



## **ARTES 4.0 Strategic Programme Line “Space for 5G/6G and Sustainable Connectivity”**

### **Work Plan 2023**

#### **Introduction**

The complete Work Plan 2023 is presented in Annex 1 in tabular form and in detailed form in Annex 2.

#### **5G Work Plan: 5G Essential**

The 5G Essential element, i.e. the 5G Work Plan, is designed to support industry in advanced technology developments that are key for the integration of satellite with terrestrial networks. These are considered essential technology developments that require ESA's intervention to get industry started to develop these urgent 5G-related satcom elements.

The validation of the developments, later on referred as '5G Hub Over-the-Air Validation', is also supported with testing over either existing space infrastructure or a new one. In the latter case, new space infrastructure will be developed as part of the 5G Essential element.



*Figure 1: Developments to Validations approach*

Within this element, several categories where ESA intervention is required have been identified. Each category corresponds to one or more activities to be placed with industry, as follows.

#### **Standardisation/Licensing/Regulatory Support'**

Standardisation is a strategic step that will be supported to ensure future compatibility and interoperability of technologies. Great efforts have already been made over the past years, allowing the recognition of 5G New Radio (NR) Non-Terrestrial Network (NTN) within 3GPP. Additional efforts to support the standardisation of satellite 5G component are foreseen, which will be implemented as part of ARTES Future Preparation activities.

**5G System Infrastructure Study'**

All technologies and system architectural options that may be the basis for European and global next-generation 5G infrastructure will be identified. That analysis will be used to determine technology readiness levels and to identify gaps that industry needs to address. The study will focus on three key areas: the overall system, the space segment and the ground segment.

**5G'5G New Radio - Radio Access Network (NR-RAN) Developments'**

The development of Radio Access Network (RAN) techniques and protocols compliant with the recently released 5G standard is crucial and will be supported to enable the direct access via satellite to the terrestrial communication networks and therefore provide full integration and compatibility.

**5G Core Network Developments**

The interoperability of satellite networks with terrestrial 5G core networks is of paramount importance to guarantee full network convergence and a set of development activities are envisaged here.

In parallel, to enable inter-operability with other satellite non-5G networks, the development of Non-3GPP Interworking Functions will also be initiated to demonstrate additional integration with 5G core networks.

**5G Testbed Infrastructure**

Adequate infrastructure is required to test the future new 5G network functions, protocols and security for 5G satellite nodes. Additional effort shall be initiated with regards to solutions for potential security vulnerabilities introduced by the adoption of 5G NTN features.

**5G Universal Satellite-Terrestrial User Equipment (UE)**

This category aims at supporting industry in developing universal (i.e., satellite-terrestrial), efficient and cost-effective user terminals. To achieve the required economies of scale, it is important to equip industry with essential user equipment building blocks compliant with the standards.

Activities within this category will focus on developing engineering breadboards, a reference protocol stack and implementing required modification to existing user equipment to enable 5G satellite connectivity.

**5G Hub for Over-the-Air Validations'** There is a degree of scepticism regarding the integration of satellite with terrestrial network especially based on historical challenges with Mobile Network Operators (MNO).

Promotion and validation are fundamental to overcome such perceptions. As explained above, the 5G SPL introduces a development to validation approach. It aims at validating over-the-air the developments undertaken through the categories previously described in realistic conditions, namely, using existing space infrastructure and therefore foster the adoption of 5G satellite technologies.

As part of the promotion of validation activities, ESA intends to build a 5G Hub in ECSAT. The 5G Hub will enable stakeholders from different sectors to collaborate, develop and test new 5G solutions. It will act as a catalyst for the proliferation communities working on 5G activities across the ESA Member States, facilitating their engagement and collaboration with one another.

**5G/6G Satellite Proof-of-Concept Missions**

Complementary to the 5G Hub over-the-air validations block, which utilises existing space infrastructure for validations, a set of 5G/6G satellite proof of concepts missions will be proposed

to develop and validate new functionality requiring new space infrastructure. This is the case, for example, to demonstrate the functionalities of a 5G gNodeB in space as well as a direct 5G broadband access from LEO to very small aperture mobile terminals (proposed in the 5G SPL Work Plan 2021), and the 6G Satellite Precursor proposed in this Work Plan 2023.

### **Beyond 5G (B5G) and 6G**

The 5G and Beyond roadmap is rapidly evolving alongside the 3GPP standardisation process, with Beyond 5G (B5G) to be specified in the next releases (rel.18 to 20) and 6G after that (rel. 21 upwards). With the establishment of satellite firmly part of rel. 17 and beyond, it is important to start identifying essential building blocks to support and align to subsequent 3GPP releases B5G and 6G. For this reason, this new category has been added to the 5G Work Plan classification to prepare next stages of development and identify early building blocks required.

### **5G Work Plan Implementation**

All the presented categories aim at fostering the integration of satellite with terrestrial networks and are considered essential technology developments to stimulate and support industry. The Executive proposes the implementation of the 5G Essential activities (i.e. the Work Plan) under the 5G SPL, following the Specific Implementing Rules for the ARTES 4.0 Generic Programme Line “Core Competitiveness”, Component A “Advanced Technology”.

Activities will be issued according to the schedule published (and regularly updated) on the ESA ARTES web site: <https://artes.esa.int/advanced-technology> (ARTES 4.0 Planned Activities Summary Table).

**ANNEX 1: SUMMARY TABLE FOR ARTES 5G/6G ACTIVITIES IN THE WORK PLAN 2023**

Activity Ref.	Title	Cost	Classification	Cost (K€) (Baseline)	Cost (K€) (Request)	Proc. Policy	Planned for
<b>SPACE SYSTEMS FOR 5G ACTIVITIES</b>							
<b>5G.01 - STANDARDISATION / LICENSING / REGULATORY SUPPORT</b>							
<b>5G.02 - 5G SYSTEM INFRASTRUCTURE STUDY</b>							
5A.084	Study and demonstrator of HEO payload architecture for 5G-connected mobile services	750	B	750	0	C	Q2
<b>5G.03 - 5G NEW RADIO NTN FUNCTIONS/PROTOCOLS DEVELOPMENTS</b>							
3A.181	5G New Radio (NR) Non-Terrestrial Networks control plane demonstrator for NGSO constellations	400	B	400	0	C	Q2
<b>5G.04 - 5G CORE NETWORK DEVELOPMENTS</b>							
<b>5G.05 - 5G TESTBED INFRASTRUCTURE</b>							
5A.083	5G regenerative processor and associated system test-bed	4,000	B	4000	0	C	Q2
3A.182	Vehicle-to-everything (V2X) services demonstration over satellite	1500	B	1500	0	C	Q4
3A.183	NGSO simulator for 5G vehicle-to-everything (V2X)	500	B	500	0	C	Q1
<b>5G.06 - 5G UNIVERSAL SATELLITE-TERRESTRIAL USER EQUIPMENT (UE)</b>							
6B.119	Artificial intelligence/machine learning front-end module for satcom 5G/6G integrated access-backhaul transceivers	500	B	500	0	C	Q4
7C.082	Highly efficient 20 W S-band amplifier for 5G-connected cars	650	B	650	0	C	Q2
7C.084	5G automotive antenna prototype and demonstration	5,000	B	5000	0	C	Q3
<b>5G.07 - 5G HUB OVER-THE-AIR DEMONSTRATIONS</b>							
7C.086	End-to-end demonstration of 5G New Radio (NR) for future railway mobile communication systems	2,500	B	2500	0	C	Q3
<b>5G.08 - 5G SATELLITE PROOF-OF-CONCEPT MISSIONS</b>							
3E.019	Open reprogrammable space infrastructure testbed for beyond 5G (B5G) end-to-end solutions and services	3,000	B	3000	0	C	Q3
3E.011	6G satellite precursor	8,000	B	8000	0	C	Q1
<b>5G.09 - BEYOND 5G (B5G) AND 6G</b>							
3A.184	Beyond 5G (B5G) and 6G non-terrestrial networks edge computing satellites	1,200	B	1200	0	C	Q2
3A.185	Spectrum sharing techniques for Beyond 5G (B5G) and 6G 3D networks	2,500	B	2500	0	C	Q4
<b>TOTAL (K€)</b>		<b>30,500</b>		<b>30,500</b>			

## ANNEX 2

### **ARTES 5G/6G WORK PLAN 2023**

#### **DESCRIPTIONS OF ACTIVITIES**

Activity Ref.	Activity Title	Budget (kEuro)	Classification
5A.084	Study and demonstrator of HEO payload architecture for 5G-connected mobile services	750	B
<b>Objective:</b>	The objective of this activity is to demonstrate the suitability of HEO payloads for 5G-connected mobile services. Key parameter trade-offs like orbit optimisation, maximum achievable throughput shall be analysed. The study shall identify key enabling technologies to support 5G type of services on a regional coverage.		
<b>Targeted Improvements:</b>	<ul style="list-style-type: none"> <li>- Reduce the complexity and total cost of the required constellation to provide 5G services to mobile users via satellite.</li> <li>- Enable a simpler antenna on mobile platforms.</li> <li>- Identify enabling technologies for a HEO 5G system.</li> </ul>		
<b>Description:</b>	<p>Current and future LEO mega-constellations plan to launch tens of thousands of satellites to the sky. This will likely lead to a similar situation of orbit congestion that GEO has been facing for years. On the one hand, a LEO-based solution would require the user antenna to have tracking capabilities, with significant complexity and cost. On the other hand, the latency of a GEO system would be too high for 5G applications. In this context, systems based on highly elliptical orbits (HEO) may be of interest for 5G mobility applications, as the pros and cons of HEO orbits lay in between of those GEO and LEO provide. 5G main features are to provide higher throughput, increase security and reliability, and reduce the end-to-end latency. It is known that one of the technological challenges connected vehicles are facing is the need of a simple, compact antenna. A HEO system has the advantage of having the satellite right above the users during the operational window around the apogee. This requires minimum or no steering capabilities for the user antenna, leading to a rather simple terminal design. Therefore, a HEO a satellite-based system could be used to provide vehicle-to-network (V2N) connectivity and serve as a 5G backup network, with a simple user terminal antenna. Furthermore, there are only 3 satellites needed per HEO orbit to provide continuous connectivity, which is a significant reduction with respect to LEO-based solutions. However, the technology for HEO orbit is not as mature as for GEO or LEO. HEO multibeam systems face some challenges (e.g., rotation and zooming of beams) that are not relevant to GEO or LEO. Additionally, the spacecraft requires more demanding AOCS system that needs to be considered.</p> <p>In the proposed activity, a system-level assessments shall be carried out, where the key drivers of 5G mobile connectivity and HEO payloads are analysed and traded-off. Examples of these parameters are optimal orbit determination, maximum allowed system latency, operational frequency band, payload architecture, platform requirements, optimal antenna architecture and maximum achievable throughput, among others. Other parameters that need to be considered are: ITU regulations, PFD limits and safety of users on mobile platforms. The study shall be complemented with a representative testbed demonstrator where identified critical components and functionalities will be tested.</p>		
<b>Deliverables:</b>	Summary report and a representative testbed demonstrator with critical functionalities of the proposed HEO payload.		
<b>Estimated current TRL:</b>	3		
<b>Target TRL:</b>	5		
<b>Technology harmonised:</b>	No		
<b>Dependency:</b>	None		
<b>S/W Clause:</b>	Yes (standard IPR regime applies)		
<b>Service Domain:</b>	5		
<b>Technology Domain:</b>	06 - RF Systems, Payloads and Technologies		

Activity Ref.	Activity Title	Budget (kEuro)	Classification
3A.181	5G New Radio (NR) non-terrestrial networks control plane demonstrator for NGSO constellations	400	B
<b>Objective:</b>	The objective of this activity is to analyse the control plane procedures and signalling in 5G New Radio (NR) standard and adapt it to the peculiarities of Non-Terrestrial Networks (NTN) based on Non-Geo Stationary Satellite Systems and test it via a demonstrator.		
<b>Targeted Improvements:</b>	New capability related to the design of 5G NTN control plane not existing today in ESA member states		
<b>Description:</b>	<p>In recent years, several players from both satellite and terrestrial mobile networking industry are looking with interest at the Non-Terrestrial Technology for providing 5G services in sparsely populated areas. For the first time in 3GPP history, satellite technology falling under the Non-Terrestrial Technology classification - is formally part of the specification. New Radio services are the big enhancement introduced by 5G, and they are aimed to providing very high data connections.</p> <p>In such service, User Equipment is provided with an antenna which is directive and even more directive if the NR service has to be provided via satellite. Adaptations to the control plane of the 5G NR standard are required for its development on satellite networks, where a User Equipment needs to point to a given satellite which is not necessarily known a priori. A long list of procedures registration, handover, etc - become therefore nontrivial if based on the terrestrial networks' procedures. This adaptation requires a review of both the satellite architecture and the signalling mechanisms of the New Radio specification. As an example, one could foresee a small channel transmitted on a global beam by each satellite including the information about which satellite is to be used by the UE to register depending on its location and at the same time the NR standard to be updated introducing a new System Information table defining such information.</p> <p>The activity shall therefore define the control plane of 5G New Radio standard for NTN networks and demonstrate its performance in a software demonstrator. The main engineering tasks required in this activity are:</p> <ol style="list-style-type: none"> <li>1) review of the 5G NR control plane procedures and signalling 2;</li> <li>2) Definition of a reference NTN architecture based on Non-Geo Stationary Orbits;</li> <li>3) identifying possible strategies for satellite networks to implement a control plane as close as possible to the current specification;</li> <li>4) identifying required modification to the current specification for having a control plane fit to be deployed on Non-Terrestrial Networks;</li> <li>5) demonstrate such architectures and control plane design in a software demonstrator.</li> </ol>		
<b>Deliverables:</b>	Summary report and software demonstrator		
<b>Estimated current TRL:</b>	3		
<b>Target TRL:</b>	4		
<b>Technology harmonised:</b>	No		
<b>Dependency:</b>	None		
<b>S/W Clause:</b>	Yes (standard IPR regime applies)		
<b>Service Domain:</b>	5		
<b>Technology Domain:</b>	06 - RF Systems, Payloads and Technologies		

Activity Ref.	Activity Title	Budget (kEuro)	Classification
5A.083	5G regenerative processor and associated system test-bed	4,000	B
<b>Objective:</b>	The objective of this activity is to implement and test the signal processing portion of a 5G LEO satellite payload capable of handling several high throughput beams assuming an active antenna configuration. The demonstrator shall be based on a processor capable of controlling a reconfigurable beam-forming network (BFN) and performing signal (re-)generation and channelisation of 5G waveforms.		
<b>Targeted Improvements:</b>	Enable 5G regenerative payload functionalities currently not available.		
<b>Description:</b>	<p>The number of 5G subscriptions is estimated to reach 3.5 billion by the end of 2026. In this context, providing a truly ubiquitous coverage (even when traveling on cruises, high-speed trains and airplanes) whilst ensuring appropriate quality of service requires a tight integration between satellite and terrestrial networks. While geo-stationary satellites are well suited for covering very large areas with a limited number of satellites, they do not provide an optimal global interactive broadband connectivity due to their large delays and relatively high beam footprint on ground. For this type of service, constellations of hundreds or thousands of satellites in low orbit are preferred thanks to their lower latency and ability to provide higher overall system throughput. In order to achieve the ambitious targets expected by 5G New Radio (e.g., very high data rates, resources flexibility, mesh connectivity and rapid adaptation to traffic variations), these LEO payloads must rely on advanced technologies like phased array antennas, optical inter-satellite links and on-board regeneration. While solutions for on-board regeneration with DVB or CCSDS waveforms already exist, these cannot be exploited for the required integration of the space segment within the 5G ecosystem.</p> <p>This activity shall design and validate the main signal processing components for advanced satellite payloads providing 5G broadband connectivity. Specifically, the focus shall be put on developing the following components:</p> <ol style="list-style-type: none"> <li>1) High-speed modems capable of (re-)generating 5G waveforms with multiple Gbps of aggregated throughput.</li> <li>2) The on-board processor including switching/routing and control paths to connect the modems to the BFN to send/receive the signals to/from the different beam direction.</li> </ol> <p>The testbed shall be composed of the regenerative processor plus the appropriate ground support equipment to perform functional and performance verification of the developed payload components, including functionally representative building blocks of the payload front-end. As a minimum, this shall include a beam-forming network capable of generating multiple beams and capable of controlling hundreds of phased array feeds. It shall also be capable of verifying performance at system level (capacity) and link level (BER, FER, throughput) by simulating the impact of the components not developed within the testbed (e.g. antenna).</p>		
<b>Deliverables:</b>	Hardware, Software, Firmware of the testbed and its supporting documentation.		
<b>Estimated current TRL:</b>	3		
<b>Target TRL:</b>	5		
<b>Technology harmonised:</b>	No		
<b>Dependency:</b>	None		
<b>S/W Clause:</b>	Yes (standard IPR regime applies)		
<b>Service Domain:</b>	5		
<b>Technology Domain:</b>	06 - RF Systems, Payloads and Technologies		



Activity Ref.	Activity Title	Budget (kEuro)	Classification
3A.182	Vehicle-to-everything (V2X) services demonstration over satellite	1,500	B
<b>Objective:</b>	The objective of this activity is to develop a testbed that allows the demonstration of vehicle-to-everything (V2X) 5G services via satellite. Using existing satellite assets and on-ground antenna for mobile applications (not necessarily aesthetically attractive), the test bed shall address both forward and return link traffic, to support the definition of future V2X applications and associated technical enhancements. The set of services to be demonstrated shall be selected based on the space segment availability.		
<b>Targeted Improvements:</b>	<ul style="list-style-type: none"> <li>- Demonstrate the beneficial impacts of reusing 5G-based modems, network equipment, and other terrestrial technologies for V2X applications over satellite.</li> <li>- Demonstrate the end-to-end performance and service provision of this emerging vertical market.</li> </ul>		
<b>Description:</b>	<p>5G terrestrial networks will be deployed for enhancing traditional cellular broadband services, as well as for introducing new types of applications in emerging markets. Among those opportunities, an important growing sector is the automotive market (e.g., self-/assisted-driving, telemetry support and updates for vehicles), for which specific technologies are currently developed in 5G standardisation groups (identified as V2X) and very soon demonstrated in live trials.</p> <p>This market opportunity is enabled by the latest 5G Release 17 specifications, which support the introduction of Non-Terrestrial Networks (NTN), such as satellite systems. It is therefore proposed to assess in this activity how broadband GEO or NGSO systems could support the deployment of an integrated 5G network for V2X services. Each service is characterised by its own set of requirements (in terms of throughput, latency, coverage, reliability, security and/or interconnectivity). Some of these services could already be supported by existing space assets, therefore a suitable satellite use-case shall be identified: an existing satellite system, the necessary service link bandwidth, and relevant V2X services to be demonstrated. For this V2X showcase, the key on-ground technology elements to be procured and developed are the following as a minimum: the on-board car equipment (e.g. mobile antenna, 5G V2X chipsets), the terrestrial road-side units, the 5G base station, and the 5G core network. While it is expected to adopt existing COTS mobile antennas in the car, the V2X terminal, the base station, and the core network shall be enhanced to support NTN and V2X applications.</p> <p>The activity shall thus address the following points:</p> <ul style="list-style-type: none"> <li>a) Review the latest 3GPP specifications (i.e., 5G Release 17) regarding V2X and NTN applications;</li> <li>b) Propose V2X services and applications to be implemented and demonstrated over a satellite system (e.g., monitoring of vehicle data functions, up-to-date situational awareness for driving, software updates, emergency lights (V-16) etc.);</li> <li>c) Identify all necessary procurements (e.g., software and hardware) to first replicate a generic terrestrial 5G-V2X infrastructure;</li> <li>d) Describe the satellite use-cases covered by the selected network architecture and the associated technology developments;</li> <li>e) Procure, implement, and verify the proposed ground segment technologies, along with the necessary software developments;</li> <li>f) Integrate all components in the terrestrial-satellite hybrid network;</li> <li>g) Validation of 5G-V2X service performance via satellite;</li> <li>h) Propose a dissemination plan and live events for showing the achieved 5G-V2X capabilities.</li> </ul>		
<b>Deliverables:</b>	Hardware, Software, Firmware of the testbed, along with the associated documentation. Live demonstrator (TRL 5)		
<b>Estimated current TRL:</b>	3		
<b>Target TRL:</b>	5		
<b>Technology harmonised:</b>	No		
<b>Dependency:</b>	None		
<b>S/W Clause:</b>	Yes (standard IPR regime applies)		
<b>Service Domain:</b>	5		
<b>Technology Domain:</b>	06 - RF Systems, Payloads and Technologies		

Activity Ref.	Activity Title	Budget (kEuro)	Classification
3A.183	NGSO simulator for 5G vehicle-to-everything (V2X)	500	B
<b>Objective:</b>	The objective of the activity is to develop and test NGSO networking techniques for 5G V2X services. The developments will be implemented and verified in a simulator modelling realistic system scenarios of 5G LEO satellites.		
<b>Targeted Improvements:</b>	Enabling the provision of 5G V2X services by satellite.		
<b>Description:</b>	<p>Due to their low altitudes, LEO satellite systems may offer low-latency 5G connectivity that, paired with on-board edge computing, enables their use for 5G V2X services from space such as traffic/congestion control, situational awareness or mapping information that can be used for self-driving vehicles. On the other hand, the continuous motion of LEO satellites brings about several challenges such as satellite handover and integration with the terrestrial networks. In addition, reliable multicasting for software and database updates with LEO satellites call for feedback suppression and routing protocols.</p> <p>To address these issues, the proposed activity will identify the networking challenges for NGSO satcom systems to provide 5G V2X services. The activity will then develop handover, terrestrial integration, multicast routing and reliable multicast feedback suppression techniques. The developments together with promising edge computing solutions will be implemented and verified in a simulator modelling realistic system scenarios of 5G LEO satellites.</p>		
<b>Deliverables:</b>	Study report, software simulator.		
<b>Estimated current TRL:</b>	3		
<b>Target TRL:</b>			
<b>Technology harmonised:</b>	No		
<b>Dependency:</b>	None		
<b>S/W Clause:</b>	Yes (standard IPR regime applies)		
<b>Service Domain:</b>	5		
<b>Technology Domain:</b>	06 - RF Systems, Payloads and Technologies		

Activity Ref.	Activity Title	Budget (kEuro)	Classification
6B.119	Artificial intelligence/machine learning front-end module for satcom 5G/6G integrated access-backhaul transceivers	500	B
<b>Objective:</b>	The objective of the activity is to develop, implement and test a breadboard of a digital transceiver front-end capable of switching between access and backhaul modes of operation for integrated satcom-terrestrial 5G/6G networks. The transceiver core shall be supported by an AI/ML engine implemented for a set of commercially available hardware and software platforms. The activity shall also provide the testbed to test the AI/ML-based transceiver breadboard and to assess its performance in a laboratory environment.		
<b>Targeted Improvements:</b>	Enabling protocol agility and radio flexibility to integrates access-backhaul transceivers supporting densified 5G/6G networking architectures not existing today. Up to 50% reduction in the parts count for the digital transceiver front-end module of 5G/6G-satcom integrated access/backhaul nodes.		
<b>Description:</b>	<p>The integration of satellite telecommunications systems in terrestrial 5G/6G networks envisions new network topologies enabled by the concept of satcom Integrated Access and Backhaul (IAB). Satcom IAB nodes will support very flexible network deployments, e.g. meshed, chained, mobile and dynamic, by allowing Radio Access Network (RAN) nodes (gNBs) to function as an ad-hoc radio relay offering backhaul connectivity to their neighbour nodes, in addition to acting as regular access node for user equipment. In that context, the challenges of densified future 5G/6G networks require further advancements of the integrated satcom element. Generic satcom node products will need to be equipped with a dynamic reconfigurable air-interface flexible enough to respond to different system requirements, operational scenarios, and link conditions.</p> <p>By moving radio functionality into software, and by moving the analogue/digital conversion closer to the air-radio interface at the antenna, a variety of software defined radio schemes may be invoked to implement critical transceiver functions for a dual access backhaul mode of operation. Moreover, viewing the transceiver front-end functionality as a learning and/or search problem in a large and complex space of possible solutions, allows for heuristic engineering approaches rooted in the mechanisms of evolution, natural genetics, artificial intelligence, and machine learning. The anticipated benefit is the implementation of protocol agnostic front-end transceiver modules of reduced complexity, increased flexibility, and ease of manufacturing.</p> <p>The aim of the activity is to develop, implement and test a breadboard of a digital transceiver front-end based on Artificial Intelligence/Machine Learning (AI/ML) engine to execute critical physical layer signal processing tasks for satcom IAB nodes. While the core AI/ML algorithm development shall remain independent of the final HW/SW platforms (such as FPGA, GPU, CPUs or even cloud computing), the core development shall consider the peculiarity of the final platforms. The targeted digital front-end IAB transceiver breadboard shall handle attributes like interference over a heavily loaded satellite channel in the presence of linear and non-linear impairments, and support handovers in multi-beam multi-layered satellite systems. The activity shall provide means to verify the AI/ML front-end implementation in the target commercially available platform and test its performance via a testbed in a laboratory environment. In comparison to the current state of art, it will create a reference design for transceiver algorithms, techniques and technologies that does not currently exist.</p>		
<b>Deliverables:</b>	Summary report; transceiver front-end breadboard; AI/ML engine and associated training data; testbed		
<b>Estimated current TRL:</b>	3		
<b>Target TRL:</b>	4		
<b>Technology harmonised:</b>	No		
<b>Dependency:</b>	None		
<b>S/W Clause:</b>	No		
<b>Service Domain:</b>	5		
<b>Technology Domain:</b>	12 - Ground Station Systems and Networks		

Activity Ref.	Activity Title	Budget (kEuro)	Classification
7C.082	Highly efficient 20 W S-band power amplifier for 5G-connected cars	650	B
<b>Objective:</b>	The objective of the activity is to design, manufacture and test a highly efficient 20 W S-band Power Amplifier		
<b>Targeted Improvements:</b>	Efficiency higher than 70% - enabling technology for S-Band automotive applications		
<b>Description:</b>	<p>Recent studies have shown the potential of satellite communications for 5G-connected cars. Although various frequency bands may be envisaged, the S-band can offer a simple systems architecture as well as a satisfactory link budget. However, due to the low gain of S-Band antennas, a dedicated high-power amplifier is necessary to close the link while offering a small footprint and high efficiency.</p> <p>This activity aims at developing such a power amplifier, which must be compatible with the constraints of the automotive market. A 20 W S-Band prototype, with 70% minimum efficiency, shall be designed, manufactured and tested.</p>		
<b>Deliverables:</b>	Summary report and amplifier prototype		
<b>Estimated current TRL:</b>	3		
<b>Target TRL:</b>	5		
<b>Technology harmonised:</b>	No		
<b>Dependency:</b>	None		
<b>S/W Clause:</b>	No		
<b>Service Domain:</b>	5		
<b>Technology Domain:</b>	06 - RF Systems, Payloads and Technologies		

Activity Ref.	Activity Title	Budget (kEuro)	Classification
7C.084	5G automotive antenna prototype and demonstration	5,000	B
<b>Objective:</b>	The objective is to design and demonstrate a new class of low-profile and conformal antennas, providing seamless connectivity for 5G services on vehicles.		
<b>Targeted Improvements:</b>	Enabling technology Satellite antennas compatible with the constraints of the automotive markets (in terms of aesthetics, aerodynamics and safety), whilst providing seamless connectivity, are currently not available.		
<b>Description:</b>	<p>The automotive sector is a crucial target group for future 5G systems, as the new standards pursue the goal of integrating mobile communications into vehicles. However, antennas providing seamless connectivity on board of vehicles are not available today, due to many technological and commercial challenges that shall not be addressed in isolation. Antennas for satellite-connected cars can be designed for various frequency bands (e.g., L-, S-, Ku- and/or Ka-Band), require compatibility with terrestrial and other satellite services (e.g., satellite radio and navigation) and must satisfy requirements of the automotive market.</p> <p>This activity will design a class of low-profile and conformal antennas, following a holistic approach where all main stakeholders (i.e., antenna technology provider, car manufacturer, satellite/terrestrial operator) are involved in the antenna design. This includes aspects such as:</p> <ul style="list-style-type: none"> <li>- Selection of at least one use-case and system definition: frequency bands (e.g. S-, Ku-, Ka-Band) satellite type and orbits (e.g. LEO, MEO, GEO and/or HEO) Optimisation of the system architecture, aiming to the automotive antenna simplification.</li> <li>- Selection of a vehicle class and associated environmental and safety constraints Co-design of the antenna/vehicle chassis, where the satellite terminal antenna aperture is embedded in the chassis frame, roof and/or other conformal structure, to guarantee a suitable aperture size and orientation, whilst minimising the impact on the vehicle design and aesthetics.</li> <li>- End-to-end demonstration of the prototype system with two or more vehicles, validating the target use-case(s).</li> </ul>		
<b>Deliverables:</b>	Summary report, Antenna Prototype, Algorithms, System Testbed.		
<b>Estimated current TRL:</b>	3		
<b>Target TRL:</b>	5		
<b>Technology harmonised:</b>	No		
<b>Dependency:</b>	None		
<b>S/W Clause:</b>	Yes (standard IPR regime applies)		
<b>Service Domain:</b>	5		
<b>Technology Domain:</b>	12 - Ground Station Systems and Networks		

Activity Ref.	Activity Title	Budget (kEuro)	Classification
7C.086	End-to-end demonstration of 5G New Radio (NR) for future railway mobile communication systems	2,500	B
<b>Objective:</b>	The objective of this activity is to develop the necessary 5G New Radio (NR) ground segment prototypes for servicing the Future Railway Mobile Communication System (FRMCS) via satellite and demonstrate the capability with end-to-end in orbit testing.		
<b>Targeted Improvements:</b>	Ensure compliance to the FRMCS safety and performance requirements by demonstrating the feasibility of servicing via a satellite link, complementing the terrestrial network. Provide ETSI RT standardisation group with the required inputs for satellite.		
<b>Description:</b>	<p>The Future Railway Mobile Communication System (FRMCS), being a successor of the GSM-R system, is planned to be operational before GSM-R's predicted saturation in 2030. In this respect, ETSI (European Telecommunications Standards Institute) is already preparing the relevant FRMCS standard. In the frame of this work, satcom is established as a component of the future system. More specifically, the integration of satcom to FRMCS was identified to be more straightforward when satcom is employing 5G NR, which is going to be the air interface for the terrestrial FRMCS access. Regarding the terrestrial FRMCS 5G NR access, live trials are planned by 2024, as it is targeted for the first stable version of FRMCS to be available for procurement by the beginning of 2025.</p> <p>To establish satellite with solid foundation in FRMCS, and to demonstrate its capability to service the terrestrial gaps of communication, it is essential that a similar activity will take place also for satellite. This activity will therefore validate with a real in-orbit demonstration the capability of satellite to service operational trains with FRMCS while using the 5G NR air interface. For this purpose, ground segment prototypes (i.e., modems on board trains and for gateways) will be designed via FPGA or SDR-based developments and validated initially in a lab environment and then on field versus the FRMCS requirements. Whenever possible, COTS RF/antenna equipment should be used for the purpose of this development. Both Forward Link and Return Link will be considered to demonstrate the interactivity of FRMCS use cases. The best candidate satellite connectivity (in terms of orbit, frequency), as well as trains of different speeds and different local environments (e.g. rural, suburban, urban) will be considered, to exhibit the response of the satellite 5G NR link and its compliance to the FRMCS requirements over a plethora of scenarios characterised by different multipath, fading and interference conditions. In addition, switching between satellite and terrestrial 5G NR networks will be showcased to offer insight on the performance of the handover that takes place when the train transitions between coverages. Satellite switching will also be demonstrated in case a satellite constellation is considered for the live trials.</p> <p>The outcome of the work will feed the ETSI FRMCS standardisation through the participation to the ETSI RT standardisation group.</p>		
<b>Deliverables:</b>	Study Report, 5G NR HW ground prototypes, over-the-air performance data, experimental data.		
<b>Estimated current TRL:</b>	4		
<b>Target TRL:</b>	6		
<b>Technology harmonised:</b>	No		
<b>Dependency:</b>	None		
<b>S/W Clause:</b>	Yes (standard IPR regime applies)		
<b>Service Domain:</b>	5		
<b>Technology Domain:</b>	06 - RF Systems, Payloads and Technologies		

Activity Ref.	Activity Title	Budget (kEuro)	Classification
3E.019	Open reprogrammable space infrastructure testbed for beyond 5G (B5G) end-to-end solutions and services	3,000	B
<b>Objective:</b>	The objective of the activity is to develop and test a reprogrammable testbed in space to permit the experimentation of Beyond 5G (B5G) satellite features and capabilities and enable technology verification and demonstration; rapid validation of end-to-end solutions and services, following the principles of continuous development/continuous integration. B5G satellite features will be implemented in the testbed as part of the activity to demonstrate its capabilities.		
<b>Targeted Improvements:</b>	Enabling development infrastructure for B5G satellite systems not existing today.		
<b>Description:</b>	<p>With the establishment of Non-Terrestrial Networks (NTN) firmly as part of 3GPP rel. 17, we are witnessing efforts for the validation of initial designs and deployments of integrated terrestrial (TN) and NTN networks to offer Enhanced Mobile Broadband (eMBB) and Internet-of-Things (IoT) services.</p> <p>Nonetheless, the work to define Beyond 5G (B5G)/towards 6G continues with the roadmap rapidly evolving alongside the 3GPP standardisation process, e.g., NTN enhancements included in rel. 18, advanced NTN features already proposed for Rel. 19 and initial assessments of B5G/towards 6G space infrastructure. However, evaluating the implementation of new architectures is challenging mainly due to immaturity of technology and lack of means for continuous development and validation of new capabilities, which hinders the time to market for NTN solutions.</p> <p>The objective of the activity is then to develop and test a reprogrammable testbed for space infrastructure to permit the experimentation of 5G/6G satellite features and capabilities and enable technology verification and demonstration; rapid validation of end-to-end solutions and services, following the principles of continuous development/continuous integration. The testbed will implement features based on mid to longer term technology trends such as cross-layer communication, dynamically programmable backhaul, OpenRAN implementations, use of AI/ML onboard, context aware routing and increased importance of security-by-design. Candidate features will be assessed and expected performance, benefits and costs for each will be identified and documented. The activity will implement and demonstrate enhanced NTN features (rel.18/19) in orbit using either transparent or regenerative payloads with onboard storage and computing and routing capabilities and intersatellite links as/if applicable.</p> <p>The testbed could be embarked for example on the ISS, existing/planned smallsats, and/or as hosted payload. The activity will take stock of all ongoing 5G satellite developments and propose convincing demonstrations. The activity will seek synergies with ARTES SPL 5G deliverables and testbeds as well as various European 5G platforms and projects and national initiatives that are already being built-up.</p> <p>The activity will be implemented in a phased approach and features will be proposed and implemented by activating CCNs.</p>		
<b>Deliverables:</b>	Study report, reprogrammable testbed, in-orbit test results.		
<b>Estimated current TRL:</b>	3		
<b>Target TRL:</b>	4		
<b>Technology harmonised:</b>	No		
<b>Dependency:</b>	None		
<b>S/W Clause:</b>	Yes (standard IPR regime applies)		
<b>Service Domain:</b>	5		
<b>Technology Domain:</b>	06 - RF Systems, Payloads and Technologies		

Activity Ref.	Activity Title	Budget (kEuro)	Classification
3E.011	6G satellite precursor	8,000	B
<b>Objective:</b>	The objective of the activity is to develop an in-orbit experiment where technologies and techniques that will be key for the role of satellites in 6G networks can be tested, validated and their performance measured. This includes very novel techniques such as AI-assisted dynamic spectrum allocation, AI-assisted dynamic service-based resource management, self-optimised air interface, characterisation of sub-THz transmission performance and novel technologies such as neuromorphic processors, sub mm-wave RF equipment and antennas, cognitive radios, software-defined radios and software-defined payloads.		
<b>Targeted Improvements:</b>	Enabling new capabilities for future 6G satellite technologies. Key performance improvements for 6G with respect to 5G in all domains (core and edge). Investigate technologies and solutions for seamless integration of satellites in future 6G networks		
<b>Description:</b>	<p>6G networks are planned to be deployed in the 2030s after a standardisation effort to be started around 2025. Satellites are considered essential to fulfil the key policy objectives of 6G, among which the sustainability support to industrial sectors (green ICT) and inclusion (reduction of the digital divide). For satellites to be considered, they must be seamlessly integrated into the 6G networks. At this early stage 6G is not fully defined but clear trends are appearing, such as: convergence of connectivity and computation, end-to-end network orchestration (terrestrial and non-terrestrial networks), Artificial Intelligence and Machine Learning (AI/ML) everywhere - distributed intelligence - for network optimisation, as well as to support vertical use cases, and ultra-high levels of security. These trends require a radical change into the architecture, management and control of satellite systems and key novel technologies and techniques need to be validated and demonstrated standalone and integrated with terrestrial systems. R&amp;D efforts for key technologies are starting worldwide in the telecommunications ecosystem so that the standardisation phase can be started on a realistic and verified foundation. For satellite solutions to be considered it is important to achieve in-orbit validation and demonstration in a realistic environment. Nowadays, with the proliferation of micro and nanosatellites with short development cycles and the availability of affordable launch solutions, In Orbit Validation/Demonstration (IOV/IOD) can be achieved with a limited cost. Acting now enables the possibility of early integration testing with terrestrial developments and the possibility of co-creation of the standard. Therefore, the activity proposed consists of the development and launch of an in-orbit 6G experiment to allow experimentation, optimisation and validation of key 6G technologies and techniques such as AI-assisted dynamic spectrum allocation, AI-assisted dynamic service-based resource management, self-optimised air interfaces, characterisation of sub-THz transmission performance, multi-access edge computing, use of neuromorphic processors for AI/ML power and mass/volume optimisation, sub-THz RF equipment and antennas, cognitive radios, software-defined radios and software-defined payloads.</p> <p>The activity will seek synergies with ESA B5G/6G deliverables as well as various European B5G/6G projects and national initiatives that are already being built-up. In addition, the activity will provide inputs to standardisation bodies and to the European 6G development roadmap.</p> <p>The activity will be implemented in a phased approach where key technologies and techniques will be reviewed and selected prior to proceeding with the development and launch activities.</p>		
<b>Deliverables:</b>	Summary report and in-orbit test data		
<b>Estimated current TRL:</b>	3		
<b>Target TRL:</b>	5		
<b>Technology harmonised:</b>	No		
<b>Dependency:</b>	None		
<b>S/W Clause:</b>	No		
<b>Service Domain:</b>	5		
<b>Technology Domain:</b>	06 - RF Systems, Payloads and Technologies		



Activity Ref.	Activity Title	Budget (kEuro)	Classification
3A.184	Beyond 5G (B5G) and 6G non-terrestrial networks edge computing satellites	1,200	B
<b>Objective:</b>	The objective of the activity is to study and define a technical and deployment roadmap for edge-computing-enabled Beyond 5G (B5G) and 6G space infrastructure. Use cases of Non-Terrestrial Networks (NTN) edge computing will be selected and a corresponding demonstrator will be breadboarded and tested.		
<b>Targeted Improvements:</b>	Enabling edge-computing-capable space infrastructure.		
<b>Description:</b>	<p>The Beyond 5G (B5G)/towards 6G roadmap is rapidly evolving alongside the 3GPP standardisation process with NTN enhancements already included in Release 18 and even more advanced NTN features proposed for Release 19 such as, for example, architectures featuring edge computing capabilities aboard the satellites to flexibly and dynamically allocate storage and processing to assigned tasks.</p> <p>Edge computing satellite systems are set to serve both direct access and transport (backhaul) connectivity and to enhance performance i.e., lower latency -shorter data paths, reduced impact on backhaul, flexibility (possibility of satellite edge-to-edge node), user equipment simplification. Edge computing on-board implies not only splitting of core functionalities between ground and payload but also customisation of the network to serve specific use cases. While applicability of edge computing in NTN networks is highly promising in terms of performance enhancement, such architectures are technical immature.</p> <p>The main objective of the activity is therefore to define a technical and deployment roadmap of edge computing enabled B5G/6G space infrastructure for provisioning services for consumer and vertical market segments, reaching levels of performance, reliability, resilience, and security set forward for mid to longer term.</p> <p>The activity will study and develop a space infrastructure architecture and techniques including:</p> <ul style="list-style-type: none"> <li>• cooperative multi-access scenarios (multi-orbit constellations), and how best to monitor, manage and synchronise NTN network nodes i.e., when two edges are visible at the same point;</li> <li>• constrained edge computing implementation on board;</li> <li>• how to minimise the consumption of resources for continuous nodes management and the split of management functionalities;</li> <li>• implications of pushing intelligence on-board and/or user equipment;</li> <li>• possibility to develop single set of network functions and components for a variety of use cases to be identified and prioritised;</li> <li>• how a continuous integration/continuous development approach can be implemented for NTN.</li> </ul> <p>The activity will be implemented in a phased approach. First, to meet the objectives, the activity will identify different architectural alternatives and will assess their pros and cons, expected performance, benefits and costs. The activity will then assess technologies readiness and identify any gaps that must be addressed by the satellite industry to implement the edge computing architectures and deploy operational networks.</p> <p>Secondly, a technology demonstrator of edge computing NTN will be proposed and implemented by CCNs but staying within the total budget envelope. Use case assessment will be performed by appropriate testbed against enhanced NTN features (at least rel.18/19).</p>		
<b>Deliverables:</b>	Study report and a breadboard of NTN edge computing.		
<b>Estimated current TRL:</b>	3		
<b>Target TRL:</b>	5		
<b>Technology harmonised:</b>	No		
<b>Dependency:</b>	None		
<b>S/W Clause:</b>	Yes (standard IPR regime applies)		
<b>Service Domain:</b>	5		
<b>Technology Domain:</b>	06 - RF Systems, Payloads and Technologies		

Activity Ref.	Activity Title	Budget (kEuro)	Classification
3A.185	Spectrum sharing techniques for Beyond 5G (B5G) and 6G 3D networks	2,500	B
<b>Objective:</b>	The objective of the activity is to investigate and develop spectrum reuse and sharing techniques for integrated NTN-TN 3D networks that allow them to pool, share, and rapidly reallocate spectrum on demand among their heterogeneous components/segments. The techniques will be prototyped in a testbed to be implemented as part of the activity.		
<b>Targeted Improvements:</b>	Enabling spectrum reuse and sharing in integrated NTN-TN 3D networks.		
<b>Description:</b>	<p>Spectrum demand for all wireless services continues to increase while service and operational convergence create more diverse, complex, and interconnected systems, such as the ones envisioned with the integration of terrestrial and non-terrestrial networks (TN and NTN respectively) which is now being considered for Beyond 5G/ towards 6G.</p> <p>While spectrum reuse and sharing may potentially satisfy the growing demand, the emerging complexity, dynamics, and heterogeneity of the different wireless systems involved make the TN-NTN integration at radio resource management (RRM) level technically challenging with existing approaches. For example, previous activities did not consider airborne layers (e.g., HAPS, UAVs), or N-system, N-band dynamic sharing where access priorities vary by band, location, and time. In future networks, the motion of network nodes such as NGSO satellites or HAPS can require updates at RRM level orders of magnitude faster than done before, or potential link outages caused by the high dynamic environment can require quick system reactions untenable by a purely centralised spectrum management approach.</p> <p>To address these issues, the activity will investigate, develop and test spectrum reuse and sharing techniques for integrated NTN-TN 3D networks that allow them to pool, share, and rapidly reallocate spectrum on demand among their heterogeneous components/segments.</p> <p>The activity will follow a phased approach. The first phase will analyse and design spectrum sharing techniques for heterogeneous integrated NTN-TN 3-dimensional (3D) networks by identifying requirements and protection criteria for the individual NTN and TN components, identifying approaches and key innovations needed, and estimating the expected gains (capacity, access) and impacts (technical, operations, regulatory). The second phase will implement the solutions in a prototype consisting of an emulation environment where the developments will be characterised, and their benefits and impacts assessed. The results will be used to engage with regulators and relevant standardisation bodies for subsequent deployment /adoption.</p> <p>The activity will seek synergies with other ESA 5G deliverables and testbeds as well as various 5G platforms projects from European and national initiatives that are already being built up.</p>		
<b>Deliverables:</b>	Study report, spectrum sharing techniques, emulation environment.		
<b>Estimated current TRL:</b>	3		
<b>Target TRL:</b>	5		
<b>Technology harmonised:</b>	No		
<b>Dependency:</b>	None		
<b>S/W Clause:</b>	Yes (standard IPR regime applies)		
<b>Service Domain:</b>	5		
<b>Technology Domain:</b>	06 - RF Systems, Payloads and Technologies		