaining the same Physical Cell Identifier (PCI) on the geographical area covered by quasi-Earth-Fixed beam. For the alternative soft satellite switch over, the UE can start synchronizing with the target satellite before the source satellite stops serving the cell in order to further improve inter-beam changeover. It is not required for the UE to be connected to the source satellite when the UE switches to the target satellite.

Finally, in terms of inter-country mobility management, if the gNB detects that the UE is in a different country to that served by the Access and Mobility Management Function (AMF), the gNB implements the Non-Access Stratum (NAS) node selection behavior specified in 3GPP TS 38.410. For RRC-CONNECTED UEs, if the gNB detects a different country scenario like this, the gNB should perform NG handover via the interface between the gNB and the CN to change to an appropriate AMF (other country) or initiate a UE Context Release Request procedure toward the serving AMF (in which case the AMF may decide to de-register the UE). In the latter, the inter-country mobility is not supported by mobility procedures like handover, but the UE needs to perform an inter-country PLMN selection procedure, as for terrestrial roaming for different countries. From Rel-18, for the purpose of selecting an appropriate AMF, the 5G Core Network (5GC) may verify the UE location according to 3GPP TS 23.501 and 3GPP TS 38.305 after the UE has attached to the network.

5.1.2 Mobility enhancements in Rel-19

In the recently approved Work Items for Rel-19 further missing mobility functions have been considered. In addition to the provision of NR NTN assistance data from E-UTRAN in the system, the concept of supporting regenerative payload eases or facilitates some of the mobility scenarios between NTN and TN, while the concept of “Store & Forward” provides new ways of communication for Internet-of-Things (IoT) applications specifically in sparse satellite constellations, where the feeder link availability is not always ensured, so that the eNB stores NB-IoT/LTE-M messages in Downlink respectively in Uplink and delivers them once the backhaul/feeder or Uu link to the UE is available.

The Rel-19 evolution of NTN is organized in three different RAN Work Items (NTN NR Evolution Aspects, IoT-NTN Evolution Aspects, and Mobility from E-UTRA TN to NR NTN).

The work for Rel-19 is scheduled to be finalized in September 2025.

5.2 Antennas and other parameters for Uu link

5.2.1 Motivation and background

The terminal types for NTN in Rel-17 and -18 are studied in 3GPP, as presented below in Table 1. These terminal types are from TR 36.763 for IoT-NTN and TR 38.821 for NR-NTN and do not yet take automotive characteristics into account. Terminal types supported are handheld devices with omnidirectional antennas and VSAT terminals with highly directive antennas. Terminal characteristics have been discussed within Rel-18 for Ka-band, and both electronic and mechanical steering antenna are studied for fixed VSAT and mobile VSAT, and the corresponding parameters are listed in Table 2.

Table 1 NTN terminals as derived from TR 36.763 and TR 38.821 for 3GPP system-level simulations and their possible applications in automotive context

	IoT-NTN (LTE NB-IoT, eMTC)	NR-NTN (5G New Radio)		
Parameters	**Cellular-IoT**	**Handheld**	**VSAT**	**New Vehicular UE (Note 1)**
Spectrum	Below 7 GHz	Below 7 GHz	Above 10 GHz	Above 10 GHz
Reference Frequency band	S Band (i.e. 2 GHz)	S band (i.e. 2 GHz)	Ka band (i.e. 30 GHz UL and 20 GHz DL)	Ka band (i.e. 30 GHz UL and 20 GHz DL)
Terminal type application in automotive environment	**Narrow-band connectivity for vehicle mounted devices**	**Narrowband connectivity to smartphones in vehicles and motorcycles, CPTW, bicycles, pedestrians**	**Unlikely for automotive applications due to large form factor, if not integrated in a glass roof antenna**	**Broadband connectivity for vehicle mounted devices (e.g. for commercial vehicles, bus, coach, caravans, motorhomes/RVs, passenger cars)**
Antenna type and configuration	Omnidirectional antenna	(1, 1, 2) with omni-directional antenna element	Directional with 60 cm equivalent aperture diameter	Directional (M,N,P,Mg,Ng) = (TBD,TBD,2,1,1); (dV,dH) = (TBD, TBD) λ with directional antenna element (HPBW=65 deg)
Polarization	Linear	Linear: +/-45°X-pol	Circular	Circular
Rx Antenna gain	0 dBi	TR 38.821 and Rel-17: 0 dBi Rel-18 NR-NTN WI: -5.5 dBi	39.7 dBi	TBD
Antenna temperature	(not reported) 290 K assumed	290 K	150 K	150 K
Noise figure	7 dB or 9 dB	7 dB	1.2 dB	1.2 dB
Tx transmit power	200 mW, 23 dBm 100 mW, 20 dBm	200 mW, 23 dBm	2 W, 33 dBm	2 W, 33 dBm
Tx antenna gain	0 dBi	(see Rx antenna gain)	43.2 dBi	TBD

Note 1: could be implemented via a phased array antenna, at least, for vehicle-mounted devices

Table 2 NTN terminal parameters for Ka-band in Rel-18 [R4-2321974]

UE Class	Fixed VSAT	Mobile VSAT
Electronic steering	Class1: 2.5 dB NF (LEO and GSO)	Class1: 2.5 dB NF (GSO)
	Class2: 6 dB NF (LEO and GSO)	
Mechanical steering	Class 1: 2.5 dB NF (LEO and GSO)	Class1: 2.5 dB NF (GSO)

In Release 17, handheld power class 3 UE was specified in [TS 38.101-5] for satellite access, as summarized in Table 3, and a reference antenna with a gain of 0 dBi is assumed for UE with integral antenna only in the specification. In Release 18, UE parameters for Ka-band are further specified in [TS 38.101-5] as summarized in Table 4.

Table 3 NTN terminal power class [TS 38.101-5]

NR Satellite Band	Class 3 (dBm)	Tolerance (dB)
n256	23	±2
n255	23	±2
n254	23	±2
Note 1: Power class is the maximum UE power specified without taking into account the tolerance Note 2: Power class 3 is default power class unless otherwise stated		

Table 4 Assumptions of UE Types for Ka-band captured in Rel-18 [TS 38.101-5]

UE Class	UE Type	Type Description	Min. Peak EIRP (dBm)	Max EIRP (dBm)
Fixed VSAT	1	Fixed VSAT supporting GSO and LEO with mechanical steering antenna.	70	76.2
	2	Fixed VSAT supporting GSO and LEO with electronical steering antenna.	70	
	3	Fixed VSAT supporting LEO only with electronical steering antenna.	61	
Mobile VSAT	4	Mobile VSAT supporting GSO with mechanical steering antenna.	70	76.2
	5	Mobile VSAT supporting GSO with electronical steering antenna.	70	
Note: Assuming that UE has single beam towards one single satellite at a given time				

It should be noted that 3GPP defined a small number of antenna types to limit the effort for system-level simulations. Other antenna types and characteristics are of course possible as well for real 5G-NTN deployments, e.g. for connectivity to vehicles.

For Ka-band, higher antenna gain can be achieved than in L- or S-band due to the aperture and the shorter wavelength. Phased array antenna can be considered as either under-roof or in-glass mounted, where the exact antenna gains need to be re-evaluated based on the patch-sizes and the attenuation of the roof material. 5GAA has evaluations for their applicability in real automotive deployments. Additionally, Table 1 (on the rightmost column) considers one possible baseline for a vehicle-mounted antenna type based on the 5GAA evaluation and applicability of GNSS-like antenna types for NTN connectivity.

Based on the above analysis, reasonable UE parameters for vehicles to support the use cases defined by 5GAA should be studied first and proposed to 3GPP to be taken into account for the evolution of NTN in Rel-19 including RF requirement, coexistence analysis and SAR requirement based on the input from 5GAA. Specifically, vehicle mounted devices with enhanced antenna gain, noise figure and/or Tx power should be considered in FR1 (e.g. for wideband) and in above 10 GHz (e.g. for broadband) for NTN.

To round up the discussion, the following paragraphs offer recommendation for UE parameters, where both performance and cost are taken into consideration. The performance provides the link budget and the corresponding data rate based on the potential UE parameters. Among these candidate UE parameters, the final recommendations then take cost, power consumption, etc. into consideration. The objective of the evaluation methodology should pick out parameters that provide significant throughput improvement while keeping cost as low as possible. As the study should consider both performance and cost, the following methodology is adopted by 5GAA to come up with reasonable UE parameters for vehicles:

1) Align with satellite parameters and candidate UE parameters for link budget calculation.

- Possible range of UE parameters are considered to check what link budget or data rate will be with different parameter combinations.
- The satellite parameters are reasonable in 5GAA and used for link budget calculation.

2) Provide the link budget performance based on candidate UE parameter combinations, and analyze the link budget sensitivity impacted by different UE parameters.

3) Provide the UE parameter analysis considering the cost, power consumption, etc.

4) Rank the candidate UE parameter combinations based on 2) and 3), and come up with high-priority UE parameter combinations.

5.3 Sensitivity analysis of parameters

5.3.1 Evaluation assumptions in 5GAA satellite parameters

For S-band, we use the same assumptions for satellites as described in TR 38.821. For Ka-band, the EIRP density of satellite defined in 3GPP is only 4 dBW/MHz, assuming VSAT terminals. In contrast, the upper regulatory limit of EIRP density based on the PFD limits given in ITU is 21.6 dBW/MHz. 5GAA takes a higher reference EIRP density than 3GPP, and uses 16 dBW/MHz as the assumption for evaluation. The satellite parameters for both Ka- and S-band are as illustrated in the following table.

Table 5 Satellite parameters for evaluation

Satellite orbit		LEO-600
Satellite altitude		600 km
Payload characteristics for DL transmissions		
Satellite EIRP density	S-band (i.e. 2 GHz)	34 dBW/MHz
Satellite Tx max Gain		30 dBi
Satellite EIRP density	Ka-band (i.e. 20 GHz for DL)	16 dBW/MHz
Satellite Tx max Gain		38.5 dBi
Payload characteristics for UL transmissions		
G/T	S-band (i.e. 2 GHz)	1.1 dB K^{-1}
Satellite Rx max Gain		30 dBi
G/T	Ka-band (i.e. 30 GHz for UL)	13 dB K^{-1}
Satellite RX max Gain		38.5 dBi

UE parameters

5GAA proposes to consider vehicle-mounted devices with enhanced antenna gain, noise figure and/or Tx power in FR1 (e.g. for wideband) and in above 10 GHz (e.g. for broadband).

A phased array antenna is recommended for Ka-band, and the parameters are summarized in Table 6. It can be observed that for the target elevation of 30 degree, 4 dB antenna gain loss occurred.

Table 6 Different antenna gains and corresponding antenna sizes for Ka-band

Antenna gain@90elevation	Antenna gain@30elevation	Antenna elements	Maximum antenna size (at 20 GHz)
25	20.7	9x9	6x6cm
29	24.5	14x14	9.75x9.75cm
31	26.7	18x18	12.75x12.75cm
33	28.8	23x23	16.5x16.5cm

5.3.2 Key findings based on link budget

Link budget for S-band and Ka-band are calculated by the following equation as defined in 3GPP [TR 38.821]

$$\mathrm{CNR}\ [\mathrm{dB}] = \mathrm{EIRP}\ [\mathrm{dBW}] + \frac{G}{T}[\mathrm{dB/K}] - k\ [\mathrm{dBW/K/Hz}] - PL_{FS}\ [\mathrm{dB}] - PL_{A}\ [\mathrm{dB}] - PL_{SM}\ [\mathrm{dB}] - PL_{SL}[dB] - PL_{AD}\ [\mathrm{dB}] - B\ [\mathrm{dBHZ}]$$

For downlink link budget computation, the value of G/T depends on the NTN terminal parameters, which can be calculated as following

$$G/T\ [\mathrm{dB}] = G_R\ [\mathrm{dBi}] - N_f\ [\mathrm{dB}] - 10\log_{10}\left(T_0\ [\mathrm{K}] + (T_a\ [\mathrm{K}] - T_0\ [\mathrm{K}])10^{-0.1N_f\ [\mathrm{dB}]}\right)$$

In addition, for uplink link budget computation, the value of EIRP is calculated as

$$\mathrm{EIRP}\ [\mathrm{dBW}] = P_T\ [\mathrm{dBW}] - L_C\ [\mathrm{dB}] + G_T\ [\mathrm{dBi}]$$

For link budget calculations, atmospheric/scintillations/shadowing losses are not considered, i.e. $PL_A = PL_{SM} = PL_{SL} = 0$. Only polarization loss is considered for additional loss PL_{AD} and 3dB polarization loss is assumed with 1RX.

For the link budget calculations in S-band within 5GAA, two receive antennas and one transmit antenna are assumed, as in 3GPP. Despite this, an interference limitation scenario with a C/I of 10 dB is assumed. Carrier-to-Noise-and-Interference Ratio (CINR) of transmission link between satellite and UE is derived by Carrier-to-Noise Ratio (CNR) and Carrier-to-Interference Ratio (CIR) as follows

$$\mathrm{CINR} = -10\log_{10}\left(10^{-0.1CNR[\mathrm{dB}]} + 10^{-0.1CIR[\mathrm{dB}]}\right)$$

For the performance of 5G-NR, a loss of 2 dB with respect to the Shannon limit as a first approximation of the 5G-NR performance is assumed. To calculate the achievable data rate, we take the additional overhead by 5G-NR for reference symbols etc. according to TS 38.306 into account for FR1

$$\text{Data rate} = (1 - \text{overhead}) * \text{PRBnumber} * \mathrm{BW_{PRB}} * \log_2(1 + 10^{0.1(CINR-2)[dB]})$$

The resulting achievable maximum data rates for variable terminal characteristics (antenna gain, noise figure and transmit power) and for variable used Physical Resource Blocks (PRB) in the uplink are shown in the next plots for downlink and uplink in S-band. In the case of the FR1 DL, two Rx antenna elements with equal performance and Maximum Ratio Combining in the receiver are assumed. Further, uncorrelated interference from other satellite beams at the spatial separated individual antenna elements is assumed.

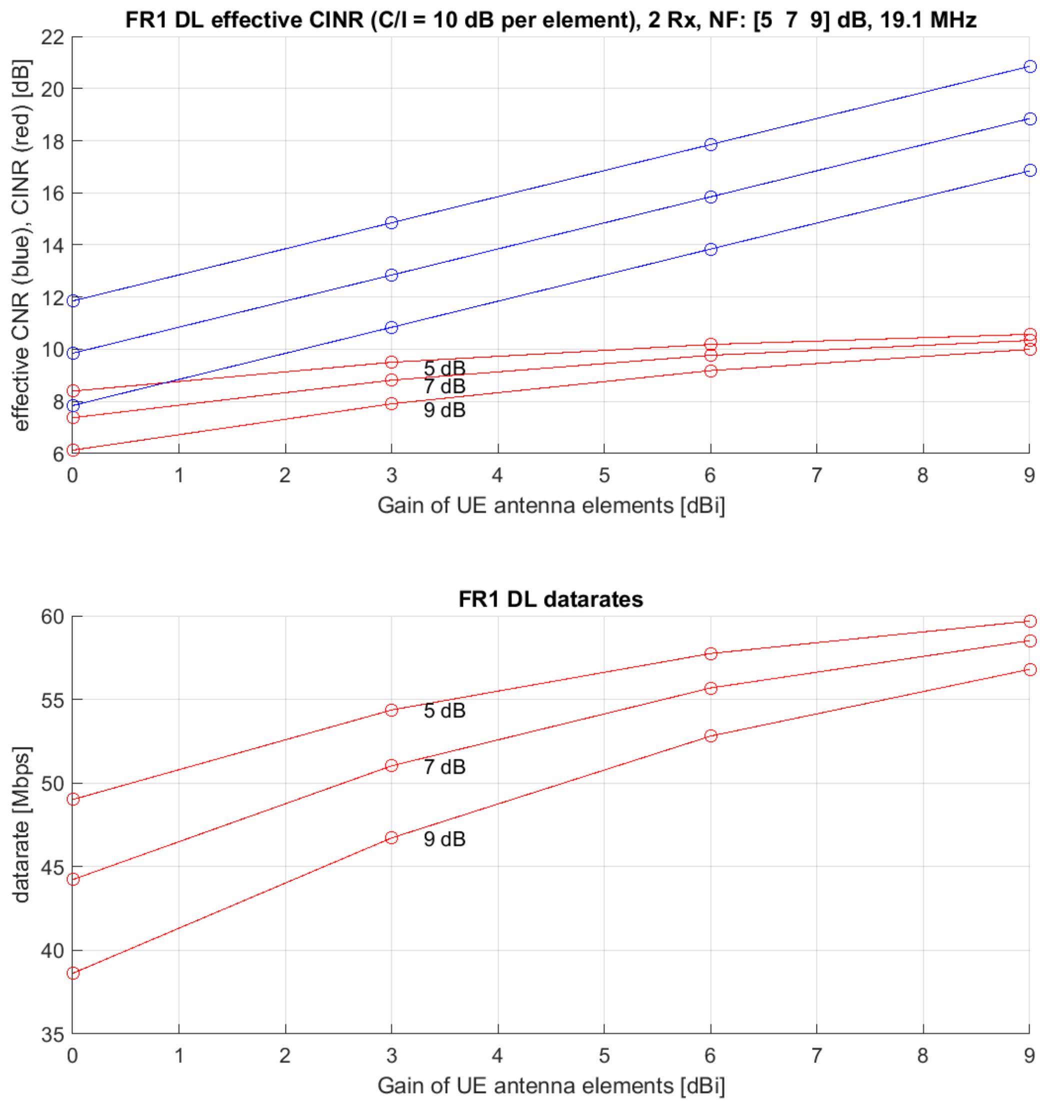
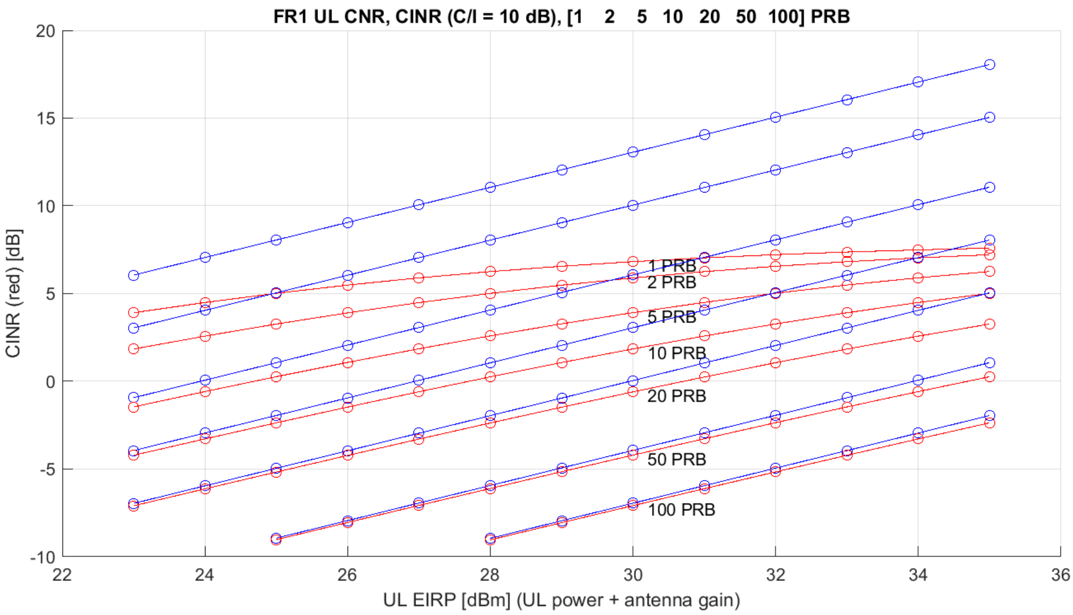


Figure 7 FR1 DL achievable data rates



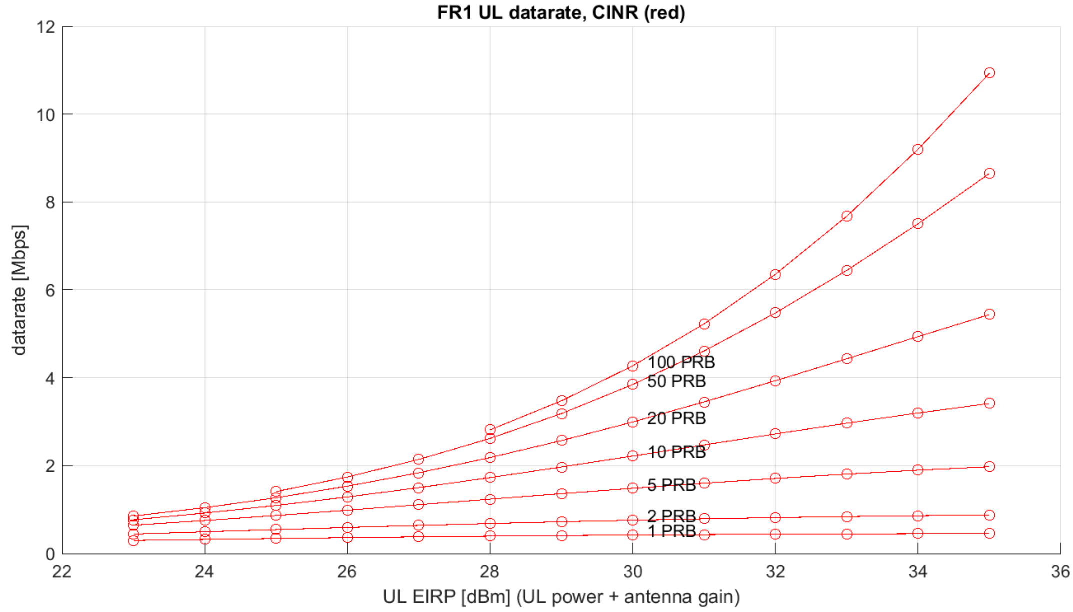


Figure 8 FR1 UL Achievable data rates

Key findings for the S-band in downlink are that the receiver noise figure and antenna gain have a moderate influence on the achievable peak data rate, e.g. 39 Mbps (NF 9 dB and 0 dBi linear antenna) to 60 Mbps (NF 5 dB, 9 dBi linear antenna). A noise figure similar to a smartphone (7 dB) seems to be sufficient for automotive terminals.

For the S-band uplink, the throughput varies heavily, depending on the transmitter power and the antenna gain. The calculated range of uplink data rate is between less than 1 Mbps (23 dBm, 0 dBi linear antenna) up to 11 Mbps (29 dBm, 6 dBi linear antenna). For the uplink throughput of automotive terminals, a higher transmit power > 23 dBm and antenna gain above 3 dBi is recommended.

For the link budget calculations in Ka-band, it is assumed that one receive antenna and one transmit antenna are needed, aligned to 3GPP. Despite this, an interference limitation scenario with a C/I of 14 dB (higher than in S-Band due to the directivity of the car antenna) is assumed. For the performance of 5G-NR, assume a loss of 2 dB with respect to the Shannon limit. To calculate the achievable data rate for FR2, take into account the additional overhead by 5G-NR for reference symbols etc. according to TS 38.306. A difference to the assumptions in 3GPP is the higher downlink power density of 16 dBW/MHz (still under the regulatory limit), compared to the 4 dBW/MHz in 3GPP as assumed for VSAT high gain antennas.

The resulting achievable maximum data rates for variable terminal characteristics (antenna gain, noise figure and transmit power) and for variable used Physical Resource Blocks (PRB) in the uplink are shown in the next plots for downlink and uplink in Ka-band.

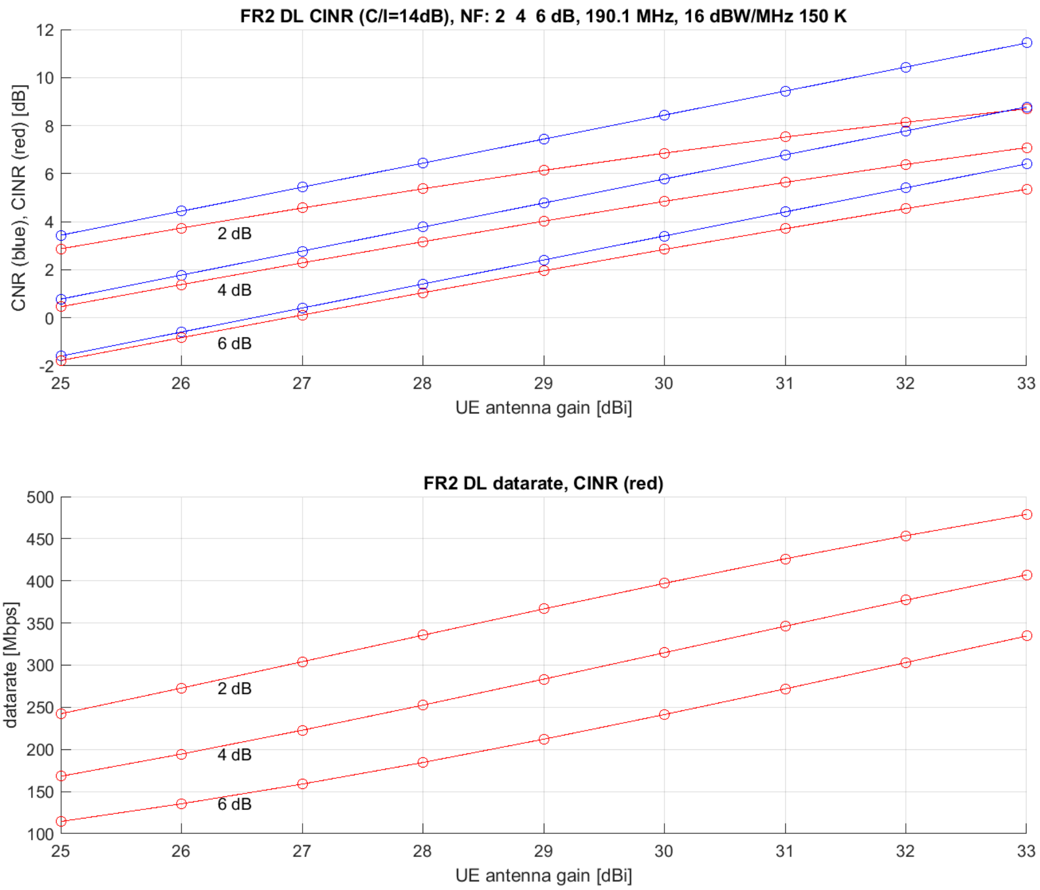


Figure 9 FR2 DL achievable data rate

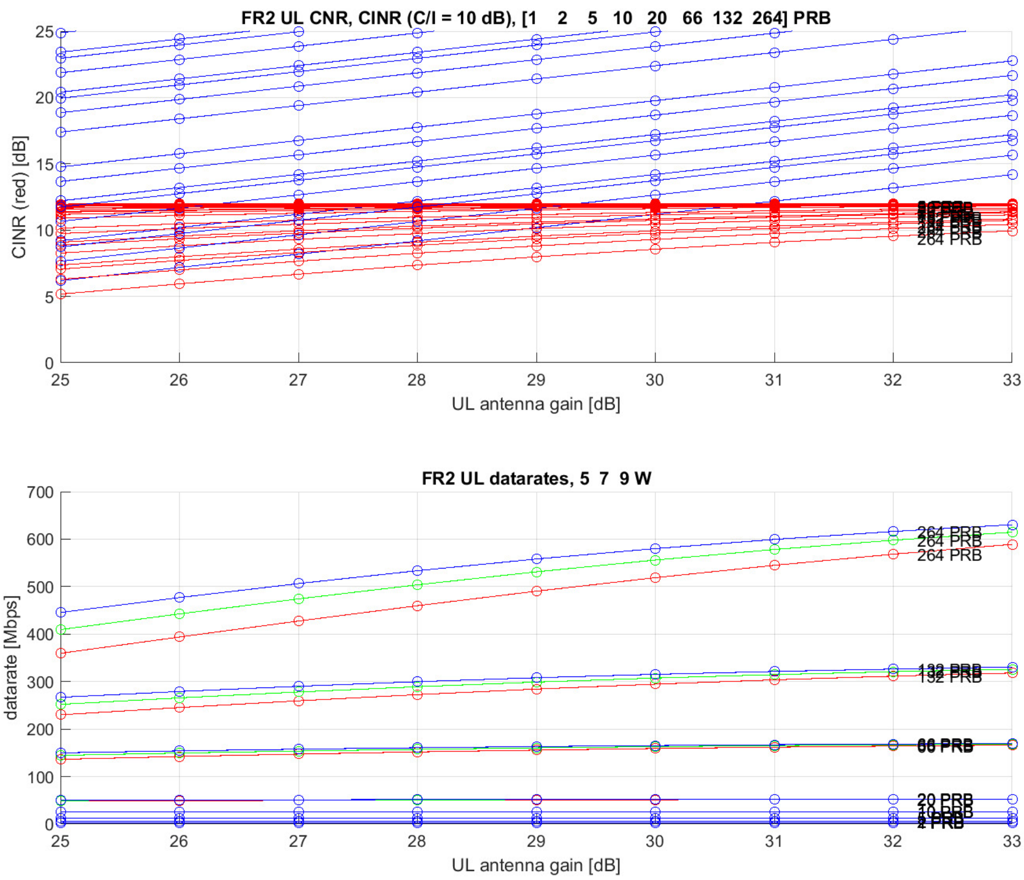


Figure 10 FR2 UL achievable data rate

Key findings for the downlink in Ka-band are that data rates vary strongly with the UE antenna gain as well as with the noise figure. Nevertheless, the beneficial higher gains and lower noise figures would result in bigger form factors and slightly higher energy consumption.

For the uplink in Ka-band, the achievable data rate strongly varies with the number of available bandwidth (in terms of PRBs). Dedicating all available PRBs to a single UE in contrast would cause higher delays, because the terminals would have to be scheduled successively, not in parallel in time. A compromise would be to schedule few terminals in parallel. Another key finding is, that due to the interference limitation, the uplink throughput only varies moderately with the transmit power and antenna gain. A smaller transmit power < 5 W is sufficient, resulting in less expensive Ka-band antenna arrays (e.g. 25 dBi) and smaller form factor.

5.4 Adaptation of the findings to feasible antenna design

A Space-to-Earth communication link is subject to high losses, with free-space path loss the main cause. In order to enable robust signal transmission with this high-path attenuation, in addition to transceiver amplifiers, the properties of the associated antennas are also essential.

5.4.1 Aspects and parameters for antennas feasibility

When considering the Space-Earth link budget, a high antenna gain is in principle desirable, but there are physical limits. Since the antenna gain is expressed relative to the isotropic radiator, a higher antenna gain, for example, means that the antenna will have a preferred radiation direction. A theoretical consideration for the maximum possible antenna gain at a given radiation angle range (expressed by the minimum elevation angle) is shown in Figure 11.

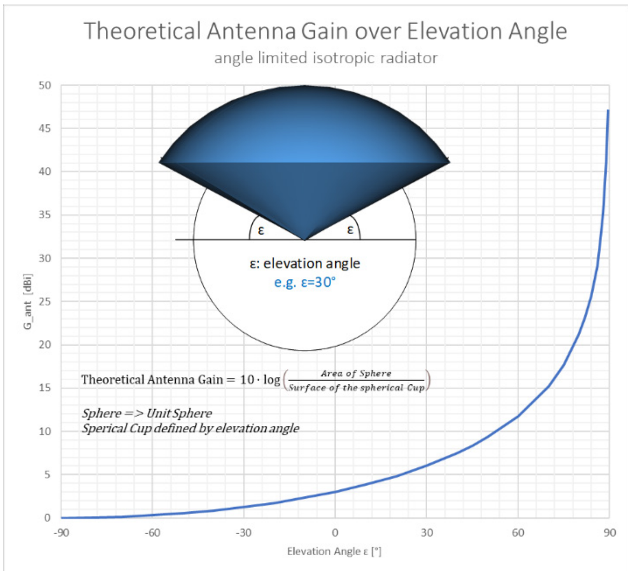


Figure 11 Theoretical antenna gain over elevation angle

These theoretical values cannot be achieved in practice due to additional requirements for the antenna such as frequency, bandwidth, and size. Antenna gain requirements therefore have an impact on the antenna size, the complexity and the associated manufacturing effort as well as the performance in terms of radiation and frequency.

These dependencies are summarized in Figure 12.

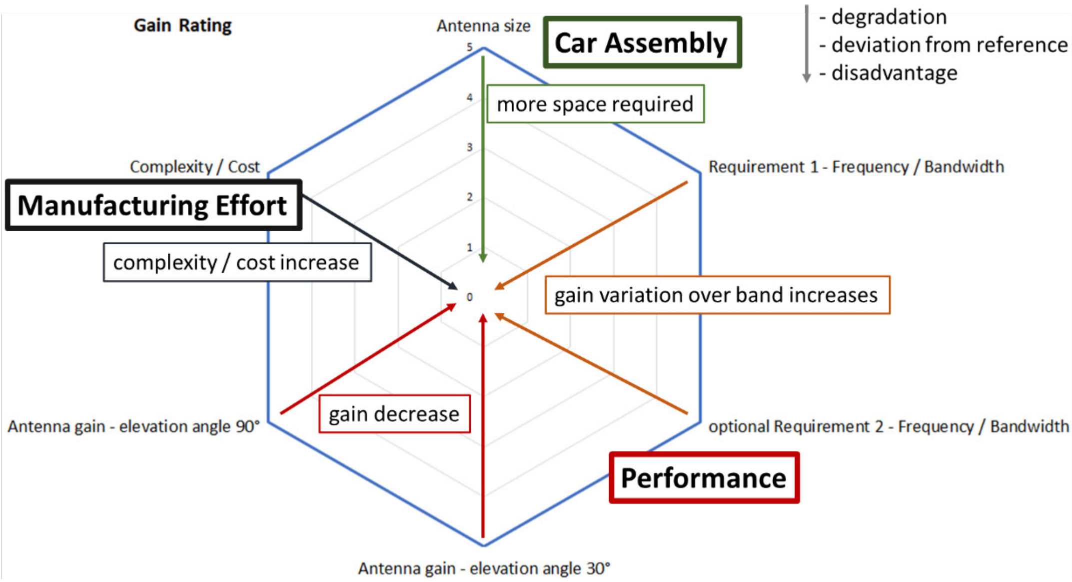


Figure 12 Antenna gain dependencies

The following section lists the assumptions and results for the two considered frequency ranges: L/S-band and Ka-band.

5.4.2 Assumption and results – L/S-band antenna

To estimate possible achievable gains for future L/S-band antennas for an automotive environment, a simulation and a benchmarking-based assessment were performed.

The assessment results were ranked in four classes:

- 0 dBi (dual band – e.g. band n255 and n256 support)
- 3 dBi (dual band – e.g. band n255 and n256 support)
- 3 dBi (single band – e.g. band n255 or n256 support only)
- 3 dBi (Tx or Rx single band – separate antennas for RX and TX)

Higher gain classes were dismissed since a more complex system with beamforming techniques would be required.

The radiator reference size is set to 5x5 cm. The size of the ground plane and required distances to the surroundings are not and cannot be taken into account here. The result of the assessment is shown in Figure 13.

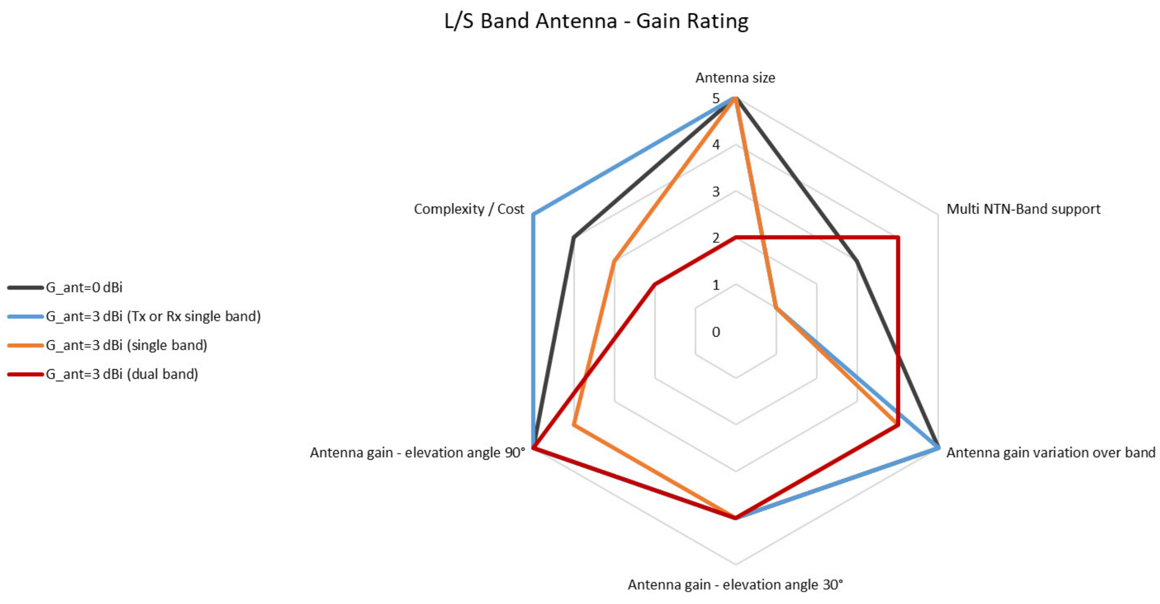


Figure 13 L/S-band antenna gain rating

A dual-band antenna for elevation angles between 30° and 90° with a gain of 0 dBi can be realized within an area smaller than 5x5 cm. There are slight differences in antenna gain between the two bands and an acceptable reduction in gain at lower elevation angles.

Simulations show that a 3 dBi single-band antenna for either Tx or Rx at elevation angles between 30° and 90° can be realized within an area of less than 5x5 cm. A distributed gain of 3 dBi between 30° and 90° elevation can be achieved, but only for a narrow bandwidth of 80 MHz to 100 MHz. This bandwidth only covers the downlink or uplink case for one band.

To achieve dual-band support for a 3 dBi antenna over the required elevation range, two radiator structures must be combined, which requires an area of more than 5x5 cm and also increases the complexity of the antenna.

5.4.3 Assumption and results – Ka-band antenna

In order to achieve the required high antenna gains for the Ka-band, an antenna array is used. The antenna gain of an antenna array increases from the gain of a single antenna element as well as the number of antenna elements. The number of antenna elements also affects the beam width and gain for low elevation angles. The distance between the individual antenna elements depends on the frequency and therefore has an impact on the size of the array. Due to the frequency duplex spacing of 10 GHz, the antenna elements have a different spacing for RX and TX. The first assumption is therefore to consider separate arrays for RX and TX. The total area of the antenna system results from the areas of both arrays. The radiator reference size is set to 20x20 cm.

The assessment results were ranked for antenna gains between 25 to 33 dBi in the frequency range of

- uplink frequency from 27.5 to 30 GHz
- downlink frequency from 17.7 to 20.2 GHz

The overall result of the assessment is shown in Figure 14.

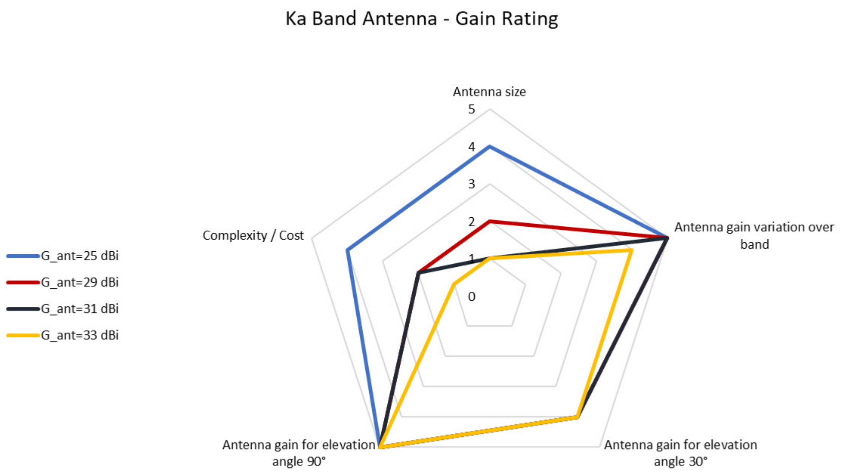


Figure 14 Ka-band antenna gain rating

It should be mentioned that the complexity of the antenna array increases with the possibility of switchable circular polarization – however, this has not yet been analyzed in detail and is not taken into account in this assessment.

Here is an example of an antenna array for NTN in Ka-band:

Uplink antenna:

- Array size: 24x24 antenna array
- 576 antenna elements
- Array area: 13x13 cm
- Antenna Gain over elevation angle: from 27 to 33 dBi
- Beam width @600 km: 50 km

Uplink antenna:

- Array size: 12x12 antenna array
- 144 antenna elements
- Array area: 10x10 cm
- Antenna Gain over elevation angle: from 22 to 28 dBi

Beam width @600 km: 100 km

5.5 Recommendation of antenna parameters in the defined conditions

Based on the above analysis, the recommended antenna parameters are as follows, according to the Liaison Statement from 5GAA to 3GPP in RP-232733:

Table 7: Recommended antenna parameters

Band	DL	UL	Notes
S/L-band	NF = 7dB Max. Gain, boresight of main lobe = 0 and 3 dBi	Tx Power: PC3 (23 dBm) and PC2 (26 dBm) Max. Gain, boresight of main lobe = 0 and 3dBi	At LEO-600
Ka-band	NF = 4 and 6 dB Min. Gain and Max. Gain, boresight of main lobe = 25 and 31 dBi	Tx power: 37 dBm and 38.5 dBm Min. Gain and Max. Gain, boresight of main lobe = 25 and 31 dBi Min. EIRP and Max. EIRP boresight of main lobe = 32 dBW and 39.5 dBW	Flat antennas with beamforming have been considered, different from VSAT, assuming a new satellite EIRP density of 16 dBW/MHz at LEO-600; UE antennas temperature 150 K.

5.6 Feasible data rates for the recommended antenna parameters

The feasible data rates for the recommend antenna parameters in the last section are as following:

Table 8: Feasible data rates at 30 deg for S/L-band (2Rx,1Tx)

DL	NF	Max. Gain, boresight of main lobe	Data rates 25 PRB (4.5 MHz), 52 PRB (9.37 MHz), 106PRB (19.08 MHz)
	7 dB	0 dBi	10.44 Mbps, 21.37 Mbps, 44.25 Mbps
		3 dBi	12.04 Mbps, 25.03 Mbps, 51.03 Mbps
UL	Tx Power	Max. Gain, boresight of main lobe	Data rates 1 PRB (0.18 MHz), 2 PRB (0.36 MHz), 25 PRB (4.5 MHz), 52 PRB (9.37 MHz) 106PRB (19.08 MHz)
	23 dBm	0 dBi	0.3 Mbps, 0.44 Mbps, 0.88 Mbps, 0.92 Mbps, 0.94 Mbps
		3 dBi	0.36 Mbps, 0.59 Mbps, 1.6 Mbps, 1.76 Mbps, 1.84 Mbps
	26 dBm	0 dBi	0.36 Mbps, 0.59 Mbps, 1.6 Mbps, 1.76 Mbps, 1.84 Mbps
		3 dBi	0.41 Mbps, 0.72 Mbps, 2.75 Mbps, 3.22 Mbps, 3.51 Mbps

Table 9: Feasible data rates at 30 deg for Ka-band (1 Rx, 1 Tx)

DL	NF	Max. Gain, boresight of main lobe	Data rates 66 PRB(47.52MHz), 132 PRB (95.04 MHz), 264 PRB (190.08 MHz)
	4 dB	25 dBi	21.46 Mbps, 42.93 Mbps, 85.85 Mbps
		31 dBi	55.88 Mbps, 111.76 Mbps, 223.51 Mbps
	6 dB	25 dBi	13.57 Mbps, 27.14 Mbps, 54.28 Mbps
		31 dBi	39.91 Mbps, 79.82 Mbps, 159.64 Mbps
UL	Tx Power	Max. Gain, boresight of main lobe	Data rates for 1 PRB(0.72 MHz), 66 PRB (47.52 MHz), 132 PRB(95.04 MHz) 264 PRB(190.08 MHz)
	37 dBm	25 dBi	2.61 Mbps, 107.24 Mbps, 163.1 Mbps, 226.69 Mbps
		31 dBi	2.63 Mbps, 147.48 Mbps, 259.89 Mbps, 428.29 Mbps
	38.5 dBm	25 dBi	2.62 Mbps, 118.88 Mbps, 188.32 Mbps, 273.64 Mbps
		31 dBi	2.63 Mbps, 153.85 Mbps, 278.4 Mbps, 474.9 Mbps
Note: 4 dB antenna gain loss is assumed at 30 deg for data rate calculation			

It should be noted that the data rates are calculated based on the satellite evaluation assumptions in 5GAA; the results will be different under other satellite assumptions and the data rate will be reduced if more repetitions are applied in a real application based on the gap between the link budget and the decoding thresholds.

6. Analysis of spectrum requirements and availability

General introduction

In the assessment of any new technology or deployment approaches and addition of a new use case for telecommunications, it is crucial to conduct a comprehensive analysis of the frequency spectrum situation. This analysis entails gaining an understanding of the current spectrum allocations, potential interference issues, and the impact on existing services. It also involves evaluating the compatibility of the proposed technology or use case with authorized equipment regulations to ensure compliance and prevent regulatory obstacles.

For the case of NTN for automotive use cases, both the ITU and 3GPP play essential roles in this process. The ITU, as a specialized agency of the United Nations, takes responsibility for international telecommunications regulations. It serves as the coordinator of global spectrum allocation and management, conducting studies, developing international agreements, and offering recommendations that govern spectrum usage worldwide. By bringing together governments, industry experts, and stakeholders, the ITU establishes international regulations and policies related to telecommunications. It allocates specific frequency bands for various services and technologies, such as mobile IMT based networks (2G, 3G, 4G, 5G, 6G), local networks using unlicensed spectrum (e.g. RLAN, WiFi), satellite communications, and broadcasting. These efforts ensure the coexistence of different systems and services without causing harmful interference. Moreover, the ITU facilitates spectrum coordination between countries, enabling global harmonization and interoperability of communication systems. Recommendations on spectrum allocations are regionally defined by the respective regulatory bodies like CEPT, FCC et al.

3GPP [www.3gpp.org] is a collaborative partnership among telecommunications Standardization Organizations (SDOs) developing global technical specifications which are turned into regional binding standards by the respective organizational partner of 3GPP (e.g. ETSI for Europe, ATIS for USA, ARIB for Japan, CCSA for China, TSDSI for India, and TTA for South Korea). 3GPP's focus lies in the development and maintenance of mobile communication specifications, including 2G (GSM), 3G (UMTS), 4G (LTE), 5G (NR) and in future 6G. By assembling industry experts from around the world, 3GPP defines the technical specifications for mobile network technologies, which are based on the ITU requirements for IMT systems.

The collaboration of all experts around the globe ensures that new technologies and use cases are evaluated by taking into account the respective spectrum regulatory framework and authorized equipment, allowing for seamless integration of innovative solutions while preserving the integrity of existing communication systems including worldwide roaming.

In light of the above, it is of utmost importance to understand the status quo at both regulatory (ITU) and standardization (3GPP) levels to best portray the operational envelope around NTN developments and deployment implications. Both levels are tackled in the following paragraphs.

ITU

At ITU level, it is possible to extract the necessary information about allocation and identification in L-band, S-band and Ka-band for civil satellite usage from the Article 5 of the Radio Regulations (WRC-19 Edition). The current allocation of frequencies to Mobile Satellite Services (MSS) and Fixed Satellite Services (FSS) in the various regions for non-Geostationary Orbit (non-GSO) satellite networks as well as allocation of services and identification of applications (such as IMT) is offered in the following passages, together with a picture outlining said regions in which the primary services are allocated.

It is very important to note that automotive usage in non-MSS bands is defined as land Earth Stations in Motion (land-ESIM) type of service in FSS by the ITU; due to the cross-border nature of the ITU decisions, the Radio Regulations are prescribing technical and operational characteristics for Aero- and Maritime-ESIMs, and are recognizing the strictly country-specific nature of land-ESIMs, thus leaving the licensing of such systems to each individual country.

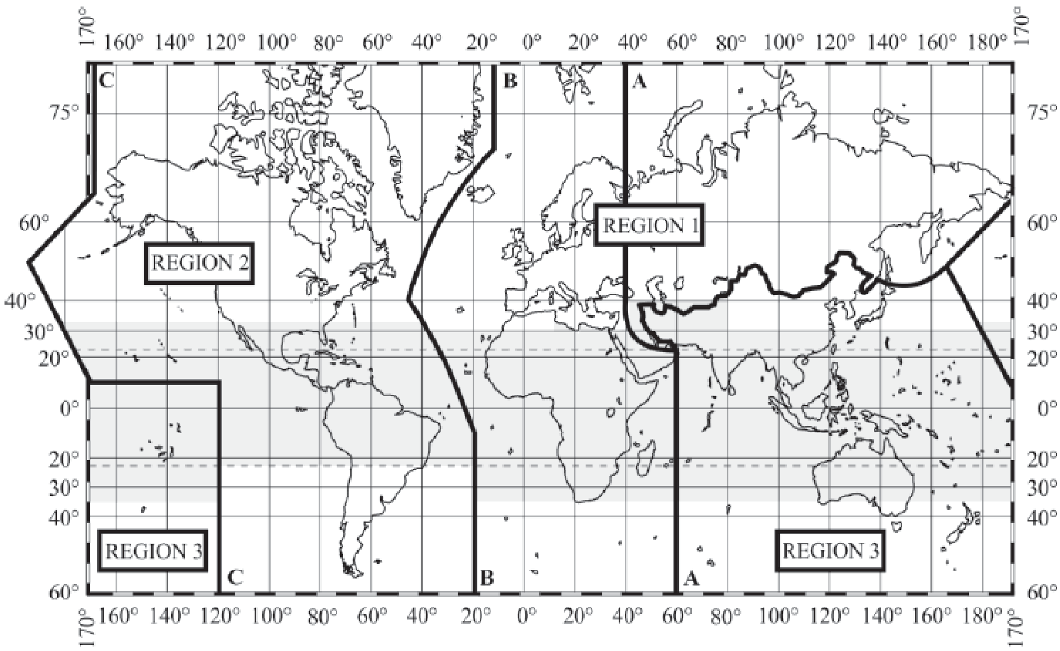


Figure 15 ITU regions with harmonized bands

Table 10 ITU frequencies

Frequency (MHz)	Direction (UL/ DL)	Bandwidth (MHz)	Regional Allocation (R1, R2, R3)	Service Allocation (MSS, FSS)	IMT Identification in MS
1518 – 1525	DL	7	R1, R2, R3	MSS	MS co-primary
1525 – 1559	DL	34	R1, R2, R3	MSS	MS secondary in 1525 – 1535 MHz
1610 – 1626.5	UL	16.5	R1, R2, R3	MSS	No
1626.5 – 1660	UL	34	R1, R2, R3	MSS	No
1980 – 2010	UL	30	R1, R2, R3	MSS	Yes co-primary (no co-frequency or co-coverage) apart from countries in footnote 5.389F
2010 – 2025	UL	15	R2	MSS	Yes co-primary (no co-frequency or co-coverage)
2160 – 2170	DL	10	R2	MSS	Yes co-primary (no co-frequency or co-coverage)
2170 – 2200	DL	30	R1, R2, R3	MSS	Yes co-primary (no co-frequency or co-coverage) apart from countries in footnote 5.389F
2483.5 – 2500	DL	16.5	R1, R2, R3	MSS	MS co-primary
17700 – 17800	DL	100	R2	FSS	MS secondary
17800 – 18100	DL	300	R2	FSS	MS co-primary (Art 21)
17700 – 18100	DL	400	R1, R3	FSS	MS co-primary (Art 21 from 17800)
18100 – 18400	DL	300	R1, R2, R3	FSS	MS co-primary (Art 21)
18400 – 18600	DL	200	R1, R2, R3	FSS	MS co-primary (Art 21)
18800 – 19300	DL	500	R1, R2, R3	FSS	MS co-primary (Art 21)
19700 – 20100	DL	400	R1, R3	FSS (and MSS secondary)	No
19700 – 20100	DL	400	R2	FSS / MSS	No
20100 – 20200	DL	100	R1, R2, R3	FSS /MSS	No
27500 – 28500	UL	1000	R1, R2, R3	FSS	MS co-primary
28500 – 29100	UL	600	R1, R2, R3	FSS	MS co-primary
29500 – 29900	UL	400	R1, R3	FSS (and MSS secondary)	No
29500 – 29900	UL	400	R3	FSS / MSS	No
29900 – 30000	UL	100	R1, R2, R3	FSS / MSS	No

3GPP

3GPP defines standardized frequency bands and band usages in each release. From 3GPP Rel-17 onwards operational ranges for NTN have been defined as follows.

Table 11 FR1 and FR2 frequency ranges

Frequency range designation	Corresponding frequency range
FR1-NTN[1]	410 MHz – 7125 MHz
FR2-NTN[2]	17300 MHz – 30000 MHz
NOTE 1: [NTN bands within this frequency range are regarded as a FR1 band when references from other specifications.]	
NOTE 2: [NTN bands within this frequency range are regarded as a FR2 band when references from other specifications.]	

As part of the Rel-17 only FR1-NTN range-based frequency bands have been defined. Other bands outside the FR1 and FR2 have been added as part of Rel-18.

In 3GPP Rel-17 and Rel-18 following L-band, S-band and Ka-band NTN operating bands are defined for NR NTN in TS 38.101-5.

Table 12 NTN satellite bands in FR1

NTN Satellite Operating Band	Uplink (UL) Operating Band Satellite Access Node Receive / UE Transmit $F_{UL,low} - F_{UL,high}$	Downlink (DL) Operating Band Satellite Access Node Transmit / UE Receive $F_{DL,low} - F_{DL,high}$	Duplex Mode
n256	1980 MHz – 2010 MHz	2170 MHz – 2200 MHz	FDD
n255	1626.5 MHz – 1660.5 MHz	1525 MHz – 1559 MHz	FDD
n254	1610 – 1626.5 MHz	2483.5 – 2500 MHz	FDD
Note: NTN satellite bands are numbered in descending order from n256			

Table 13 NTN satellite bands in FR2

Satellite Operating Band	Uplink (UL) Operating Band SAN Receive / UE Transmit $F_{UL,low} - F_{UL,high}$	Downlink (DL) Operating Band SAN Transmit / UE Receive $F_{DL,low} - F_{DL,high}$	Duplex Mode
n512[1]	27500 MHz – 30000 MHz	17300 MHz – 20200 MHz	FDD
n511[2]	28350 MHz – 30000 MHz	17300 MHz – 20200 MHz	FDD
n510[3]	27500 MHz – 28350 MHz	17300 MHz – 20200 MHz	FDD
Note 1: This band is applicable in the countries subject to CEPT ECC Decision(05)01 and ECC Decision (13)01 Note 2: This band is applicable in the USA subject to FCC 47 CFR part 25 Note 3: This band is applicable for Earth Station operations in the USA subject to FCC 47 CFR part 25. FCC rules currently do not include ESIM operations in this band (47 CFR 25.202).			

In addition, the following operating bands are defined for IoT NTN in TS 36.102:

Table 14 E-UTRA Operating Bands

E-UTRA Operating Band	Uplink (UL) Operating Band BS Receive UE Transmit			Downlink (DL) Operating Band BS Transmit UE Teceive			Duplex Mode
	F_{UL_low}	–	F_{UL_high}	F_{DL_low}	–	F_{DL_high}	
256	1980 MHz	–	2010 MHz	2170 MHz	–	2200 MHz	FDD
255	1626.5 MHz	–	1660.5 MHz	1525 MHz	–	1559 MHz	FDD
254	1610 MHz	–	1626.5 MHz	2483.5 MHz	–	2500 MHz	FDD
253[2]	1668 MHz	–	1675 MHz	1518 MHz	–	1525 MHz	FDD

Note 1: Satellite bands are numbered in descending order from 256
Note 2: UE assigned to channels and allocated frequency resources in the lower portion of Band 253 may experience blocking or harmful interference from terrestrial networks in adjacent or nearby frequencies when operating in the proximity with terrestrial base stations

NTN systems for automotive – Frequency selection

When selecting suitable frequencies (and consequent architectures) for the operation of NTN systems for automotive, it is of utmost importance to first outline the envelope of assumptions such frequencies shall respect. From the 5GAA position paper on the topic – and from the following discussions – the most high-level envelope of assumptions looks as such:

- The selected frequency must be suitable for the design, development, and manufacturing of an automotive terminal (UE) of 20x20 cm in size, or smaller, to facilitate integration in vehicles.
- The selected frequency must allow for an architectural deployment in line with the 5G NTN current or future specifications developed by 3GPP to ensure interoperability and global roaming.
- The selected frequency and resulting NTN system must be operated in a TN-first fashion, thus implying that, whenever possible and more convenient, the transfer of data shall happen on TN.

From the above envelope, and considering the ITU and 3GPP frequencies listed in previous paragraphs, a number of possible solutions can be considered for the deployment of NTN systems:

- Scenario 1: "Satellite-to-legacy-user-equipment" in IMT-only bands using 3GPP technologies such as LTE or NR (UEs do not use/need any optimizations).
- Scenario 2: "Satellite-to-NTN-user-equipment" in MSS bands (S- and L-bands), requiring at least 3GPP Rel-17 UEs.
- Scenario 3: "Satellite-to-NTN-user equipment" in FSS bands (Ka-band), requiring at least 3GPP Rel-17 UEs.

The above scenarios can be arranged in a table to assess their characteristics.

Table 15 Evaluation of NTN scenarios

Characteristics	Scenario 1	Scenario 2	Scenario 3
Usage of pre-existing smartphone-like antennas typical in handhelds or "shark-fins" in automotive	Yes	Yes	No
Usage of new antennas (5x5 cm or smaller) for automotive	Yes	Yes	No
Usage of new antennas (20x20 cm or smaller) for automotive	Yes	Yes	Yes

Can operate where co-frequency IMT base stations are active	No	No	Yes
Compliant with ITU RR Article 5	Non-conforming use (requires country-by-country proof of harmful interference avoidance mechanisms for RR Art 4.4)	Yes	Yes
Requires country-by-country spectrum leasing rule change and agreements between spectrum holder and user	Yes	Yes, only if operations are designed in co-frequency and co-coverage with IMT base stations	No
Requires country-by-country license	Yes (it leverages pre-auctioned IMT spectrum and needs approval from at least one MNO per country holding the terrestrial usage rights)	Yes	Yes
Target data-rate performance (cumulative in one beam)	NB	NB + WB	NB + WB + BB
Currently-available spectrum at ITU	Technically all IMT spectrum MNOs are willing to license under RR Art 4.4	See ITU allocation table above	See ITU allocation table above
Currently-standardized spectrum at 3GPP	*(Technically all IMT spectrum MNOs are willing to license)*	FR1-NTN bands: NR NTN: n256, n255, n254 IoT NTN: 256, 255, 254, 253	FR2-NTN bands: n512 n511 n510

Conclusions and recommendations

The aim of this TR is to lay out a clear vision on the integration of a Non-Terrestrial Connectivity layer for connected vehicles. That near-time vision is built on the analysis and consensus of the automotive and telecommunication industry represented by 5GAA. It is thus understood as a guideline for decision-makers in regulation and policy bodies as well as underlying technology suppliers, what decisive steps need to be taken now in order to make the vision of space-connected vehicles a reality on our roads.

The motivation to call for extending coverage from Terrestrial Networks to Non-Terrestrial Networks is driven by the demand of mobile customers who are asking for ubiquitous connectivity and for the existing coverage gaps in terrestrial mobile networks to be bridged.

From a 5GAA point of view there is now a window of opportunity because the automotive industry is going through a period of positive disruption thanks to new digital services enabling new business models. Meanwhile, the space sector is leveraging the benefits of lower launch costs and groundbreaking connectivity solutions enabling massive Low-Earth Orbit constellations. At the same time, progress is made in terms of the mobile network standards and regulatory developments The time to act is now!

NTNs can only be considered as an attractive solution if they are implemented in a cost-efficient manner. Therefore, close interworking with terrestrial networks based on global 3GPP standards is the key success factor.

To drive this process, two major targets must be achieved.

1. It needs a joint vision, which applications are most relevant, what time frames are necessary for developing the necessary standards and technologies, deploying vast LEO constellations, and lastly, when mass implementation can be expected. **5GAA has talked to all major stakeholders and has developed a NTN Roadmap where all information can be found condensed into one picture.**
2. Automotive requirements must be “injected” into the already ongoing discussion on interworking of NTN and Terrestrial Networks. A lot of standards have already been established, for instance in 3GPP Release 17, or are being implemented in Release 18, but automotive requirements have not been part of the discussion. For instance, 3GPP has considered only characteristics of handheld antennas and antennas with 60 cm equivalent aperture (e.g. parabolic antenna) for satellite communication. **5GAA proposes therefore to add the parameters of automotive-type antennas into the set of common assumptions for the upcoming 3GPP releases.**

NTN Roadmap – a joint vision towards mass deployment of NTN services

Three main factors are influencing when and how NTN services will be available:

1. Service Level Requirements of use cases benefitting from NTN: One of the great surprises of the present report was that no new NTN use cases have been identified, but instead the existing terrestrial use cases have been extended by NTN. Data rate requirements have been identified as the most important criterion for the classification of use cases. Use cases are therefore classified into narrowband (< 400 kbps), wideband (< 10 Mbps), and broadband (> 10 Mbps) data rate use cases.
2. Standardization process of terrestrial mobile networks via 3GPP and the availability of technologies based on these standards: Starting with Release 17, 3GPP created the necessary standards to extend the cellular ground network with Non-Terrestrial Layers. Release 17 was focused mostly on intra-NTN mobility scenarios like cell reselection and intra- and intersatellite handover based on the legacy mobility procedures of the cellular network. First chipsets based on Release 17 are expected in 2025, and first mass deployment of respective user terminal technology can be expected in 2027. In Release 18, the focus was more on TN-NTN mobility procedures. Finally, in Release 19, further missing mobility functions will be implemented, and **5GAA has decided to propose new parameters for automotive suited antennas in this release.**
3. Availability of satellite networks is the third factor for determining the implementation process of NTN services. As of the first half of 2024, there are mostly proprietary GEO, MEO and LEO constellations in space. Today's Geostationary satellite networks are relatively costly, have high latencies and can only provide very low data rates to a limited number of customers at the same time. First LEO satellite networks providing broadband data rate services are also proprietary and require user terminals which are quite expensive and ill-suited for automotive integration. However, first offerings of narrowband connectivity for handhelds based on IoT-NTN 3GPP Rel-17 with 3GPP frequencies below 3 GHz (S- and L-band) can be seen in 2024 as well. Between 2026 and 2028, it is expected that the Space layer to support New Radio NTN 3GPP Rel-17/18, allowing first wideband data rates in bands below 6 GHz and (later) broadband data rates at bands above 10 GHz.

Taking all these drivers together, mass deployment may well take place in three waves:

1. From 2027 on, Narrowband Data Rate Use Cases based on 3GPP Release 17 will be implemented. Emergency call, road and safety information in remote areas or remote access are some prominent examples.
2. From 2029 on, Wideband Data Rate Use Cases will be mass deployed based on NR NTN 3GPP Release 17/18. Data collection and sharing for HD Maps (objects), over the air software updates or entertainment use cases, like video streaming and conferencing, will become technically feasible. Such

use cases would also require the deployment of LEO satellite constellations working in the S- and L-band with sufficient satellites to cover them.

3. From 2030 on, Broadband Data Rate Use Cases, like 4K video streaming or cloud gaming, will be deployed but would require the deployment of LEO satellite constellations working in higher frequencies, like Ka- and Ku- band. Additionally, more sophisticated (and likely more costly) user terminals will be necessary, possibly limiting the number of customers who can afford it.

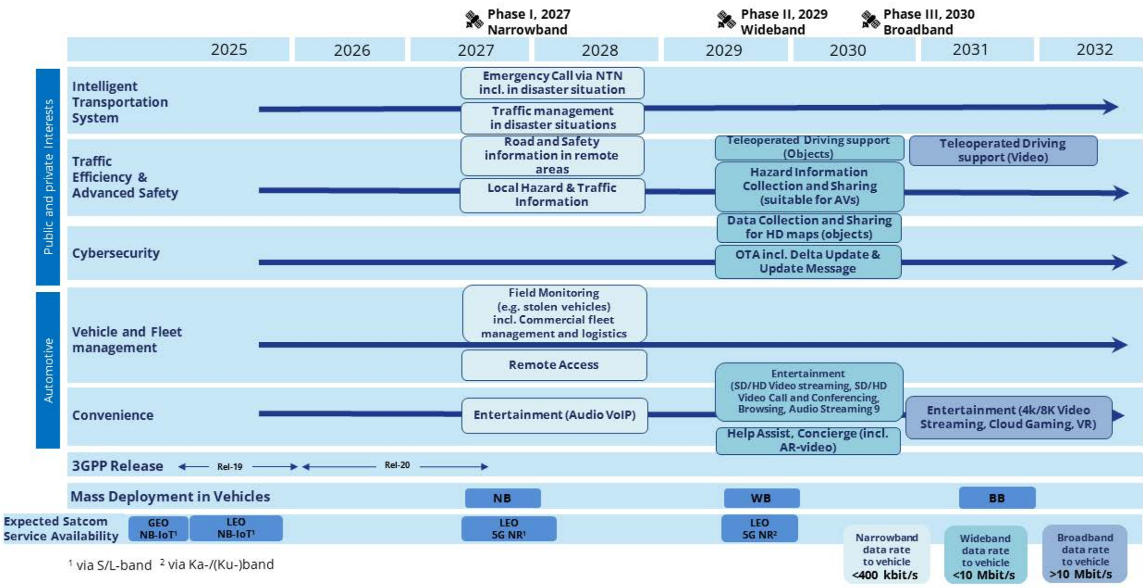


Figure 16 NTN-Use Case Roadmap Proposal for Mass Deployment-Geo/Leo

This NTN Roadmap has been the basis for the proposal by 5GAA to integrate two new automotive terminal types into the standardization process of the next 3GPP releases. Reasonable UE parameters for vehicles to support the use cases defined by 5GAA should be studied first and proposed to 3GPP to be taken into account for the evolution of NTN in Rel-19, including RF requirement, coexistence analysis and SAR requirement.

Specifically, vehicle-mounted devices with enhanced antenna gain, noise figure and/or Tx power should be considered in FR1 (e.g. for wideband) and in above 10 GHz (e.g. for broadband) for NTN. In order to make a comprehensive recommendation of UE parameters, both performance and cost are taken into consideration.

Key findings for the maximum achievable data rate are as follows:

- S-band in downlink: Receiver noise figure and antenna gain have a moderate influence. A noise figure similar to a smartphone (7 dB) seems to be sufficient for automotive terminals.

- S-band uplink: The throughput varies heavily, depending on the transmitter power and the antenna gain. To maximize throughput of automotive terminals, a higher transmit power > 23 dBm and antenna gain above 3 dBi is recommended.
- Ka-band downlink: Data rates vary strongly with the UE antenna gain as well as with the noise figure. Nevertheless, the beneficial higher gains and lower noise figures would result in bigger form factors and slightly higher energy consumption.
- Ka-Band uplink: The achievable data rate strongly varies with the number of available bandwidth (in terms of PRBs). Additionally, due to the interference limitation, the uplink throughput only varies moderately with the transmit power and antenna gain. A smaller transmit power < 5 W is sufficient, resulting in less expensive Ka-band antenna arrays (e.g. 25 dBi) and smaller form factor.

A Space-to-Earth communication link is subject to high losses, with free-space path loss accounting for the largest losses. To enable robust signal transmission with this high path attenuation, in addition to transceiver amplifiers, the properties of the associated antennas are also essential.

Unfortunately, the theoretical values for the maximum antenna gain cannot be achieved in practice due to additional requirements for the antenna, such as frequency, bandwidth, and size. Antenna gain requirements therefore have an impact on the antenna size, the complexity and the associated manufacturing effort as well as the performance in terms of radiation and frequency.

Based on the above analysis, the recommended antenna parameters are as follows, according to the Liaison Statement from 5GAA to 3GPP in RP-232733:

Table 16 Recommended antenna parameters

Band	DL	UL	Notes
S/L-band	NF = 7dB Max. Gain, boresight of main lobe = 0 and 3 dBi	Tx Power: PC3 (23 dBm) and PC2 (26 dBm) Max. Gain, boresight of main lobe = 0 and 3dBi	At LEO-600
Ka-Band	NF = 4 and 6 dB Min. Gain and Max. Gain, boresight of main lobe = 25 and 31 dBi	Tx power: 37 dBm and 38.5 dBm Min. Gain and Max. Gain, boresight of main lobe = 25 and 31 dBi Min. EIRP and Max. EIRP boresight of main lobe = 32 dBW and 39.5 dBW	Flat antennas with beamforming have been considered, different from VSAT, assuming a new satellite EIRP density of 16 dBW/MHz at LEO-600; UE antennas temperature 150 K.

For S/L-band DL, with a noise figure of 7 dB and depending on the maximum gain, boresight at lobe (0 or 3 dBi) and PRBs between 25-106, between 10.44 and 51.03 Mbps data rate are achievable.

For S/L-band UL, with a TX power between 23-26 dBm, a max. gain boresight between 0-3dBi and PRB between 1-106, up to 3.51 Mbps data rate are achievable.

For Ka-band, depending on the noise figures, the max. antenna gain and the PRB, up to 223 Mbps for DL and 475 Mbps UL are achievable.

Finally, spectrum availability is one of the most important preconditions for successful deployment of satellite connectivity. Two organizations play a pivotal role for spectrum allocation. ITU is responsible for the current allocation of frequencies to Mobile Satellite Services and Fixed Satellite Services in different regions as well as identification of applications (such as IMT). One of the key challenges regarding FSS is that automotive usage is defined as land Earth Stations in Motion (land-ESIM) type of service and is recognized as strictly country-specific nature of land-ESIMs, thus leaving the licensing of such systems to each individual country.

From 3GPP Rel-17 onwards, 3GPP has defined operating bands for NTN in MSS/FSS allocations. In Rel-17, bands were defined in L-band (1.6 GHz) and S-band (2 GHz). In Rel-18, operating bands in Ka-band (20/30 GHz) were added.

From the above envelope, and considering the available ITU and 3GPP frequencies, a number of possible solutions can be considered for the deployment of NTN systems:

- Scenario 1: "Satellite-to-legacy-user-equipment" in IMT-only bands using 3GPP technologies such as LTE or NR (UEs do not use/need any optimizations).
- Scenario 2: "Satellite-to-NTN-user-equipment" in MSS bands (S- and L-bands), requiring at least 3GPP Rel-17 UEs.
- Scenario 3: "Satellite-to-NTN-user equipment" in FSS bands (Ka-band), requiring at least 3GPP Rel-17 UEs.

Taking all these assumptions into consideration, the following key messages can be derived:

1. The overwhelming majority of use cases do only need narrowband or wideband data rates. From 5GAA's point of view, some key elements must be combined to maximize the impact of NTN and the benefit for the mobile customers.
    a. Satellite connectivity must be based on global mobile telecommunication standards to enable interworking with terrestrial networks.
    b. The so-called FR1 frequencies between 410 MHz and 7.125 MHz, typically used for LTE and NR TN and the S/L frequency bands are preferable from

the automotive industries point of view, because the existing antennas and user terminals can be used with no or just minor modifications. This would mean that millions of customers could benefit from NTN rather instantly.

c. Deploying the necessary satellite constellations in the Low-Earth Orbit will help to provide the best link budgets and consequently open up NTN to increase the number of customers, ultimately enabling wideband data rate services.

2. Only a small number of use cases require broadband data rates but this will grow in the future, making it necessary to focus on optimizing user terminal parameters and costs in FR2, and on facilitating widespread adoption of broadband NTN services by automotive customers.

Annex I: Glossary of terms

3GPP:	Third-Generation Partnership Project
5GAA:	5G Automotive Association
AD:	Automated Driving
ADAS:	Advanced Driver Assistance Systems
API:	Application Programming Interface
ARIB:	Association of Radio Industries and Businesses of Japan
AV:	Automated Vehicle
AVP:	Automated Valet Parking
C-SAE:	China Society of Automotive Engineers
C-V2X:	Cellular Vehicle-to-Everything Communication
CACC:	Cooperative Adaptive Cruise Control
CAICV:	China Industry Innovation Alliance for the Intelligent and Connected Vehicle
CHO:	Conditional handover
CEPT:	European Conference of Postal and Telecommunications Administrations
CPS:	Collective Perception Service
EMC:	Earth moving cell
ECID:	Enhanced Cell Identity
ERTRAC:	European Road Transport Research Advisory Council
ETSI:	European Telecommunication Standards Institute
EU:	European Union
FCC:	Federal Communications Commission
GNSS-RTK:	Global Navigation Satellite Systems Real Time Kinematic
HD:	High Definition
IMT-2020:	International Mobile Telecommunications 2020
ISO:	International Standard Organization
ITS:	Intelligent Transportation Systems
GSMA:	Global System for Mobile Communications
Kbps:	Kilobit per second
LEO:	Low Earth Orbiting
Mbps:	Megabits per second
MEC:	Mobile Edge Computing
MCS:	Maneuver Coordination Service
MHz:	Megahertz
MIC:	Ministry of Internal Affairs and Communications of Japan
MNO:	Mobile Network Operator
NCAP:	New Car Assessment Program
NGSO:	Non-Geo Stationary Orbit
NR:	5G New Radio
NTCAS:	National Technical Committee of Automotive Standardization of China
NTN:	Non-Terrestrial Networks
OEM:	Original Equipment Manufacturer

PRB: Physical Resource Blocks
PSM: Pedestrian Safety Message
OTDOA: Observed Time Difference Of Arrival
PSAP: Public Safety Answering Points
QoS: Quality of Services
RAT: Radio Access Technology
RAN: Radio Access Network
SAE: Society of Automotive Engineers of United States
SatComs: Satellite Communications
SDO: Standard Development Organization
SLRs: Service Level Requirements
SSB: Synchronization Signal Block
SSO: Standard Setting Organization
ToD: Tele-operated Driving
TR: Technical Report
TSG: Technical Specification Groups
URSP: User Route Selection Policy
V2I: Vehicle-to-Infrastructure Communication
V2N: Vehicle-to-Network Communication
V2P: Vehicle-to-Pedestrian Communication
V2V: Vehicle-to-Vehicle Communication
V2X: Vehicle-to-Everything Communication
VAM: VRU Awareness Message
VDA: German Association of Automotive Industry
VRU: Vulnerable Road User

Annex II: References

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