SATis5

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Satellite is 5G

SATis5 Whitepaper

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SATis5 Project Partners:

ESA Technical Officer: Maria Guta (ESA ESTEC)

Authors: Marius Corici (Fraunhofer FOKUS), Konstantinos Liolis, Christos Politis, Alexander Geurtz (SES), Joe Cahill, Shane Bunyan (ST Engineering iDirect), Thomas Schlichter (Fraunhofer IIS), Florian Völk (Bundeswehr University Munich), Adam Kapovits (Eurescom GmbH)

Contact: marius-iulian.corici@fokus.fraunhofer.de

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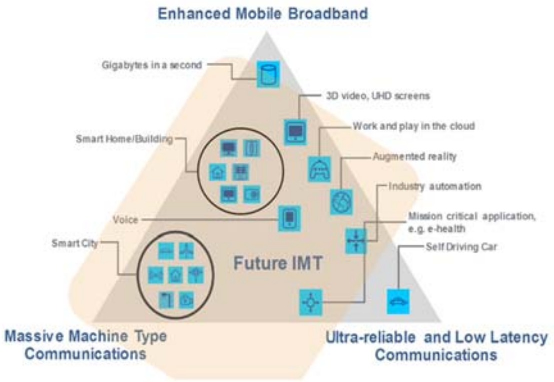
Executive Summary: Integrating Satellite is What is Needed for Many 5G Use Cases

To support the broadest range of use cases, both global and local network markets with very different requirements, 5G needs to integrate within a comprehensive system of all available communication technologies, exploiting their particular strengths and values, next to the New Radio. Satellite networks are among the most mature communication technologies having specific advantages in geographically distributed and dynamic networks. They provide highly efficient, effective and expedient network deployments leveraging their intrinsic advantages in broadcasting capabilities, global coverage, reduced reliance on terrestrial infrastructure and high security.

Exploiting these specific features as part of a complete 5G system, many use cases can be better and more rapidly served using an integrated 5G satellite-terrestrial network rather than relying on terrestrial only solutions. These include providing communication services to remote areas and also to rural and dense urban environments like on-premise local networks, content distribution, content acquisition, highly distributed IoT networks and private mobile and nomadic network deployments.

The SATis5 satellite-terrestrial Proof of Concept (PoC) testbed has validated the use of satellite as a means of connectivity in these use cases providing valuable results and insight into what satellite and terrestrial network convergence can offer and is capable of today. Through the deployment of a significant number of edge nodes – each with its own specific focus and customization – SATis5 demonstrated that satellite networks should be considered as part of the 5G use case deployments. Satellite communication is mature and ready for this challenge.



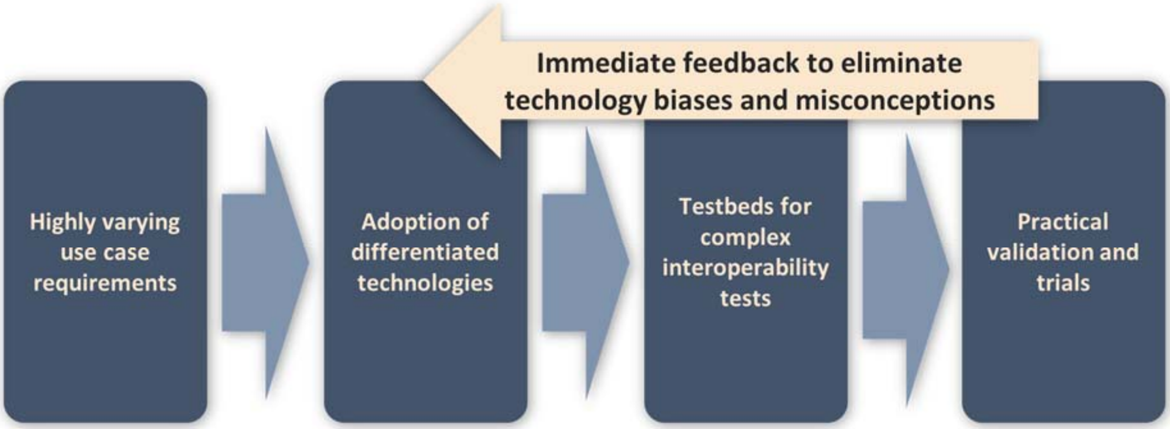
Area of use cases potentially better served with convergent Satellite-Terrestrial 5G

The 5G Challenge: High Level of Complexity

The fifth generation of mobile technology (5G) promises to fundamentally change how consumers and businesses communicate, paving the way for new use cases that capitalize on the speed, capacity, latency and flexibility that 5G offers. The 5G revolution is already underway in several markets. Several vertical sectors, including automotive, e-Health, energy, public safety, defence, entertainment and manufacturing have identified use cases in which they plan to leverage 5G capabilities to meet their requirements.

These verticals often have different and more demanding requirements on the network compared to traditional voice and mobile broadband services. They also require the privacy and security of their data and increased service reliability. 5G caters for these requirements through network slicing – an allocation and dedication of resources to logical networks, and isolation of those logical networks.

No single technology can meet the aggregated requirements presented by these verticals; furthermore, not all of the planned network capabilities will be required for every 5G application at the same time. It is also understood that network operators prefer single technology solutions from a simplicity and cost of operation perspective; however, single technology solutions rarely offer the best performance in the most economical way and do not necessarily meet all requirements.



The Challenge: Intense complexity in implementing the use case variation

Use cases demand end-to-end solutions from 5G, including a mix of technologies such as communication terminals, access networks, transport and core network, virtualization solutions and applications. The network characteristics selection depends on the capacity needed, the deployment time required and the approach concerning network management, being localised or centralised. As a result, 5G is a highly complex environment, with technology and solution choices having far reaching, but not necessarily obvious implications regarding overall performance.

A comprehensive testbed including all necessary technologies with potential options offers the most realistic environment for the functional validation and performance evaluation in the specific use cases. Such a testbed provides the fundament for the necessary technology interoperability tests, covering standard functionality, gaining an understanding and insight, enabling the acquisition of crucial hands-on training and experience, as well as demonstrations. In order to address all potential technologies in its technology mix, satellite solutions should also be included.

The practical trialling and testing of the different technologies in realistic environments give the possibility to understand and evaluate the performance and usability of existing and new services and applications. 5G considers a very large number of key performance indicators in general, but for almost any particular service and application only a subset is required, thus offering the opportunity to consider and include more than one technology in the delivery of that service and to improve the end-to-end system performance.

Benefits: Satellite Answers to the 5G Challenges

Unlike previous generations, 5G requires a flexible technology framework able to support and combine (using hand-over and multi-connectivity) multiple access technologies that best respond to the ever-increasing requirements of the consumer markets regarding bandwidth and the massive connectivity required by mMTC/IoT. The technology must also be able to address critical service requirements from several vertical markets, such as transport, media, logistics, public safety, etc. This offers a unique opportunity for the satellite industry to expand its ecosystem by establishing itself in the global communications ecosystem and to benefit from a significant market renewal.

Satellites stand ready to support the 5G ecosystem with their unique attributes, including:

- Ubiquity: Satellite can provide high-speed capacity across the globe addressing needs like capacity augmentation inside geographic gaps, overspill to satellite when terrestrial links are congested, general global wide coverage, back-up/resilience for network fall back and especially communication during an emergency.
- Mobility: Satellite is the only readily available technology capable of providing connectivity anywhere at sea or air for moving platforms, planes, ships and trains.
- Broadcast/multicast: Satellite can efficiently deliver rich multimedia and other content across multiple sites simultaneously using multicast streams with information-centric network and content caching for local distribution.
- Security: Satellite networks can provide efficient solutions for secure, highly reliable, rapid and resilient deployment in challenging communication scenarios, such as emergency response.

Based on these unique satellite attributes, various organisations around the world have correctly recognised the key role of satellite in the 5G ecosystem. As an illustration, satellite has been included and anchored in the 5G roadmap of 3GPP: several relevant 3GPP SA and RAN study items have been successfully completed in 3GPP Release-15 and Release-16 already, and new relevant work items in the normative phase have been selected in both TSG SA and RAN for 3GPP Release-17.

Moreover, by leveraging their unique attributes, satellites can help ensure that the benefits of 5G are ubiquitous (not just limited to urban areas) and can help push common content to the edge of 5G networks so content can be delivered to mobile devices with minimal delay. Indeed, 5G based satellite networks will enable MNOs and telco operators to address markets that are currently difficult to serve and hence address crucial 5G challenges:

- Extend service coverage in currently un-served areas where the deployment of cellular networks is not economically viable;
- Address parts of population which are currently underserved;
- Ensure service continuity for users (anyone willing to benefit from 100% coverage in outdoor condition);
- Provide connectivity to mMTC/IoT devices to serve the needs of society and several industry verticals such as transport, logistics, utilities & mining industry (e.g.

5G Terrestrial – Satellite: Smarter Applications for Heterogeneous Communication Requirements

surveillance of remote infrastructures), public safety, e-agriculture;

- Provide connectivity service on board of moving platforms travelling through areas with partial service coverage (vessels, aircraft, trains and even buses);
- Enable the scale-up and scale down of network capacity to respond to traffic demand evolution; support seasonal or conjuncture overlay; enable offload network; allow segmented services upon required security or QoS criteria.

Satellite can provide significant contributions towards fulfilling 5G use case requirements for the following verticals:

- Media & Entertainment – provide broadband service with broadcast/ multicast via satellite to network edges in outdoor and directly to indoor environments.
- Transportation & Logistics, including automotive – satellite integrated with moving platforms such as airplanes, vessels, trains and buses to provide real time asset monitoring, rich multimedia, infotainment, Over-The-Air services, etc. For many of these cases, satellite is in an augmenting role to the insufficient terrestrial coverage.
- Extraction industries – providing connectivity to remote locations of oil & gas off shore platforms, mines, etc.
- Health – improve remote access and monitoring for patients, especially those furthest away from health facilities.

- Utilities (energy, water, waste) – improve the reach for critical infrastructure monitoring, environmental monitoring, emergency prediction, etc.
- Agro industry (agriculture, food processing) – As part of future food security, vast majority of industry is located outside of urban regions. Relevant example applications include broadband access, smart agriculture, remote monitoring, asset tracking, etc.
- Public safety – satellite connectivity for public safety communications, mission critical communications, emergency communications, etc. providing the means for immediate infrastructures deployment in the interest location.

5G Use Cases Enhanced with Satellite

- Improved reliability through alternative connectivity independent from terrestrial
- Providing backhaul for ultra-low latency services deployed at the network edge
- Mobile and nomadic network deployment use cases
- Enhanced and mesh IoT and multimedia use cases
- Global use cases
- Provide convergence with data processing and earth observation
- End-to-end secure / governmental use cases

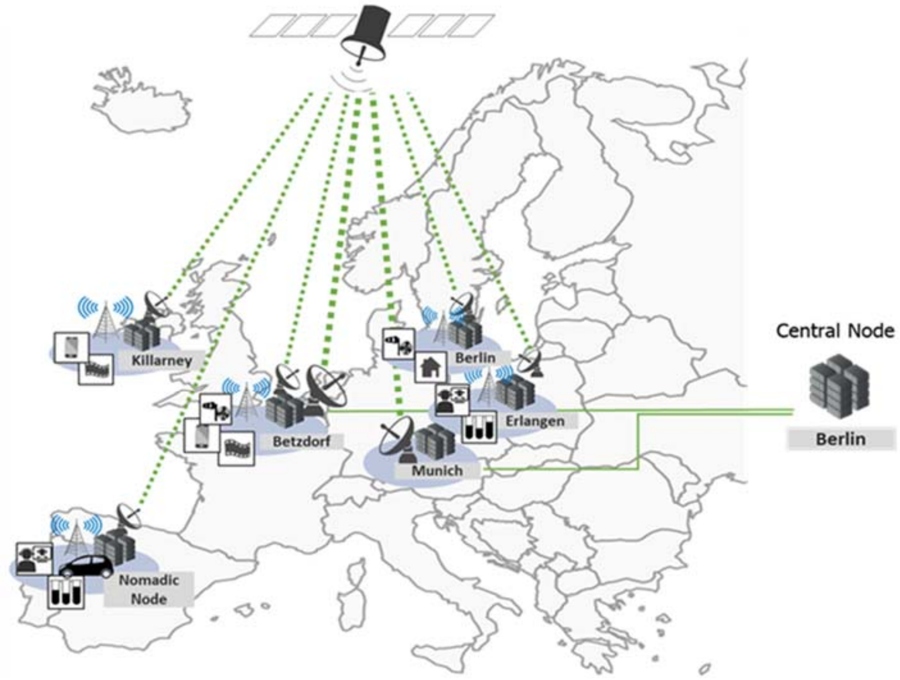
SATis5: Practical Proof-of Concept (PoC) Testbed

One of the key initiatives in satellite-terrestrial convergence as part of 5G is the SATis5 project. SATis5 corresponds to a comprehensive 5G PoC testbed integrating 5G terrestrial islands with satellite networks. It offers an infrastructure for testing terrestrial-satellite integration and identifying and verifying satellite technology advantages within 5G.

The SATis5 testbed includes two satellite hubs in Betzdorf and Munich each using different satellite ground segment equipment, and a large number of satellite connected nodes placed in different 5G trial locations (e.g. Berlin, Erlangen, Munich, Betzdorf, Killarney, Nomadic). While maintaining the convergence with the central nodes located in Berlin and in Betzdorf, each of these remote nodes had its own flavour of local use cases to address the specific local market needs and R&D activities.

As far as local access networks are concerned, SATis5 spans across 5G access networks, LTE, NB-IoT LTE and non-3GPP access such as 60 GHz WLAN, WiFi and LoRA. With this, practically all of the major technologies used in connecting local devices were tested, providing a comprehensive assessment of the capabilities of the satellite-terrestrial convergence.

Within SATis5, network level integration was implemented using 3GPP core network technologies. For managing the connection of the devices, the Fraunhofer FOKUS Open5GCore (www.open5Gcore.org) was used. Open5GCore is one of the most advanced prototypes of the 3GPP standard 5G core network architecture, including all of the major functionality required for 5G and 4G connectivity as well as interoperating with



SATis5 Testbed

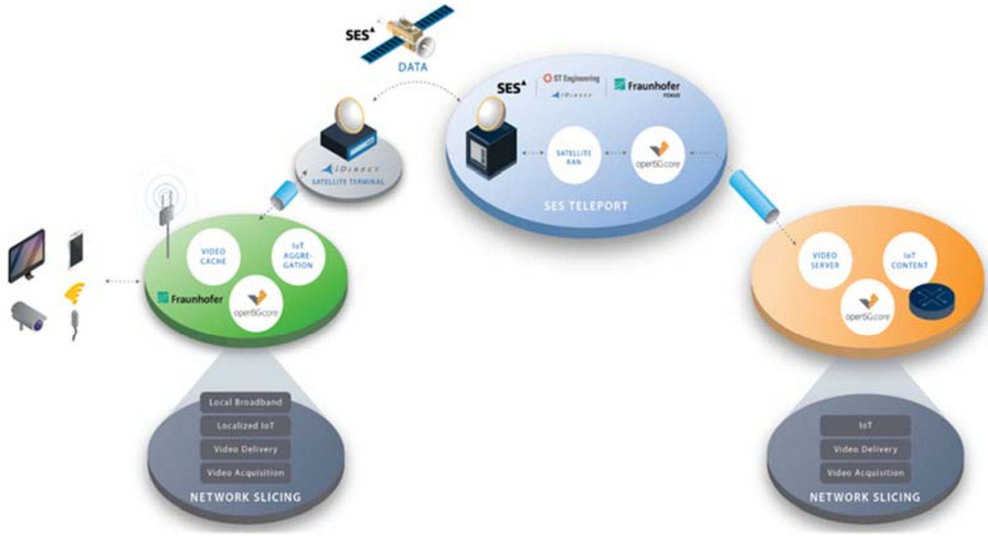
commercial 5G base stations (both standalone and non-standalone) and mobile phones. Open5GCore is based on a highly flexible architecture, which enabled its deployment in different types of edge-central split network slices addressing the specific use case needs of 5G connectivity and unleashing the specific characteristics of satellite networks for both the direct and the backhaul connectivity.

As the world's leading satellite operator with over 70 satellites in two different orbits, Geostationary Orbit (GEO) and Medium Earth Orbit (MEO), SES (www.ses.com) powered the SaTis5 testbed space segment with its ASTRA 2F GEO satellite (28.2°E), delivered seamless connectivity between the hub platforms (Betzdorf, Munich) and the various remote locations (Berlin, Killarney, Betzdorf, Erlangen, Munich, Nomadic). SES provided end-to-end managed services to actively enable the SATis5 over-the-air validation tests and demonstrations. For example, SES provided ASTRA 2F GEO Ku-band Occasional Use (OU) satellite capacity for more than 190 days amounting to more than 190 MHz of bandwidth for the various SATis5 over-the-air tests and demonstrations, including flagship events such as the Mobile World Congress (MWC), Fraunhofer FOKUS FUSECO Forum and the IEEE 5G World Forum.

The satellite network deployed at the SATis5 testbed was built using ST Engineering iDirect's satellite ground segment solutions (www.idirect.net). In particular, the ST Engineering iDirect's 5G-enabled Velocity™ Intelligent Gateway (IGW) system located at Betzdorf teleport and Newtec DIALOG™ system located at Munich teleport were employed both using satellite capacity provided by SES ASTRA 2F. ST Engineering iDirect's 5G-enabled satellite ground segment solution for the SATis5 testbed implements a variant of the architecture captured in ETSI TR 103 611 "Seamless integration of satellite and/or HAPS (High Altitude Platform Station) systems into 5G systems", specifically "Scenario A3 – Indirect mixed 3GPP NTN access with bent-pipe payload". Firstly, a standard 3GPP 5G core network is integrated in order to operate the control and user-plane functions of the satellite network. For the SATis5 testbed this is an instance of Open5GCore. Once this is in place, the hub-side of the existing satellite network is modified to comply with standard 3GPP interfaces, using N2 and N3 interfaces to communicate with the standard 5G core network. The satellite terminal is also modified to communicate with Open5GCore via the 5G standard N1 interface. This results in a 5G-enabled satellite terminal presenting itself as a 5G UE to the 5G core network and the satellite hub-side network presenting itself as a standard gNB. This new satellite RAN (SatRAN) gNB connects with the satellite 5G core network, Open5GCore, on the network side and while continuing to use the proven and efficient waveform of the iDirect satellite terminal over the satellite radio. It is also important to highlight that the Open5GCore, a standard 3GPP 5G core network, is unmodified and all modifications are incorporated in the 5G-enabled satellite network. Together, the modified satellite terminal, SatRAN and standard 3GPP 5G core network provide the satellite network connectivity. This architectural approach allows for easy integration with the end-to-end mobile network as they have a common look-and-feel as both, Terrestrial and Satellite networks, are using an instance of the Open5GCore network. The successful integration of the Open5GCore network was a first of its kind for the adoption of a 5G core network into the satellite network when demonstrated in Barcelona at MWC 2019.

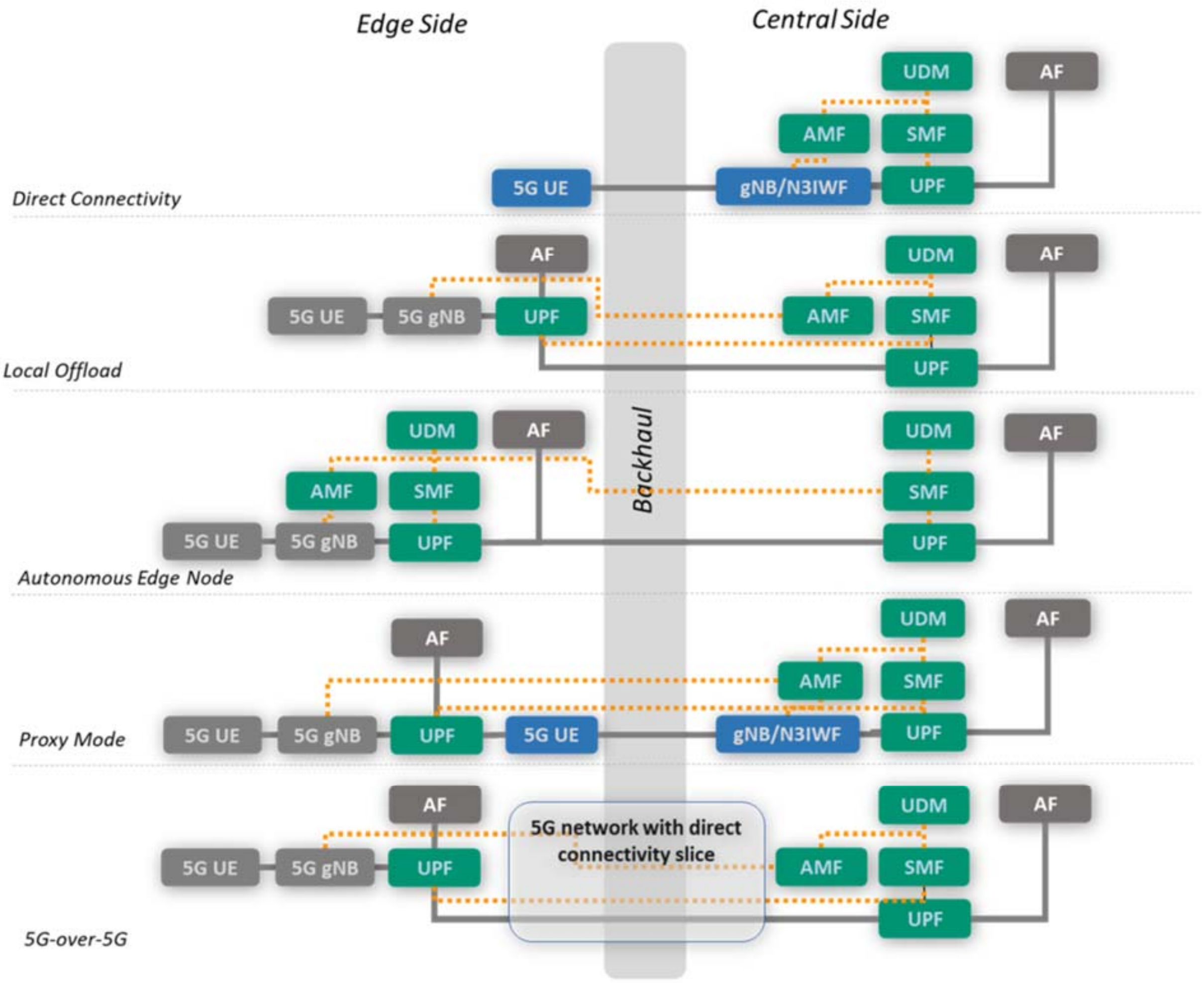
To prove the convergence within the 5G system between the terrestrial and the satellite technologies, a highly distributed network was deployed as an independent infrastructure using the satellite network to connect the multiple remote nodes. It also represents a best-practices example of how highly distributed non-public networks can be deployed to address the needs of global use cases.

The distributed network was used for the testing and validation of a large set of prominent use cases including eMBB and mMTC, addressing large bandwidth requirements, a large number of devices as well as ultra-low latency communication by



End-to-end validation environment for a static deployment scenario the deployment of a large number of network functions on-premise at use case location as extensions to the remote node. The use cases were divided into two types – static and nomadic.

The different use cases were integrated and demonstrated in parallel by using customized network slices in the terrestrial and satellite domains as well as across both. The slices included the customization towards the specific local access network and devices. The devices span from communicating phones, video cameras, display devices, different sensors or even the satellite modems

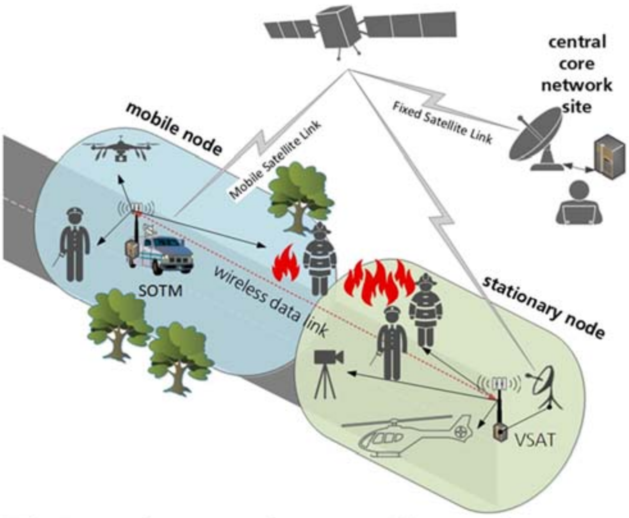


SATis5 Slice Models for Edge-Central Split

themselves. Furthermore, the slices were designed with different edge-central split models for enabling local and private data paths, end-to-end data paths as well as different trust levels within the control plane. Through this, a best practice was established on how to build and manage a highly complex system as expected by the 5G networks.

For the static deployment scenario, five different network slices were deployed addressing different use cases such as local broadband communication, localized IoT with central aggregation, video delivery to a large number of edge nodes and video acquisition. All of these slices were running on top of a 5G-enabled satellite network where a standard 3GPP 5G core network (another instance of Open5GCore) was seamlessly integrated within the satellite network, allowing easy integration with the end-to-end telecom system. The different slices have proven to have complementary communication characteristics enabling them to share the same satellite communication resources without negatively affecting their end-to-end service.

In addition, SATis5 deployed a nomadic 5G network using a van (www.unibw.de/satcom), which enabled the establishment of local networks on behalf of the public protection and disaster relief (PPDR) use cases. Using the same slices for video acquisition, video delivery and IoT, the SATis5 5G nomadic network is able to provide comprehensive use cases addressing the different operational requirements with local command centres as well as with central node sites. The four key



SATis5 end-to-end nomadic environment

requirements for such a nomadic PPDR deployment are:

a) Fast network deployment is necessary to minimize operational constraints. Lightweight and small-sized equipment for easy transport and self-set-up is required;

b) Broadband and secure communication facilities to support the accurate assessment of the situation;

c) The network needs a flexible topology and traffic demand; and

d) Availability of wireless communications is essential: *"It needs to work first time, every time.*"

The same technology could also be used for additional use cases where networks can be dynamically deployed for short durations of time such as live TV video transmissions, logistics of public events (e.g. tours of concerts), construction sites, ambulance response and dynamic deployment of health testing centres and hospitals.

The SATis5 testbed acted as a leader for demonstrating the 5G satellite-terrestrial convergence. It provided a best-practice implementation and easy to understand demonstration of 5G technologies, paving the way for technology acceptance within the communication networks decision-makers.

Moreover, SATis5 addressed PoC laboratory simulations of the 5G Non-Terrestrial Network (NTN) direct access waveform based on the 5G New Radio (NR) air interface as currently specified within Release 17. These in-lab radio simulations were performed by Fraunhofer IIS (www.iis.fraunhofer.de) and showed the technical viability of using the 5G NR waveform over transparent satellites. Because of the OFDM based waveform used in 5G NR and the higher peak to average power ratio (PAPR), the impact of the non-linearity of the high power amplifiers used at the satellite downlink needs further analysis. Therefore, two models for currently deployed HPAs were simulated: Travelling Wave Tube Amplifier (TWTA) and Solid State Power Amplifier (SSPA). The results showed that the application of 3GPP Release-17 RAN for NTN scenarios with transparent satellites is feasible but needs careful planning of the required output back-off and the achievable throughput for the specific satellite architecture

Use Case	Description	Significant results	Conclusions
Video Delivery	Downlink distribution of large amounts of live and stored data	Delivery time: • First video – 788ms delay • Next videos – 3ms delay	Very high efficiency using the satellite broadcasting and edge caching
Video Acquisition	Live content uplink from dynamic locations	End-to-end delay: 1900ms from which: • Local access: 12ms • Transcoding: 1428ms • SatCom: 290ms	Very stable uplink at any location
NB-IoT	3GPP IoT data uplink	Non-time critical data uplink with: • 287ms delay • 0.02% packet loss	Highly reliable support for massive IoT
LoRA	Non-3GPP data uplink	Non-time critical non-3GPP data uplink with 290ms delay	Easy integration of non-3GPP
5G core network integration	Satellite network operated as a 5G network	Demonstrated capability to leverage off-the-shelf 5G core network capabilities to manage a satellite network	Low overhead integration of satellite in existing telco networks; Opens up satellite industry to 3GPP ecosystem.
Nomadic node	Movable connectivity islands with satellite backhaul	Instant network availability at use case location	Easy to initiate, cost effective connectivity when and wherever needed
Multi-orbit satellite	GEO/MEO multi-orbit integrated satellite communication	Demonstrated seamless traffic handover between multi-orbit systems	Integrated multi-orbit satellite systems will provide greater service flexibility

During the over-the-air tests, GEO Ku-band satellite link capacity was used over satellite ASTRA 2F (28.2°E). It has proven to be highly stable and appropriately dimensioned to the specific frequency allocation. Very low jitter and packet loss were observed, practically being equivalent to a cable connection, even though weather conditions highly varied during the different test campaigns. For this reason, capacity related measurements proved less significant: the link was there and it consistently had the expected capacity to transmit the expected data without any issues. No significant operational changes were required to adjust the data rates of the different communications.

System Procedures	**Description**	**Significant results (mean)**	**Conclusions**
5G Registration	Initial device authentication, authorization and access control	Duration: 1369ms	Larger delay, not significant overall
5G PDU Establishment	Establishment of data sessions	Duration: 1415ms	
PFCP messages	Control-data plane communication	Duration: 630ms	
NB-IoT LTE attachment	Attachment of sensor devices	Duration of edge only attachment: 2123ms	Highly reliable support for massive IoT
NB-IoT LTE data exchange	End-to-end data path exchange	Duration: 287ms Packet loss: 0.02%	
Slice deployment	End-to-end virtual machines deployment across satellite link	Duration of deployment: • Virtual machines with edge orchestrator – 106s • Virtual machines and local mmWave backhaul – 134s • Virtual machines and satellite backhaul – 161s • Containers with satellite backhaul – 0.72s	Edge network management is needed for both the 5G systems with terrestrial and satellite backhaul

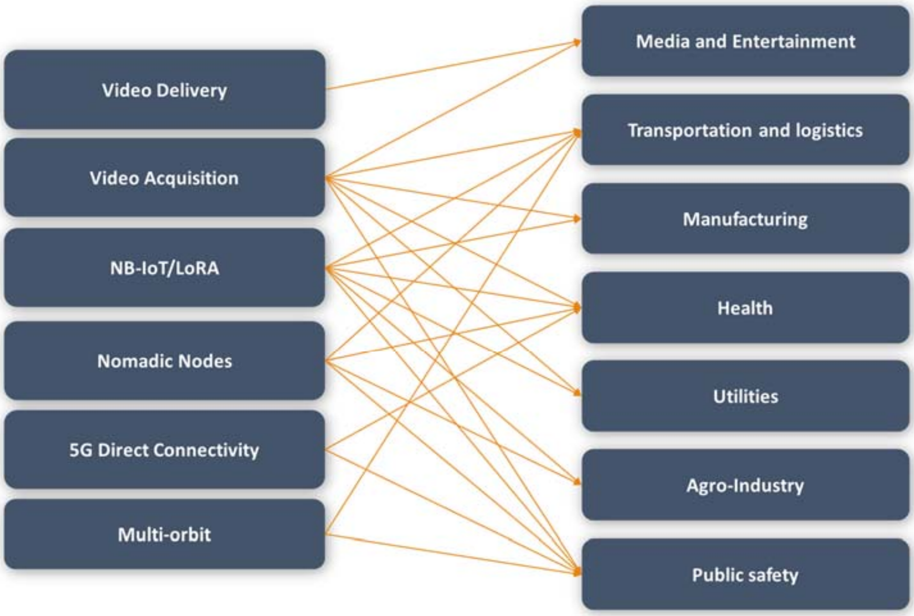
System Procedures	Description	Significant results (mean)	Conclusions
Satellite link spectral efficiency	Measure of the satellite transmission efficiency	• Outbound (FWD) carrier efficiency = 2.46 bits/Hz • Inbound (RTN) carrier efficiency= 1.43 bits/Hz (*)	Measurements were well within acceptable range for assigned capacity and configuration

* NOTE: The spectral efficiency figures above correspond to the following system configuration:
ST Engineering iDirect's DVB-S2 satellite system operated on the SES's ASTRA 2F GEO satellite (28.8°E) with remote VSAT sites using 1.2m antennas, 4W BUCs, MODCOD of 16APSK-8/9 on the DVB-S2 outbound (FWD) link and 8PSK-3/4 on the TDMA inbound (RTN) link, and carrier roll-off factor of 20% .

Furthermore, during the use case validation, the different operations needed at the network level were tested and evaluated. For all these measurements, the satellite network had a round trip time of 558ms. This delay will be lower when using lower orbit satellite networks. From the perspective of the 3GPP related procedures, there was no specific need to adapt the core network functionality to cope with satellite communication except some delay related configurations.

With this consideration, the network functions that were specifically designed for terrestrial core networks can be easily ported to a satellite-terrestrial 5G convergent system requiring only configuration changes and not functionality enhancements. More than this, the core networks may be further extended to use the reliable satellite downlink channel and the broadcasting and security capabilities to further reduce the complexity of the current procedures and thus to simplify the communication functionality.

The measured results have proven that a converged satellite-terrestrial 5G system will function for a large number of use cases. The different use cases are fundamental building blocks in establishing the networks required by different verticals. In the following steps, while moving onto pilots, the SATis5 testbed will concentrate on the configuration and customization of these use case groups to address the needs of the different verticals.



Use case elements for different verticals

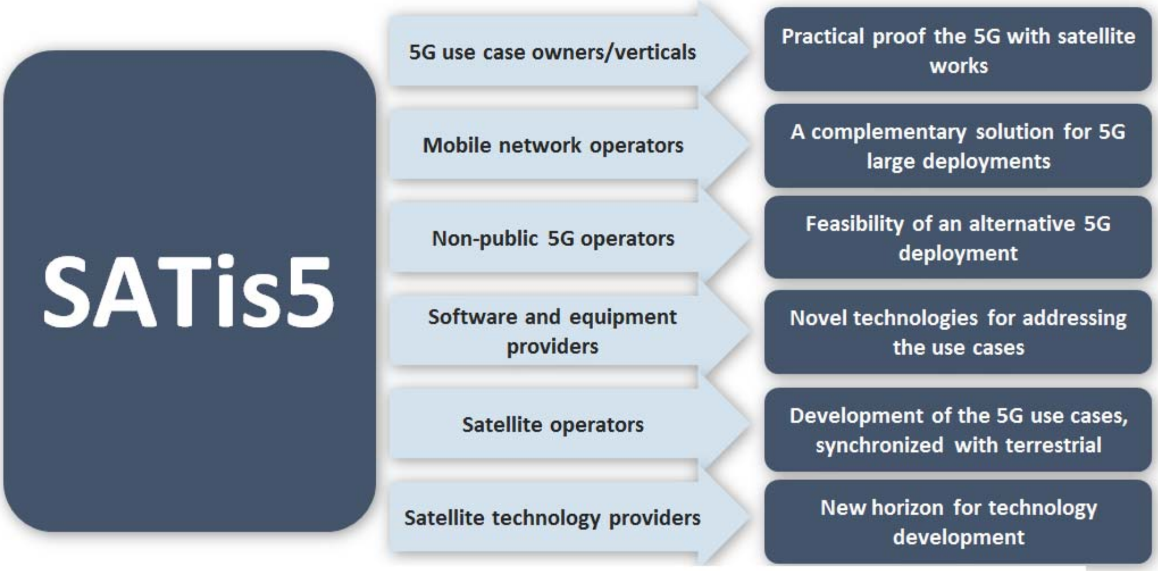
How You Could Benefit from SATis5

SATis5 provides a comprehensive testbed infrastructure deployed across Europe, integrating satellite and terrestrial 5G communication technologies within an end-to-end convergent system. The testbed integrates a broad set of technologies and acts as a blueprint reference implementation for 5G satellite convergence. It can be used immediately for different goals:

- Publicity and awareness creation – SATis5 provides a live infrastructure able to convince different decision-makers regarding the advantages of adopting a certain technology and the further development of use cases;
- Knowledge transfer – for better understanding of the 5G KPIs, of the use cases and of the role of satellite networks within 5G, SATis5 provides hands-on experience by using directly the existing infrastructure or by replicating and tailoring it for certain customer or use case requirements
- Enhancing own R&D activities – SATis5 testbed is easy to customize and to extend

with new components and services, providing a comprehensive, up-to-date and standard-based 5G environment enabling the jump-starting of the R&D related activities, immediate integration and demonstration of third party new concepts, validation of prototypes or products or services

- Evaluating the role of 5G with satellite – before making a decision which 5G network to acquire and which technologies should be incorporated, SATis5 is offering a generic vendor-open environment for testing and evaluating the technologies and to enable a hands-on practical definition of the specific vendor selection requirements
- Support 5G SatCom upstream and downstream stakeholders – SATis5 provides means to validate innovative 5G technological solutions in collaboration with several industrial sectors and 5G verticals
- Support creation of innovative 5G ecosystems to deliver socio-economic returns which is accomplished by leveraging on investments undertaken to validate the development of innovative business models and value chains for satellite, in collaboration with terrestrial and 5G verticals stakeholders



How to benefit from SATis5

Next Steps in Satellite Convergence

Premise	Strategic Recommendation
SATis5 has validated the 5G KPIs	Provide optimizations towards better usage of satellite network characteristics
	Focus the testbed towards vertical use case pilots
	Extend the testbed to a global 5G testbed by adding new locations
	Increase the product oriented capabilities – development of an MVP, integration with automation and management, etc.
	Integrate the non-terrestrial-network 5G new radio as access technology
Adoption of 5G in satellite network	The adoption of standard network elements enables simplified integration of satellite with terrestrial networks. It also exposes satellite to the 3GPP ecosystem, opening the door for use of third-party applications, such as terrestrial billing systems. Further integration is possible now that the initial integration steps have been successfully completed.
Flexible satellite payloads	Developing new and innovative use cases that leverage the next generation of satellite (mega-)constellations that have flexible payloads and dynamic resources management
Share of lower orbit satellite will increase	Spreading functionalities across different spacecraft/constellations for a differentiated service to achieve more capacity with low delay
5G technologies become available for local networks and carriers	Develop new use cases which require mobile and temporary/nomadic/portable deployments
	Use and join the 3GPP ecosystem (not only network level, but also management, OAM, transport). Requires continuous participation
Multimedia and IoT market is increasing	Deep integration of the satellite and terrestrial broadcast systems
	Expand the wide area broadcasting capabilities

Next Steps in Satellite Convergence

Premise	**Strategic Recommendation**
	Interference mitigation for large number of terminals
Edge and Cloud Computing	Deep integration of satellite features with edge network to improve the service offering at the edge
	Increase system flexibility for a reduced CAPEX and OPEX
Data Driven Network Management	Further integration with standard management and orchestration systems
	Furthering the AI/ML usage bottom up aligned with edge management
	Convergence with Earth Observation services for an extended data acquisition
Optical space backhauling	Deep integration of an optical space backhaul as part of a global private and secure 5G network infrastructures
Security	Building a security and trust model to allow terrestrial and satellite network operators to interwork more easily
Standardisation	Further work on the standards based seamless integration of satellite into 5G terrestrial networks

Summary and Conclusions

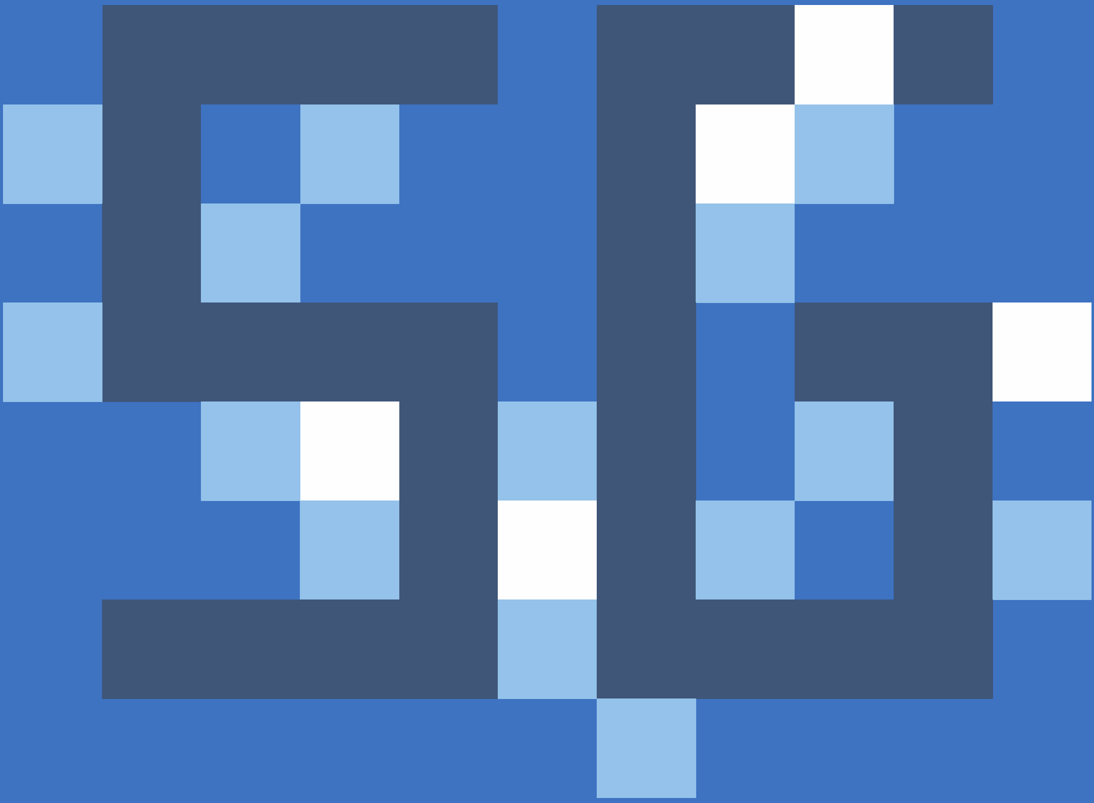
Based on the results obtained with the SATis5 testbed it is clear that currently available satellite communication can greatly contribute to the 5G ecosystem. Considering its unique characteristics, satellite communication provides a large number of advantages and offers very useful unique features to address the requirements of verticals with minimum adaptation to the technology.

Comprehensive testbeds are necessary to verify the correct integration and evaluate the performance of new technologies in the technologically diverse 5G systems, as well as to validate their fit to address specific use case requirements. Testbeds enable stakeholders to validate use cases, evaluate their performance and obtain insight and understanding of gaps and complexities. SATis5 provided such a comprehensive testing environment for converged 5G satellite-terrestrial systems mirroring the current prototypes and practical developments and thus the SATis5 testbed is a first of its kind.

Based on the experience gained in understanding the issues for 5G systems and considering the many aspects satellite can usefully contribute to, the SATis5 project team expects that satellite communication will play a significant role in 5G.

We expect that first adopters embracing the idea of integrating satellite in 5G services delivery will enjoy a competitive advantage in the long run. By using the SATis5 testbed open platform the different technology stake-holders can build upon the momentum created by SATis5 and take forward to exploit and maximise the potential of satellite-terrestrial 5G network integration by pursuing the many research directions SATis5 has identified.

SATis5 has taken the first steps and has practically demonstrated the convergence between the satellite and terrestrial networks in the 5G ecosystem. Building upon the SATis5 work, there is a number of identified R&D and standardization activities to further enhance the convergence and provide additional benefits for 5G networks. These will be part of the next phases of the standardization in 3GPP and could easily be integrated into the existing testbed.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