

6G SNS



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6G-SANDBOX

Supporting Architectural and technological
Network evolutions through an intelligent, secured
and twinning enabled Open eXperimentation
facility

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ABSTRACT

This document includes additional technical information on 6G-SANDBOX, which helps proposers to understand the 6G-SANDBOX technologies and capabilities. The document also includes some guidelines to consider when building and exposing hardware and software in Open Call 2.

1 INTRODUCTION

6G-SANDBOX will build an experimental facility to create ad-hoc Trial Networks for experimenters. A **Trial Network** (TN) is a fully configurable, manageable end-to-end network that can be used to perform advanced experimentation activities. A TN is defined by a TN template that includes a description of components that conform it. An experimenter can customize these components and their interconnection.

The main components of a TN are:

- **Router.** Provides access to all TN elements using different protocols (e.g., SSH), through VPN connectivity). The router also implements some basic security rules like firewalling TN services. A router is a mandatory component of the network.
- **Virtual Networks.** A TN also defines one or more virtual private networks to interconnect the TN elements. An experimenter network will be always available to provide an administration entry point to each element. The experimenter can define additional networks to interconnect the TN elements. These networks can include special purpose equipment (e.g., satellite links) or configurations.
- **Kubernetes.** The TN can include third-party applications that may require a Kubernetes cluster to be deployed. A Kubernetes cluster can be included as part of the TN so the experimenter can deploy any Helm chart.
- **Virtual Machines.** Generic VMs can be added to a TN to run any application. The experimenter can specify the capacity of the VMs (e.g., CPU or memory) as well as advanced configurations (e.g., GPU PCI-passthrough devices).
- **5G Networks.** The TN can include the deployment of 5G network, including a 5G core as well as radio equipment.

Figure 1 shows the main components and high-level architecture of the Trial Network.

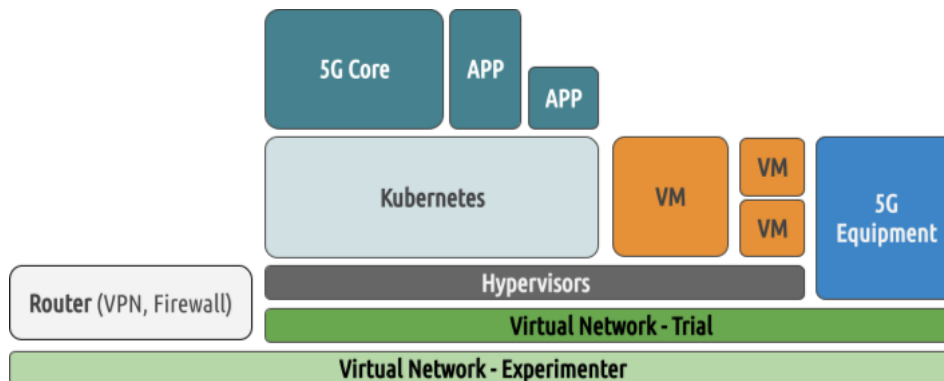


Figure 1: Main components of a Trial Network

Open Call 2 ambition is to enhance the set of components to be available in 6G-SANDBOX sites to be used in the TNs. This document provides technical information to assist in the creation of such components. The following sections describe the four experimental platforms in the projects, the equipment required to measure KPIs and the guidelines to build the new components.

2 PLATFORM ARCHITECTURES

2.1 MALAGA PLATFORM

Malaga platform is represented by Victoria Network, which includes a wide variety of mobile networks and other technologies set in different locations. The current status is highlighted in green in Figure 2. The main site of the platform is the University of Malaga campus, where outdoor and indoor 5G deployments are available. For outdoor deployments, two solutions based on Nokia cells are provided: one with 10 microcells working on FR1 (b7 and n78) and another with two cells for mmWave FR2 (n257 and n261). For indoor deployments, a Nokia picocells based deployment is available, with two cells in FR1 (n78). In addition, a full O-RAN solution is provided in the same band (n78).

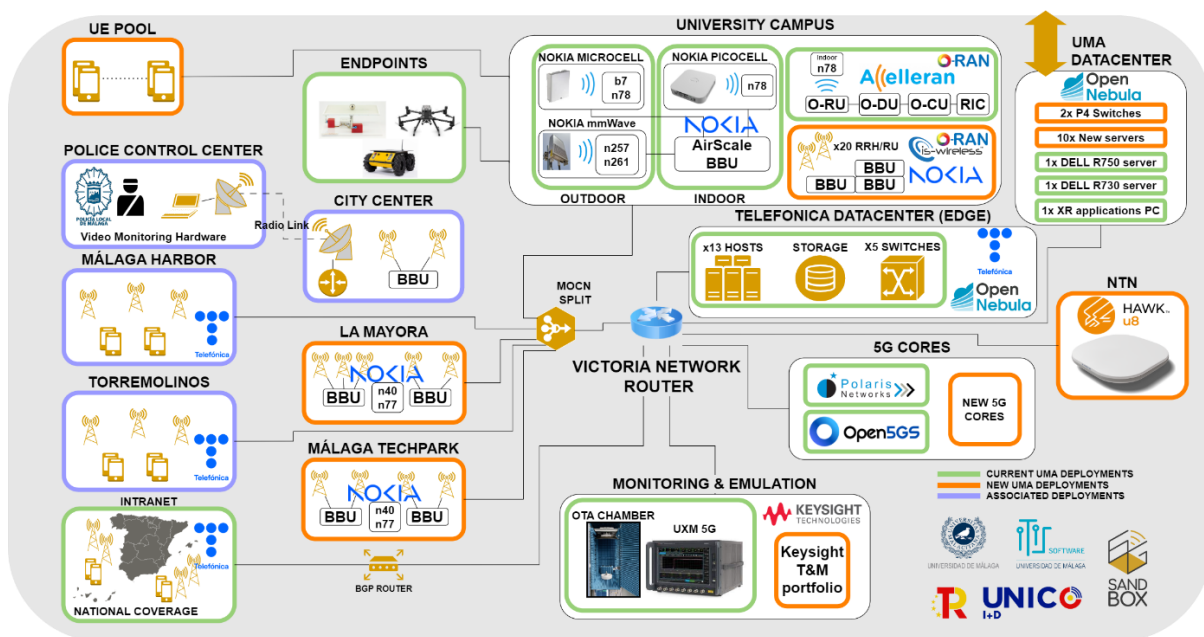


Figure 2: Malaga Platform

Furthermore, Victoria Network includes other locations with RAN deployments not associated directly with UMA, but to related entities, and that are also linked to its infrastructure through a MOCN split. Firstly, the Police control Center is connected to a RAN deployment in Malaga city center using a radio link. In addition, other RAN locations from Telefonica, like Malaga Harbor and Torremolinos, are also part of the network.

Regarding 5G cores, Polaris 5GC Unicorn and Open5GS options are available.

Another important element currently available is the Intranet service, which is provided by Telefonica. Through the Intranet, any user registered in the system and owning a commercial SIM card from Telefonica can connect to Victoria Network infrastructure. This is a very valuable feature as it provides coverage to experimenters in any location in Spain.

Victoria Network also provides 5G networks in controlled and emulated environments. At this time, an OTA chamber and a 5G emulator (Keysight E7515B UXM 5G Wireless Test Platform) are available, together with a set of software tools for testing and measurement that will be extended during the project. All of this equipment is provided by Keysight.

Finally, the testbed includes two datacenters:

- UMA datacenter: This is the main datacenter that includes the routers, switches, firewalls, storage systems, servers, etc. to support all services and applications in Victoria Network. An important element allocated here is the Infrastructure Manager, based on OpenNebula.
- Telefonica datacenter: This is an additional datacenter acting as Edge with another OpenNebula deployment to provide virtualized resources to experimenters.

Note that the Victoria Network will be enhanced during the lifetime of 6G-SANDBOX with the following features and innovations (see the areas highlighted in orange in Figure 2):

First, the University campus RAN deployment will be extended with both traditional and distributed solutions. Traditional RANs will be based on Nokia equipment and O-RAN implementations will be provided by IS-Wireless. However, additional approaches not provided by these entities can also be expected. In total, about 20 new RRH/RUs will be available.

In addition, two new RAN locations will be added to the network. One in La Mayora, which is a public institute that owns land where it leads international studies on the production of subtropical and Mediterranean fruits, as well as the introduction of new varieties of exotic fruits. The second location is in Malaga TechPark, which is a business park specializing in the ICT sector and where the new RAN deployment will cover different areas.

Note also that new commercial 5G cores are expected. However, specific information about the solutions/providers is not available at this time. It is important to note that some solutions can come directly from Open Calls.

As far as Monitoring and Emulation features, Keysight's Testing and Monitoring portfolio will be extended and made available for experimenters. This portfolio includes an extensive set of more than 20 tools. These are mainly software applications, but new hardware equipment will be also available in Malaga.

In addition, Victoria Network will soon have a Non-Terrestrial Network (NTN), as a LEO satellite receiver will be installed on the University campus. This will allow testing of multipath connectivity between different endpoints.

All of the enhancements described above will require more computing and storage capacity. To address this, UMA datacenter will be expanded with about 10 new servers to allocate the coming services. In addition, two new P4 switches will be acquired to improve data transport and include telemetry in Victoria Network.

2.1.1 6G-SANDBOX AVAILABLE RIS

The RIS that is being developed for the Malaga site is targeted to be compliant with the following technical specification. The 6G-SANDBOX RIS operate in the 5G NR Band n261 (27.5 - 28.35 GHz). The operation bandwidth for a single user is limited to 100 MHz.

The RIS tile has the following specifications:

- Physical Size: < 10 x 10 cm², weight: < 2 kg
- Regulation Information: Same as Nokia mm-wave Airscale (TBC)
- Max RIS Gain range 20 – 25 dB per polarization
- FoV: ±30° Azimuth, ±10° Elevation
- Programming Interface: FPGA Interface C API
- Power consumption: 15 – 20 W

2.2 ATHENS PLATFORM

The Athens platform is an advanced large-scale 5G Stand Alone (SA) experimental facility, which spreads across two locations within the metropolitan region of Athens as shown in Figure 3 -- the COSMOTE/OTE Academy campus and the NCSR Demokritos campus. These two locations are interconnected with a dedicated 10G dark fiber and represent two fully operational 5G SA networks.

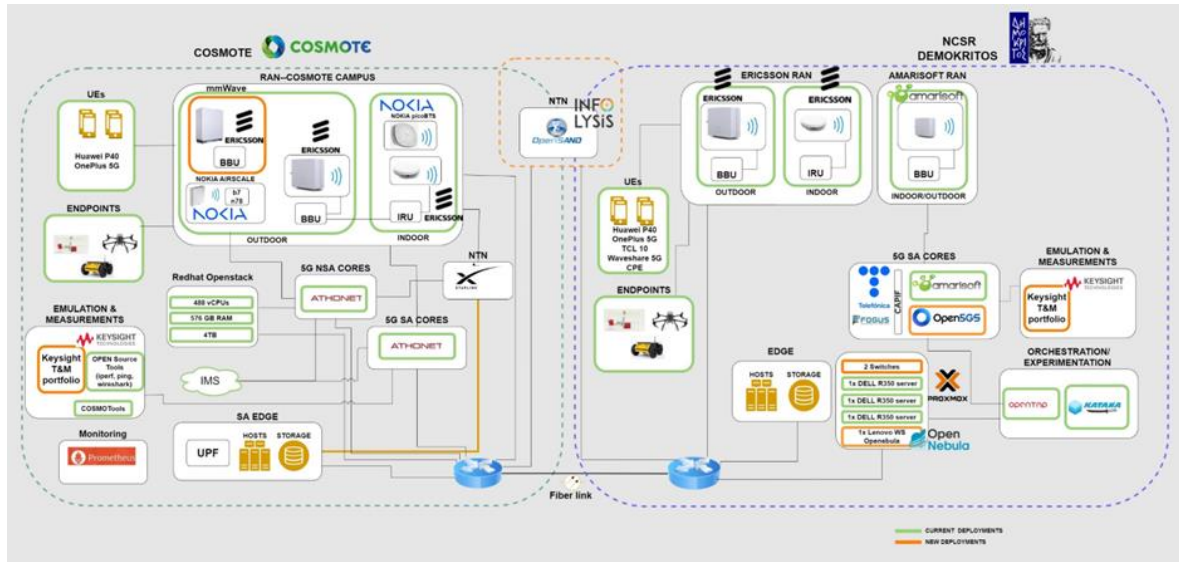


Figure 3: Athens Platform

The first 5G SA network is based on ATHONET 5G SA Core and ERICSSON BBU/RRU/RAN, being deployed both at the COSMOTE and NCSR Demokritos campuses. More specifically, the ATHONET 5G Core is located on the COSMOTE/OTE Academy premises and is used to drive two ERICSSON BBU units, one deployed at COSMOTE campus and one deployed at NCSR Demokritos campus. Each of these two BBUs is controlling 3 ERICSSON RRU/RAN units at each domain, therefore realising a large scale 5G network with six indoor/outdoor cells/RAN units in total for both sites.

The other 5G SA network is deployed only at NCSR Demokritos campus and is based on Amarisoft 5G RAN and a variety of potential 5G SA Core implementations, such as Amarisoft, Open5GS and Athonet, which are supporting a different level of openness (e.g., NEF/CAPIF). Thus, the NCSR campus site includes two radio access networks that are connected to different 5G cores, which enable further research in inter-PLMN handover and roaming scenarios. A scenario for the realization of the inter-PLMN capabilities could be a UE moving from the coverage area of one PLMN to another PLMN while maintaining its ongoing session, from Operator A (e.g., COSMOTE) to Operator B (e.g., NCSR).

For the Core Networks, the supported options are as follows:

- Amarisoft 5G SA Core: The Amarisoft 5G Core network solution provides essential network functions for the operation of a 5G network all integrated within the same software component: Access and Mobility Management Function (AMF), Authentication Server Function (AUSF), Session Management Function (SMF), User plane Function (UPF), UDM (Unified Data Management) and 5G-EIR (5G Equipment Identity Register).
- Athonet 5G SA Core: ATHONET 5G Stand Alone (SA) core network includes two UPFs (User Plane Function) to emulate the edge and core 5G network data plane. The network also features 3GPP (3rd Generation Partnership Project) Control Plane Network Functions, including the Access and Mobility Management Function (AMF), Session Management Function (SMF), Authentication Server Function (AUSF), and User Data Management (UDM) Function. These functions enable management and control

of the network. The network also supports 3GPP interfaces, including N1, N2, N3, N4, and N6, which enable communication between network functions. This configuration is hosted at COSMOTE Cloud facilities, providing a secure and reliable infrastructure.

The Radio Access Network (RAN) is based on the Ericsson BBU 6630 which is a baseband unit that provides high-performance connectivity for mobile networks. The unit is compatible with various radio units, including the 4408, which is designed to provide high-capacity and low-latency connectivity for outdoor deployments. In addition to the radio unit, the system also includes the Indoor Radio Unit (IRU) 8848 and Dot 4479 B78L, which are essential components for the indoor deployment of a 5G network. The GPS system is used for synchronization purposes and ensures accurate timing and location data for network operations. These components form a powerful and reliable radio access network that delivers high-speed connectivity and low latency. Nokia Airscale and 5G Small Cell (RRH) deployments are also supported.

At NCSR site, the Amarisoft 5G NR which is also supported can operate in FDD/TDD frequency bands below 6 GHz with up to 50 MHz of bandwidth. It supports various subcarrier spacing options for both data and synchronization signals and can operate in MIMO configurations up to 4x4 in DL. The MIMO layers can be also complemented in either (a) one 5G cell with 50MHz bandwidth and 2x2 MIMO configuration or (b) three 5G cells with 20MHz bandwidth and 2x2 MIMO configuration each.

Enhancements and Innovations

NTN

On top of the terrestrial dedicated dark fiber link between the two sites in Athens platform, a satellite/NTN-emulator is currently under deployment, which will enable multi-operator and multi-access scenarios, such as inter-PLMN hybrid-access and dual-connectivity, with agility and low cost. ATSSS (Access Traffic Steering, Switching, and Splitting) enables efficient use of multiple RATs in a multi-connectivity scenario. The emulated satellite opens this field for further research into custom solutions where different PDU sessions per access can run in parallel. Specifically, the solution supported by Athens platform involves the use of MPTCP to combine multiple network paths (i.e., the terrestrial and the emulated satellite/NTN) in a single TCP connection.

The satellite emulated based approach of the Athens testbed can emulate a complete DVB-RCS2 – DVB-S2 system in a realistic and flexible way and its ability to interconnect with real equipment and applications provides excellent experimentation means. It is a distributed platform, which is composed of a satellite network on the operator side and Satellite Terminals (STs) at the client side. The satellite operator part is composed of a backbone network between satellite Gateways (GWs), capable of being interconnected to external networks, providing satellite network access on each terminal and gateway. The offered emulation platform allows the experimenter to emulate mesh and star configuration schemes as well as multi-spot and multi-gateway topologies. It provides configuration and monitoring (real time and offline) tools to evaluate the performance of the emulated scenarios, supporting IPv4, IPv6 and Ethernet connectivity.

Keysight tools

All pertinent 6G test and measurement software tools provided by Keysight will be deployed on the Athens platform, with the explicit objective of boosting and augmenting the capabilities of the platform. These tools will be integrated seamlessly into the existing infrastructure, equipping the Athens platform with advanced functionalities for comprehensive testing and measurement within the context of 6G technology. This strategic deployment aims to enhance the platform's potential and enable efficient evaluation and optimization of 6G networks, thereby supporting the experimenters.

OpenNebula

OpenNebula will be installed in the Athens platform, serving as an additional infrastructure manager within the broader infrastructure of the 6G-SANDBOX facility. By leveraging OpenNebula in the Athens platform, users/experimenters will benefit from its robust features and capabilities, since the platform enables the expansion of multi-cloud environments to the edge, combining the utilization of virtual machines (VMs) and containers. This allows for increased flexibility in application deployment, catering to diverse requirements. Furthermore, OpenNebula's ability to leverage public cloud and edge resources ensures that the Athens platform can tap into a wide range of infrastructure providers. By utilizing resources from different providers, the Athens platform can effectively harness the power of hybrid and edge environments, providing enhanced performance and scalability.

Open5GS

As of the time of this document's writing, a "clean" installation of Open5GS core network is currently underway and is aimed at advancing the capabilities of Athens platform. Moreover, the Amarisoft RAN will be seamlessly integrated with the Open5GS core. Open5GS is an open source 5G core network and a highly suitable option for the Athens platform due to its support for distributed NF deployments, which aligns with the evolution toward the distributed 6G architecture. One of the key advantages of using Open5GS is the ability to deploy UPF in different locations within the testbed, such as at the edge site and the core site, and associate them with different network slices (e.g., S-NSSAI). Overall, this approach allows for greater flexibility and enables the support of multiple user planes in three dimensions, including network slicing, traffic steering, and Application Function (AF) traffic influence.

Ericsson mmWave

The Athens platform and more specifically COSMOTE site, is set to undergo an enhancement in the RAN segment, through the integration of Ericsson mmWave technology. This enhancement aims to optimize and strengthen the platform's ability to provide reliable and efficient wireless connectivity, enhanced coverage, increased network capacity, and improved performance in the outdoor environment.

2.3 BERLIN PLATFORM

Fraunhofer FOKUS operates the 5G Playground in its location in Berlin. The Playground is used in multiple Projects to implement and validate various use cases for 5G and upcoming 6G. It is also used for the implementation of the Open5GCore Platform. The Playground has a long history in the mobile communication field and has constantly evolved from older technologies like 3G and 4G.

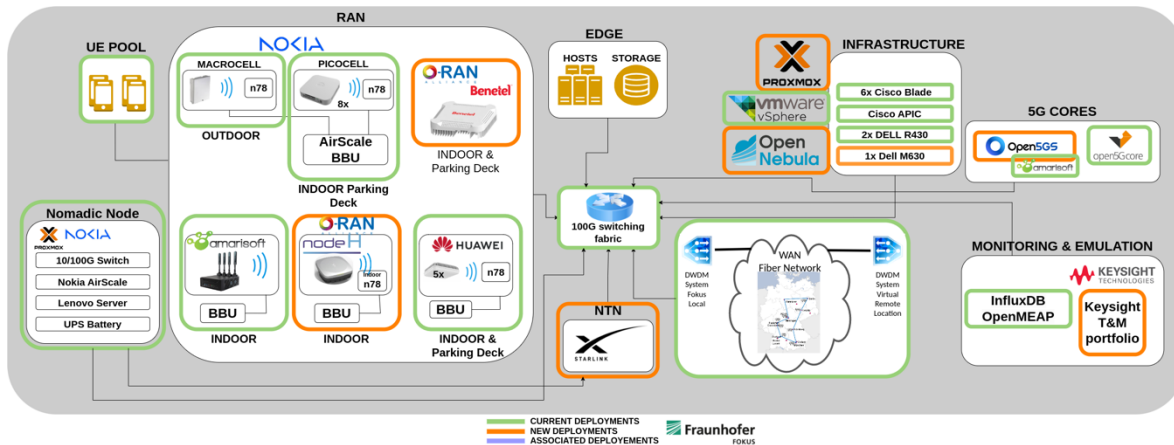


Figure 4: Berlin Platform

In its current state, the platform consists of outdoor and indoor 5G cellular equipment from various vendors using mainly the Private network spectrum 3.7 to 3.8 GHz band n78.

Indoor coverage includes a distributed MIMO cell installation from Huawei and Nokia covering the entire underground parking deck, which is also used by other departments for autonomous driving activities. Another Nokia Macro Node cell is located on the roof to provide outdoor coverage in the vicinity of the building. Throughout the laboratory floor, Huawei micro remote radio heads are installed to provide coverage to the lab environment. In addition to the “big” vendor RAN we also have SDR based gNodeB from Amarisoft and ETTUS USRP supporting OpenAir and srsRAN software stacks. To cover ORAN use cases, the USRP-based setups can be used in addition to small cells from NodeH. The networks are configured as 5G SA with Slicing and RAN Sharing enabled to support multiple core networks at the same time. As core network the Fraunhofer FOKUS developed Open5GCore is used most of the time. However, other (open source) cores are also available and can be activated for specific PLMN (MCC/MNC). The Playground basically operates multiple standalone Operators, each with its own pool of sim cards, which can be produced on demand.

For the UE side, the playground has mobile phones from several vendors interconnected to multiple indoor locations and accessible via ADB remote control software. In addition to the consumer mobile phones, embedded modem M.2 cards and CPE Devices are also available.

In addition to the fixed installed RAN components, so-called Nomadic Nodes are available. These Fidge-sized mobile racks include compute, network and storage resources together with RAN equipment from Nokia or Huawei and power supply. These Nodes can be used to implement and validate nomadic ad-hoc private network scenarios.

From the infrastructure side, the playground components are interconnected with operator grade 100 Gbit switches that operate in a redundant leaf spine architecture. Dedicated Isolated network setups can be created by management software and further delegated to individual projects. Compute and Storage resources are managed by VMware hypervisor which provides virtual machines to the projects using the Playground. In addition to the six VMware servers, bare metal servers can be added to the infrastructure to support special use cases which rely on direct hardware access. For the 6G-SANDBOX project, the installation of additional servers with the Proxmox virtualization system is planned.

In addition to the redundant 1 Gbit internet uplink via the DFN, the testbed also has a direct fiber connection to a German wide WAN fiber loop. By using a 96-channel Carrier grade DWDM system from Nokia, this WAN link can be used to connect remote locations across Germany. By using two of these DWDM systems, a 900 KM loop is configured which can be used to simulate remote locations in the same testbed. To cover NTN use cases, a Starlink antenna is also available in the playground. A secondary Starlink antenna used for nomadic applications is planned in 2023.

2.4 OULU PLATFORM

University of Oulu has 5G Test Network (5GTN) with campus wide small cell, macro-cell and distributed antenna based cellular network to be complemented by NFV based EPC and 5G backhauling solution (<http://5gtn.fi/>).

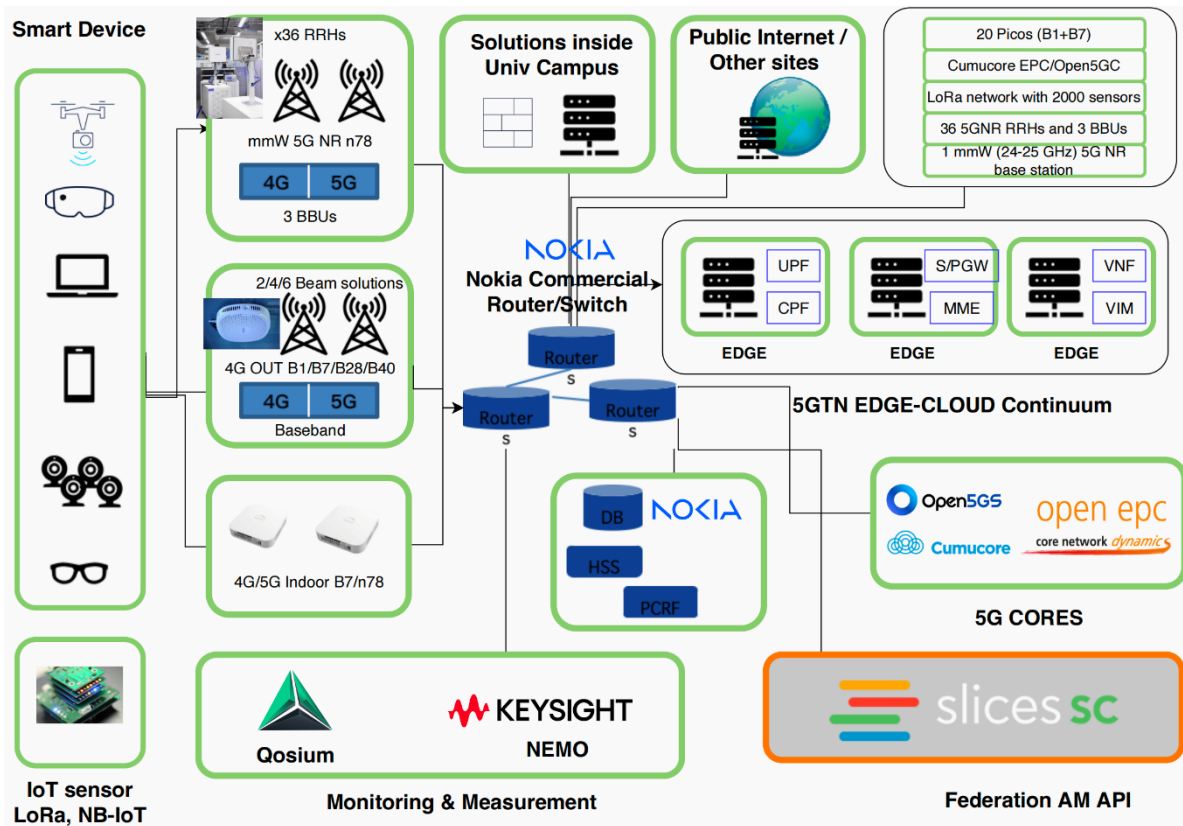


Figure 5: Oulu Platform

Full-scale 5G test network supports using 5G devices, higher frequency bands, cognitive management functionalities, system testing tools for new solutions. The 5G Test Network feature evolution follows 5G research and standardization progress, acting as verification platform for theoretical 5G research. The cellular devices part of the network is composed of 30 LTE small cells (700 MHz, 2.1, 2.3, 2.6, 3.5 GHz) and 2 macro cells (2.3 GHz). The network has two 5G NR base stations (3.5 GHz) complemented with User Equipment from MediaTek (10) that are easily integrated to any device, and 5G enabled mobile phones from several vendors. The network is currently being complemented by mmW (24-28 GHz) 5G NR base stations as well as with 36 remote radio head (RRH) based cloud RAN 5G NR devices. For research purposes, we have also several pre-standard 5G capable NOKIA proof-of-concept (PoC) devices at 26-28 GHz. In early 2023, NOKIA Open edge system will be deployed allowing the use of RAN Intelligent Controller (RIC) with xApps.

We have also deployed open air interface (OAI) 4G and 5G NR protocol stacks with USRP radios. The network is controlled by operator grade EPC (Evolved Packet Core), thus making OULU in practice a network operator with production SIM cards for mobile devices. The current operational EPC version is 5G NSA compliant, but for research purposes 5G stand-alone (SA) core is also available. The network within the campus is complemented by wireless sensor network (IoT, internet of things) extension with approximately 2,000 different types of sensors with wireless connectivity through NB-IoT, LTE-M and LoRa. Furthermore, the network has large data computing servers for network data analytics purposes. Some of these servers are distributed within the network thus allowing multi-access edge computing (MEC) as well as caching services. The NOKIA EPC has open application programming interfaces (virtualized EPC) that make it possible to integrate new services to e.g., network management.

In the future, OULU platform will include SLICE-SC to facilitate full control over the parameters of an experiment and enable the repeatable experiments regardless of the physical infrastructures, i.e., different sites within the consortium, and conduct valid experimental results, which are easy to cross-reference and replicate. SLICE-SC provides Transnational Access to its available infrastructures, which means free of charge, transnational access to research infrastructures for selected user groups. The access includes the logistical, technological, and scientific support and the specific training that is usually provided to external researchers using the infrastructure. TA can be Physical Access and Remote Access. OULU will facilitate the open call through the TA enabled by the SLICE-SC.

3 KPIS MEASUREMENTS AND VALIDATION CAPABILITIES

Below is listed a set of tools and equipment available in the context of 6G-SANDBOX to be used for testing, measurement, capture and validation.

3.1 BREAKINGPOINT

Performance and Cybersecurity Testing

Capabilities: web, encrypted-web, data center, social-media, and business application mix tests, application protocols

Highlights:

- Simulates more than 640 real-world application protocols
- Allows for customization and manipulation of any protocol, including raw data
- Generates a mix of protocols at high speed with realistic protocol weight
- Offers HTTP1.0, HTTP1.1 and HTTP/2 as transport with support for NAT and Proxy (for selected applications)
- Supports more than 110,000 attacks and malwares
- Delivers from a single port all types of traffic simultaneously, including legitimate traffic, DDoS, and malware
- Bi-monthly Application and Threat Intelligence (ATI) subscription updates ensure you are current with the latest applications and threats
- Combined with the CloudStorm platform, BreakingPoint reaches a staggering performance with a fully-populated chassis—2.4 Tbps / 1.44 billion sessions and 42 million connections per second—to emulate enterprise-wide networks to continent scale mobile carrier networks
- Leverages the hyperscale performance of the new APS-100/400GE Series platform. A single APS-ONE-100 delivers unparalleled real-world TLS performance of up to 100K TLS connections per second and 3.2M TLS concurrent connections and 150Gbps encrypted throughput. The ground-breaking scale of a 10-appliance system generates 1M TLS CPS, 32M TLS concurrent connections, and 1.5 Tbps encrypted TLS throughput.

3.2 CLOUDPEAK

Virtual network infrastructure validation

Capabilities: web application to benchmark the performance of virtualized network infrastructures, Network Functions Virtualization (NFV), NFV Infrastructure (NFVI), management and orchestration (MANO), mobile edge computing (MEC)

Highlights:

- Validate and benchmark VMware vCenter and OpenStack-based private clouds
- Testbed for single compute node or large environments with many racks
- Individually validate the compute / network / storage performance dimensions
- Measure VIM performance with custom VM instantiation / VM termination test methodology
- Leverage subscription licensing for low startup cost and flexibility of pay-as-you-grow model
- Predefined test scenarios for NFVI validation
- Validate from a VNF or network perspective through real workload and powerful traffic emulation
- Includes industry-proven workload emulation from the OPNFV Yardstick portfolio
- Measure scheduler capability to isolate the good workloads and the bad noisy neighbors
- Measure the performance impact of VNF instantiation and VNF workloads in presence of (noisy) neighbors

3.3 CYPERF

Scalable network application and security testing for distributed cloud

Capabilities:

CyPerf employs lightweight agents deployed across a variety of environments to realistically model dynamic application traffic, user behavior, and threat vectors at scale. It validates cloud and hybrid networks, security devices, zero trust implementations and services for more confident rollouts.

CyPerf generates authenticated and unauthenticated application traffic and security attacks across a complex network of proxies, software-defined wide area networking (SD-WAN), Secure Access Service Edge (SASE), SSL VPN tunnels, IPsec tunnels, Transport Layer Security (TLS) inspection, elastic load balancers, web applications firewalls (WAF) and zero trust enabled environments.

Highlights:

- Test the functionality and performance of zero trust policies with authenticated and unauthenticated application traffic and security attacks.
- Validate cloud, SASE, and SD-WAN migration in half the time with more fidelity by replicating distributed deployment environments with realistic workloads.
- Emulate thousands of SSL VPN tunnels to test the scale, performance, and robustness of VPN Gateways.
- Validate the control plane performance and scalability of IPsec Gateways, as well as the application performance and security efficacy of IPsec VPN enabled network security solutions.
- Perform head-to-head comparisons to determine the most cost-effective cloud infrastructure and security controls.
- Validate elastic scalability of cloud infrastructures and security architectures with dynamic auto-scaling test agents.
- Access key performance indicators easily—application throughput, max concurrency (connections / users), application latency, Transport Layer Security (TLS) performance, and threat detection efficacy.
- Measure and compare hybrid, multi-cloud, container infrastructures for your specific workloads and security controls.

3.4 HAWKEYE

Active network performance monitoring (QoS monitoring, application & web monitoring, Wi-Fi monitoring, cloud monitoring)

Highlights:

- Take control of user experience with real-time QoS monitoring
- Proactively detect, diagnose, and fix performance problems
- Validate deployments by simulating live network traffic
- Monitor distributed networks from core to edge
- Troubleshoot outages faster with hop-by-hop visualization

Hawkeye supports a variety of service level agreement (SLA) and quality of experience (QoE) objectives, including:

- Speed test from site to site with advanced configuration on traffic profiling
- Advanced Bandwidth availability or verification with bit blasting or TCP-based testing
- Class of service (COS) implementation validation with oversubscription scenarios
- IP network SLA verification (one-way delay, jitter, loss)
- Unified communications tests (Teams, Zoom)
- Office 365 applications
- Real-time streaming verification
 - o Mean opinion score (MOS) for voice – G711, G729, AMR ...
 - o Media delivery index (MDI) for video streaming
- Echo tests (ICMP, TCP, UDP) and path discovery to any interface on the web

- User experience tests (downloading web pages, etc.)
- DNS response time
- Netflix, YouTube, and any Dash/Adaptive streaming test
- Multicast video
- Remote destination port opening verification
- Wi-Fi monitoring

Deployment solution:

- Deploy Hawkeye on premise web server in central location (NOC, data center, etc.)
- Deploy software and hardware endpoints to any network location:
- Customer premises
- Mobile devices – Wi-Fi or Cellular
- Remote sites and head offices
- Network aggregation points (PEs)
- Core network, MPLS routers
- Data centers
- Virtual machines and servers
- In public cloud locations (Amazon, Azure...)

3.5 UXM 5G WIRELESS TEST PLATFORM (MALAGA CENTERED)

Highlights:

The Keysight E7515B UXM 5G wireless test solution is a highly integrated signaling test platform with multiformat stack support, rich processing power, and abundant RF resources. Supporting the latest 3GPP Release 15 and beyond, the E7515B UXM 5G wireless test solution enables you to establish a 5G call with a device under test (DUT) in different 5G New Radio (NR) deployment modes; non-stand-alone (NSA), stand-alone (SA), and frequency bands FR1 and FR2. The solution performs signaling test for device RF characteristics, protocol compliance, and functional key performance indicators. It also supports LTE, eMTC and C-V2X signaling formats.

The E7515B UXM 5G wireless test solution supports extended test coverage in a single unit, including the following capabilities:

- 5G NR 8CC DL, 4 CC UL 2x2, with LTE 2CC
- Wide bandwidth in each RF port
- Multiple angle of arrival (AoA) test
- Internal fading for 5G NR and LTE formats
- Frequency extensions to high IF and millimeter-wave with the use of a common interface unit and remote radio heads (RRH)

3.6 IXLOAD

L4-7 performance testing and QoE testing by emulating web, video, voice, storage, VPN, wireless, infrastructure, and encapsulation/security protocols to create realistic scenarios.

Highlights:

- Offers the industry's highest HTTP, SSL, and IPsec performance and scale
- Delivers end-to-end testing of converged wireless and wired application delivery infrastructure and services
- Provides real-time insight into QoE
- Emulates fully integrated broadband network infrastructures with application traffic testing
- Serves as the only test solution in the market that can model the dynamic nature of user behavior
- Achieves seamless application performance validation across physical and virtual networks

Featured test:

- IxLoad Wireless Evolved Packet Core Simulation
- IxLoad Wireless eNodeB Simulation
- IxLoad Wi-Fi Offload
- IxLoad Data Test Solution
- IxLoad Video Test Solution
- IxLoad Voice Test Solution

3.7 IXNETWORK

L2-3 network infrastructure performance testing.

Highlights:

- Offers test coverage from 1G to 800G Ethernet
- Provides comprehensive protocol coverage for routing/switching, multiprotocol label switching (MPLS), software-defined networking (SDN), data center networking, carrier Ethernet, broadband access, time synchronization, automotive and industrial Ethernet (AVB/TSN), L2 security (MACsec)
- Generates traffic flows that mimic realistic user applications and scenarios
- Works smoothly in virtualized network environments, and runs from any commercially available compute environment
- Delivers end-to-end test system automation
- Performs rapid isolation of service violations, including thorough traffic-flow analysis

3.8 LOADCORE

5G Core Testing and Validation

Highlights:

- Simulate UE behavior in 5G use case deployments: Network slicing, multi-access edge computing (MEC) low latency and offloading, video optimization
- Perform service quality validation with subscriber modeling, multiplay traffic generation, and quality of experience (QoE) measurements
- Validate complex scenarios for service-based architectures
- Validate 5G nodes and interfaces via specialized Ixia hardware or Virtual Edition (VE)
- Scale up to millions of subscribers using stateful application traffic mixes that can interact with real servers and peers
- Enforce and validate multiple user-plane QoS characteristics per flow or session
- Control test traffic mix and intensity using network objectives to independently manage control- and user-planes

3.9 THREATSIMULATOR

A breach and attack simulation platform that provides enterprise security teams with insights into the effectiveness of their security posture and actionable intelligence to improve it.

Highlights:

- Part of Keysight's Security Operations Suite of enterprise security tools.
- Safe and cost-effective way to measure and validate the effectiveness of your production security tools.
- Enables you to perform automated breach and attack simulations on a regular basis.
- Eliminates the assumptions that security controls are deployed and configured correctly.
- Identify environmental drifts from historical visualized results.
- Active validation of all phases of the Attack Life Cycle.
- Reduces compliance audit time with data-driven evidence.

- Prove security attacks are properly identified and reported.
- Justify current and future IT spending.
- Content refreshed at regular intervals, including the provision of malware feeds daily.

3.10 EXATA

Network Digital Twins — Development, analysis, testing and cyber assessment.

Highlights:

- Scalability to thousands of nodes enables more sophisticated design and analysis
- Real-time simulation optimizes productivity
- High-fidelity models deliver accurate results
- Cost-effective “lab-based risk reduction” network simulation technology provides solutions to mission-critical, business-critical problems
- Test and validate interoperability, scalability, and performance: Seamless integration with live equipment such as servers, computers, radios, and sensors as well as a full network environment
- Accurately analyze behavior under different network conditions: Integrate with live applications such as VoIP, chat, video feeds, file transfers, and database queries
- Analyze and capture network traffic with packet sniffer/analysis tools
- Interaction with Simple Network Management Protocol (SNMP) managers from companies such as Hewlett-Packard, IBM, and SolarWinds

3.11 CLOUDLENS

Public, Private, Hybrid Cloud Visibility

Highlights:

- Capture and forward Full Packets and/or Netflow from Virtual Machine (VM), containers or inter-Pod network traffic and forward it to tools, or physical and/or virtual packet brokers for aggregation, advanced filtering, and deduplication
- Virtual packet processing and aggregation in your cloud which traditionally relies on physical packet brokers
- Aggregate and deduplicate packet data; originate and terminate tunnels without the need for physical hardware
- Virtual packet processing with AppStack capabilities leverages Keysight’s advanced application intelligence with signature-based application detection, geolocation, NetFlow and IxFlow (enhanced NetFlow)
- Management UI that can be deployed in any cloud, for better control and security
- Multi-platform capable, cloud service provider and platform agnostic
- Auto-scales elastically, on-demand with cloud instances
- Handles cloud scale (thousands of instances). Auto-scales elastically, on-demand with cloud instances
- Easy-to-use, drag-and-drop interface with a network to tools layout

3.12 PATHWAVE SYSTEM DESIGN (SYSTEMVUE)

One environment for system architecture, design, and verification

Highlights:

High fidelity RF characterization built in

1. Non-linearity, spurs, phase noise, impedance, and more
2. X-parameters, fast circuit envelope models
3. Verified waveforms and vector modulation analysis
4. Shared measurement science with decades of Keysight instrumentation designs
5. Flows directly into chip- and circuit-level RF design

Multi-domain modeling and simulation

6. Everything needed for physical layer (layer 1) analysis
7. Behavioral model libraries in intuitive workflow
8. Simulation in both time- and frequency-domain
9. Open interfaces for third party RF component models

Phased array analysis

10. Powerful frequency, time, and cross-domain simulation of complete phased array systems
11. 'Best in class' simulation speed for phased arrays and other complex RF designs
12. Intuitive array configuration and links to antenna design software
13. Beam measurement and visualization tools
14. 5G, Radar, EW, and Satellite applications

Libraries for real-world RF systems

15. MilCom & SatCom data links and SDR
16. Electronic warfare, SIGINT, and EMSO
17. Space vehicle communication links
18. 5G NR and 3GPP specifications
19. Wi-Fi 6 and connectivity specifications
20. Automotive radar systems

3.13 RIC TEST (MALAGA CENTERED)

RIC Test emulates O-RAN network nodes and traffic profiles on different RAN Intelligent Controller's (RIC's) interfaces, allowing testing of the Near Real-Time RIC (and of xApps it hosts) and of the Non-Real-Time RIC (and of rApps it hosts).

Highlights:

- Supports all E2 node types defined in the standard, at configurable mix and quantity
- Supports 5G NSA and SA configurations
- Simulation of thousands of sessions across multiple emulated E2 nodes
- Configurable allocation of emulated (UE ranges to each node
- Configurable traffic modeling to drive measurements of interest towards the xApp
- E2AP and E2 interface support
- O1 interface support
- Stateful E2AP for each emulated node
- Key performance measurements (KPM) service model support for all node types
- Network interface (NI) and RAN control (RC) service models support in roadmap

3.14 WAVEJUDGE WIRELESS ANALYZER

Modular and scalable test platform that captures and decodes LTE, 5G, and Wi-Fi signals as a part of the SJ001A WaveJudge Wireless Analyzer Toolset

Highlights:

- Unique solution for passive signal capture and analysis
- Support for 5G real time decoding
- Support for 3GPP NR Rel 15-17 (NR NTN, RedCap, V2X)
- Support for 3GPP LTE Rel 9-16
- Support for Wi-Fi 802.11ax and 802.11be
- Channel BW up to 800 MHz per port
- RF ports scalable chassis, 2, 4, 6, or 8
- Single RF module covering FR1 and FR2 bands
- SSD storage for long IQ captures to troubleshoot intermittent issues
- Superior EVM and decoding performance
- Streaming analytics and charting
- Advanced triggers
- Expanded filtering and visualizations

3.15 UESIM UE EMULATION SOLUTIONS (MALAGA CENTERED)

For Radio Access Network Testing

Highlights:

- 5G RAN functionality validation (NSA/SA mode) by full protocol stack assessment, from layer 1 to 7
- Functional testing – full stack and single layer – up to thousands of UEs
- Load testing of 5G RAN
- Up to 8xCC, 2x2/4x4 MIMO, 256 QAM DL/UL
- FR1, FR2, O-RAN eCPRI
- Massive MIMO AAS, MU-MIMO support
- Extremely compact footprint with potential to grow up to 5,000 active UEs/cell
- gNB wrap-around testing with core emulation option
- O-RAN fronthaul interface support with different 5G RAN split architecture options
- Real smartphones applications and traffic profiles simulation
- Service quality validation with subscriber modeling, and multi-play voice, video, and data traffic generation: eMBMS, VoNR/VoLTE, ViNR/ViLTE
- Inter-Beam and Inter-Cell advanced mobility scenarios support
- Fading and interference simulation
- OTA/field and conducted/lab testing
- 3GPP R15/R16 support

3.16 CuSIM – O-DU MIDHAUL SOLUTIONS (MALAGA CENTERED)

CuSIM helps infrastructure vendors, chipset providers and mobile operators active in the O-RAN arena to validate the O-DU functionality by emulating traffic over the midhaul interface

Highlights:

1. Cloud Native Architecture
2. Support of Standalone configuration procedures
3. Support of thousands of sessions across multiple O-DUs
4. Non-UE Associated F1-AP Signaling
5. UE-associated F1-AP Procedures
6. RRC and NAS Procedures
7. Support for DU Handovers
8. Network Initiated and UE Initiated QoS flows
9. VoNR
10. Option to configure single or multiple PDU sessions per UE
11. Topology-driven User Interface

3.17 RuSIM — UE/O-RU EMULATION OVER THE O-RAN FRONTHAUL (MALAGA CENTERED)

RuSIM enables infrastructure vendors, chipset providers and mobile operators to validate end-to-end Radio Access Network performance by emulating real network traffic over the O-RAN fronthaul interface.

Highlights:

1. Functional testing — layer by layer — up to thousands of emulated UEs
2. Performance and load testing
3. Protocol conformance testing
4. Compliance testing against interoperability specifications
5. Core emulation option for wrap-around testing
6. Fully scalable solution
7. Service quality validation with realistic subscriber and traffic modeling at a high scale

3.18 N6705C DC POWER ANALYZER

The N6705C DC Power Analyzer provides unrivaled productivity gains for sourcing and measuring DC voltage and current into the DUT.

Highlights:

- Ammeter accuracy: Up to 0.025% + 8 nA; up to 18 bits
- Arbitrary waveform generator function: Bandwidth up to 100 kHz, output power up to 500 W
- Data logger function: Measurement interval from 20 μ s to 60 seconds, with a maximum of 500 M readings per second
- Scope function: Digitizes voltage and current up to 200 kHz, 512 kpts; up to 18 bits
- Voltmeter accuracy: Up to 0.025% + 50 μ V; up to 18 bits

3.19 O-RAN STUDIO (MALAGA CENTERED)

for O-RAN Radio Unit (O-RU) Testing and Validation

Highlights:

- Quickly configure and generate 5G NR and LTE 3GPP single or multi-carrier compliant FDD and TDD waveforms
- Fully automated generation of Ethernet based O-RAN CU-plane messages with eCPRI transport encapsulation types compliant with ORAN-WG4.CUS.0-v10.00
- Real-time FrameID generation and CRC Calculation
- Analyze both FR1 and FR2 radio downlink (DL) and uplink (UL) paths
- O-RAN Sections types and Section Extensions configuration
- Beamforming support
- Capture and accurately timestamp O-RAN responses
- Visualize and fully decode O-RAN traces with flow-based filtering
- Supports split option 7.2x compliant CU-plane stimulus generation and analysis
- Measure O-RAN traffic over 10 Gbps / 25 Gbps (fronthaul) Ethernet interfaces

3.20 AC POWER ANALYZER

The Keysight IntegraVision power analyzer is an intuitive combination of accurate power measurements and touch-driven oscilloscope visualization. Within a single instrument, it delivers the dynamic views you need to see, measure, and prove the performance of your design.

Highlights:

- Measure voltage, current, and power on 4 channels: DC, 1-phase AC or 3-phase AC
- Make more accurate power measurements: 0.05% at 50/60 Hz
- Measure current directly: internal shunts to 50 Arms, or with external probes or transducers
- Address multiple test scenarios with isolated inputs
- Achieve power analyzer accuracies and scope-like waveform visualization with reduced setup time
- Address multiple test scenarios with the flexibility of wide-ranging, isolated inputs
- Visualize transients, in-rush currents, and state changes with a high-speed digitizer that captures voltage, current, and power in real-time
- Analyze voltage, current, and power in the time and frequency domains
- Explore your design and gain new insights through the 12.1" / 310 mm high-resolution display with a touch interface
- Save space on your bench with a minimum-depth form factor.

3.21 NEMO WIRELESS

Nemo Wireless Network Solutions provides drive testing and analytics solutions for all stages of the wireless network life cycle from rollout to optimization and monitoring, both outdoors and indoors.

Highlights:

Nemo Handy

- Create complex measurement scripts more easily and effectively
- Reduce test time with the intuitive user interface
- Verify the end-user QoE (Quality of Experience) with a wide range of data-testing capabilities:

- voice call testing, voice quality testing, FTP and HTTP data transfer testing, HTML browsing, email testing, iPerf testing, TWAMP testing, ping testing, SMS & MMS messaging testing, external application launch testing, mScore testing, Fast.com data testing, and video quality testing
- social media testing apps/protocols, including YouTube video and live video streaming, Facebook testing, Twitter testing, LinkedIn testing, Instagram testing, Dropbox testing, Google Drive testing, WhatsApp testing, Line testing, BiP Messenger testing, Viber testing, and Zalo testing
- Navigation application providing turn-by-turn instructions for your drive test campaigns (optional)
- Perform large-scale site acceptance projects with the optional Nemo Handy Site Acceptance Edition together with Nemo Cloud
- Perform audio quality tests (POLQA versions 2 and 3) and video quality testing including 4K PEVQ-S
- Combine scanning and indoor measurements with portable, battery-operated PCTEL Gflex™ / IBflex™ / HBflex™ and R&S®TSMA6 Autonomous Mobile Network scanners
- Streamline operations and improve responsiveness with the Nemo Cloud option, a cloud-based platform for centralized remote control
- Create fast and efficient reports in the field with the optional Nemo Instant Report option
- Available in the following product editions: Nemo Handy Field Test (FT), Nemo Handy Basic, Nemo Handy Pro, Nemo Handy Pro+, Nemo Handy Lite, Nemo Handy Autonomous, Nemo Handy Work Order, Nemo Handy Site Acceptance, and Nemo Handy SSV (Single Site Verification)

Nemo Outdoor 5G NR Drive Test

- Quality-of-experience (QoE) metrics for the services and applications your customers are actually using.
- Automated measurements with extensive scripts and large-scale measurement lists enable you to focus on the actual task at hand during drive testing.
- User-defined parameters from signaling messages can be searched and displayed in info view and graph side panel during measurement and playback.
- Versatile benchmarking capabilities, including Nemo Network Benchmarking Solution (NBM) and Nemo Backpack Pro.
- Supports Qualcomm X50/X55/X60/X65/X70, Samsung Exynos 5100/5123/5123A/5123B/ 5133/5300, HiSilicon Balong 5000, and MediaTek M70/M80 modem-based devices devices, and 3rd party scanning receivers.
- Supports 5G NR standalone (SA) and non-standalone (NSA) mode testing.
- Supports 5G NR carrier aggregation testing.
- Supports 5G NR NSA/SA forcing.
- Supports 5G NR channel/PCI forcing.
- Collects 5G NR beam specific KPIs.
- Supports massive MIMO (mMIMO) drive tests and field measurements.
- Supports Dynamic Spectrum Sharing (DSS) measurements.

3.22 VXG SIGNAL GENERATORS (MALAGA CENTERED)

The Keysight M9383B VXG-m Microwave Signal Generator is the industry's first dual-channel microwave signal generator providing up to 44 GHz frequency.

Highlights:

- Wide RF bandwidth (2 GHz)
- High output power to compensate for system loss and enable 5G power amplifier and over-the-air (OTA) testing

- Phase coherent local oscillator (LO) and baseband synchronization for multiuser or beamforming MIMO OTA testing
- PathWave Signal Generation software supports application-specific and custom signal creation
- 3GPP 5G NR standard-compliant signals with channel coding and multi-antenna port support

4 GUIDELINES TO BE CONSIDERED IN THE PROPOSALS

This section covers guidelines for the proposers to ensure specificities of the 6G-SANDBOX platform are taken into account. All these details are not expected to be part of the initial proposal, but proposers will be assisted to produce their final contributions considering all of them.

4.1 REQUIREMENTS FOR DEPLOYMENT IN VIRTUALIZED ENVIRONMENT

Proposers should provide enough information on the packages to deploy their software in the virtualized infrastructure available in each platform. The following information is a reference for software packages to be deployed in Open Nebula.

4.1.1 USING YOUR VIRTUAL MACHINES

An experimenter can prepare their own virtual machines to be part of the experiment:

- 6G-SANDBOX will provide **base templates** consisting of a base installation of popular operating systems. Initially Ubuntu, Debian, Alma Linux and FreeBSD will be provided.
- **Customized versions of the base templates** can be developed by the experimenter through the 6G-SANDBOX platform. The customized versions will be included in the 6G-SANDBOX for later use in any experimenter's TN.
- The experimenter can also customize the following attributes of the VM:
 - o **CPU topology**, including number of NUMA nodes, cores and threads per core
 - o **Memory**.
 - o **QoS requirements**, for example to ensure that a predictable number of resources are devoted to the VM.
 - o **Scratch storage** disks, to store experiment data during the experiment
 - o **User data**, to pass custom data to the VM (e.g., parameterization parameters or credentials) or execute custom scripts at boot time.
 - o **GPU**, devices to perform specific processing.

4.1.2 USING YOUR HELM CHARTS

When a Kubernetes cluster is deployed as part of the TN, the experimenter can include any application to be deployed automatically. The requirement to deploy such applications are:

- The Kubernetes application must be described as a helm chart
- The helm charts must be included in a repository provided by the experimenter
- All components referred by the helm chart need to be provided by the experimenter or accessible through a public repository.

4.1.3 PROPRIETARY SOFTWARE

6G-SANDBOX will not provide commercial software or specific OS aside from the one mentioned in this document. If your work requires a special version or specific operating system, please check for availability. If not available, be sure to plan for this as part of your work.

4.2 INCLUDING SUPPORT TO MONITOR KPIS AT APPLICATION LEVEL

The collection and delivery of KPIS will be managed using *Network as Code* (NaC) paradigm using an Application Developer NaC API. This interface will provide a set of applicable functions that will be used by the end-device

connected application. The functions will provide information about the application KPIs and the connected radio link. Below are some examples showing some functions with their returned data:

- To get the status of the radio from a defined slice ID:

Function	Return data
<code>Radio_Status(Site,21438, Slice_21438_12)</code>	<code>(OK Radio_OFF Slice_OFF Radio_Slice_OFF)</code>

- To submit a KPI using a defined sliced ID related to video:

Function	Return data
<code>Slice_KPI_send(Slice_21438_12,KPI_Video, 3)</code>	<code>(OK Failed)</code>

- To provide access to Application KPIs and data from slice ID:

Function	Return data
<code>Slice_KPI_get(Site,21438,Slice_21438_12, Start_time,End_time)</code>	<code>(File csv with KPIs)</code>

The implementation code will be provided for sending and reading experiments KPIs. The following is a python script that interacts with the API:

```

1 from __future__ import print_function
2 from nac_client import NacApi
3 from xr_video_stream import XRVideoStream
4 from pprint import pprint
5 from datetime import datetime, timedelta
6
7 # Parameters:
8 server = 'http://127.0.0.1:8000'
9 username = 'user'
10 password = '123456'
11
12 # Create instance of the NaC API class:
13 api = NacApi(server, 'basic', username, password)
14
15 print('\n#### Sites:\n')
16 pprint(api.getListOfSites())
17
18 print('\n#### Site:\n')
19 pprint(api.getSite('malaga_testbed'))
20
21 print('\n#### Create new slice:\n')
22 new_slice = api.newSlice('malaga_testbed', '21438', 'Slice_xr_video')
23 new_slice_id = new_slice.id
24 pprint(new_slice)
25
26 print(f'\n#### Slice ("malaga_testbed", "21438", {new_slice_id}):\n')
27 pprint(api.getSlice('malaga_testbed', '21438', new_slice_id))
28
29 # Create a extended Reality Video Session and send some video KPIs
30 if api.radioStatus('malaga_testbed', '21438', new_slice_id) is 'OK':
31     xr_session = XRVideoStream(new_slice_id)
32     video_data = xr_session.getStreamData('cam0')
33     if video_data:
34         if 'bitrate' in video_data:
35             bitrate = video_data['bitrate']
36             api.sliceKPIsend(new_slice_id, 'bitrate', 3)
37             pprint(f'KPI bitrate with value {bitrate} sent\n')
38         if 'jitter' in video_data:
39             jitter = video_data['jitter']
40             api.sliceKPIsend(new_slice_id, video_data['jitter'], 3)
41             pprint(f'KPI bitrate with value {jitter} sent\n')
42
43 # Get all KPIs from last hour
44 with open('slice_kpis.csv', 'w', newline='') as kpi_file:
45     kpi_data = api.sliceKPIget(
46         'malaga_testbed',
47         '21438',
48         new_slice_id,
49         datetime.now() - timedelta(hours=1),
50         datetime.now()
51     )
52     if kpi_data is not None:
53         kpi_file.write(csv_data)

```

4.3 API REQUIREMENTS

The purpose of the open call is to enlarge and make the 6G-SANDBOX experimental infrastructure ready for advanced experimentation.

All of the components, services or infrastructure, arriving through the open call, that have an API for management, operation or service, must/should be able to integrate and publish their services in CAPIF.

4.3.1 WHAT IS CAPIF?

CAPIF is a standard defined by 3GPP, which aims to "apify" the network and proposes a series of standards to address and solve the harmonized and secured exposure and consumption of APIs. **CAPIF can be defined as a directory of APIs.** API specifications are stored in CAPIF as well as information to consume these APIs. In turn, CAPIF proposes solutions related to the consumption of APIs (Access control, Monitoring, Security, Events, pay per use, discovery, etc.).

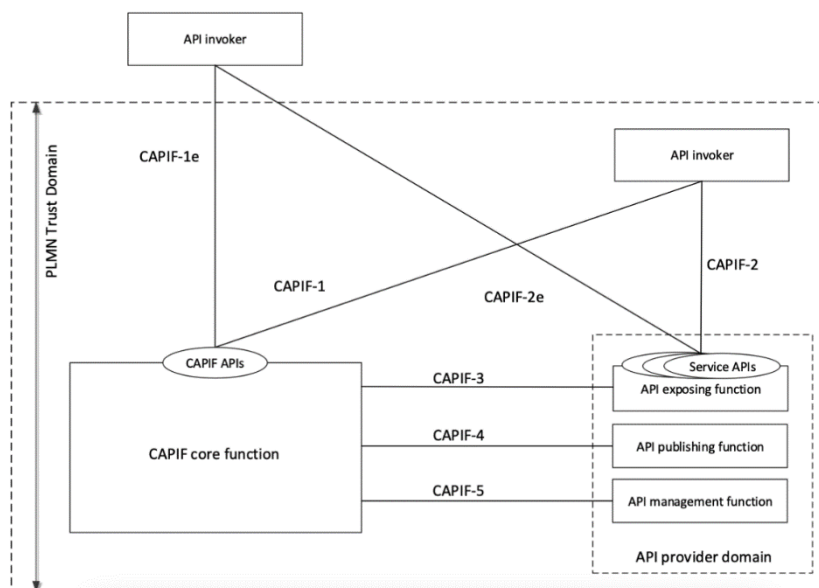
4.3.2 HOW DOES CAPIF WORK?

CAPIF is made up of a series of services, with each service being responsible for a task (e.g., security, logging, monitoring, etc.). Each service is explained in depth in the services section.

CAPIF defines a set of logical entities that are the ones that operate with CAPIF and with the APIs, these entities are:

- **Invoker:** It is the equivalent of a "client" that consumes APIs. This Invoker will have to register with CAPIF, discover the APIs, and consume them.
- **Provider:** The provider can be seen as the service provider which in turn consists of three other entities:
 - **AEF (API Exposing Function):** This entity is in charge of exposing the different services that are registered in CAPIF
 - **APF (API Publishing Function):** This entity is in charge of publishing the different services
 - **AMF (API Management Function):** This entity is in charge of managing the provider (i.e., update the provider, remove provider, etc.)

The following diagram shows the CAPIF architecture.

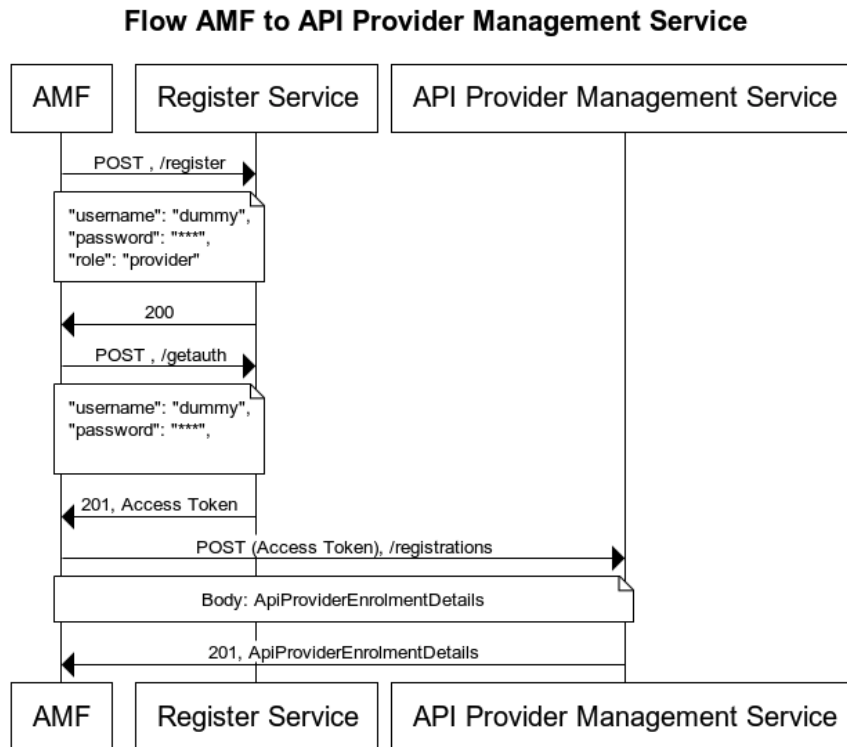


4.3.3 EXAMPLES

To better understand the integration with CAPIF, several examples are included below:

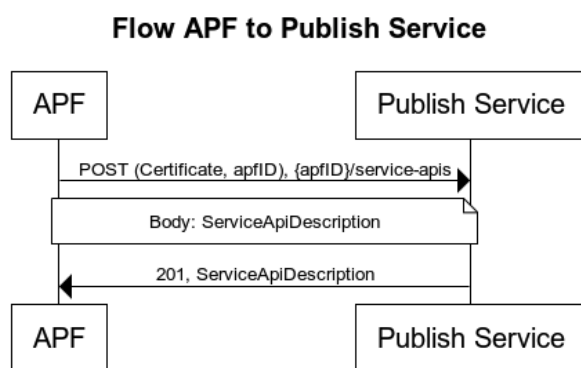
4.3.3.1 HOW TO REGISTER A PROVIDER INTO CAPIF

The provider (AMF) must use previously provisioned credentials to obtain a token with which to onboard and obtain their ID and the certificate signed by CAPIF certification authority with which to communicate with CAPIF services.



4.3.3.2 HOW TO PUBLISH AN API INTO CAPIF

The provider (APF) should publish their services into CAPIF in order to be discoverable by invokers.



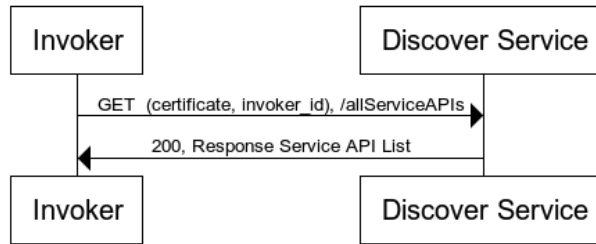
4.3.3.3 HOW TO REGISTER AN INVOKER INTO CAPIF

Just as with the provider, the invoker must use previously provisioned credentials to obtain a token with which to onboard and obtain their ID and the certificate signed by CAPIF certificate authority with which to communicate with CAPIF services.

4.3.3.4 HOW TO DISCOVER AN API VIA CAPIF

An invoker can discover published service APIs and retrieve a collection of APIs according to certain filter criteria.

Flow Invoker to Discover Service

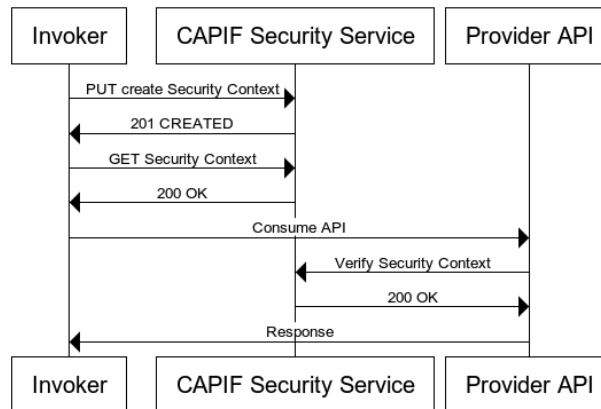


4.3.3.5 HOW TO CONSUME AN API VIA CAPIF

Although CAPIF is not an API gateway, it can manage security aspects of API exposition (certificates or token management); however, the following steps must be completed before an invoker can consume those API.

- 1- An invoker should create a security context into CAPIF indicating which service is to be consumed.
- 2- The next step is to obtain previous security context.
- 3- The invoker can then consume the API but also the provider can verify the security context to check if the invoker is authorized (This step depends on whether tokens or certificates are being used).

Invoker consume Provider API



4.3.4 OTHER CONSIDERATIONS

6G-SANDBOX testbeds will have a CAPIF Core Function deployed along with the 5G Core. CAPIF Core function will be available at a different URL for each testbed as shown below:

URL	PORT
capif.malaga.6g-SANDBOX.eu	443
capif.berlin.6g-SANDBOX.eu	443
capif.athens.6g-SANDBOX.eu	443
capif oulu.6g-SANDBOX.eu	443

Providers should obtain their credentials to access CAPIF by contacting via email to malaga.testbed@6g-SANDBOX.eu

*Note: URLs and emails should be confirmed in the coming weeks.

4.3.5 CONCLUSIONS

CAPIF functionality is considered a cornerstone in the realization of 5G openness, since it allows secure exposure of 5G core APIs to third party domains. CAPIF functionality also enables third parties to define and expose their own APIs. Indeed, CAPIF has already become a fundamental feature for the 3GPP SA6, targeting the interaction of Verticals with the 5G system. More precisely, CAPIF compliance is required in the following:

- Development of Vertical Application Enablers (VAEs) for various industries (V2X, Factories of the Future, etc.)
- Realization of the Service Enabled Architecture Layer (SEAL)
- Implementation of the service side of Edge Computing services.

To go deeper into CAPIF's specifications, you can visit these links: [29222](#), [23222](#), [33122](#).

4.4 LICENSING REQUIREMENTS

Every software module to be integrated in 6G-SANDBOX platforms should be documented regarding the following points:

1. If the software requires a valid license to be used, details on how many licenses of the module are to be provided per platform, as well as information about copy protection mechanisms (e.g., USB dongle, server license, node locked license, etc.), if any. If the software module can be used by different users, information on how many users per license are supported, and details on how to generate/obtain credentials for each user.
2. Since the software may be used outside of the platforms by external experimenters accessing remotely, licensing should also address any location-related restriction.
3. If the software module depends on additional licenses produced by a third party (for example, the software module is an extension of a commercial or open-source software with a restrictive licensing model), the burden of obtaining the necessary licenses is with the proposer.

It is responsibility of the software module provider to ensure that IPR and licensing is properly described and handled by the proposer. In no case will the 6G-SANDBOX Project be liable due to mishandling or bad practice on the part of the proposer.

4.5 HARDWARE REQUIREMENTS

We envision that proposals may include hardware as part of the project. Hardware will broadly fall into two general categories: base stations (BS) (in a broad sense) and user equipment (UE), such as mobile devices, smartphones, tablets, laptops, etc.

6G-SANDBOX needs to know at submission stage about special requirements which the hardware may imply. The requirements are needed to understand the deployment implications.

In general, UE devices must be compatible with 3GPP TS 38.101, specifically in terms of operating spectrum, maximum transmitted power and receiver sensitivity.

The base station equipment should follow 3GPP TS 38.104. If the base station provides beam steering capabilities with a high gain antenna, it is expected to have an available API to ensure the ability to illuminate the 6G-SANDBOX RIS effectively. Further information on RIS can be found in section 4.6.

4.6 REQUIREMENT AROUND PROPOSAL CONTRIBUTING RIS TECHNOLOGIES

Proposal contributing additional RIS technologies to the 6G-SANDBOX testbed are not limited by weight, size or power consumption as long as the provider can ensure its safe operation.

Proposal must include an example scenario describing how the RIS should be used in the 6G-SANDBOX environment. An example of such a scenario using the 6G-SANDBOX MM-wave RIS is shown below in Figure 6.

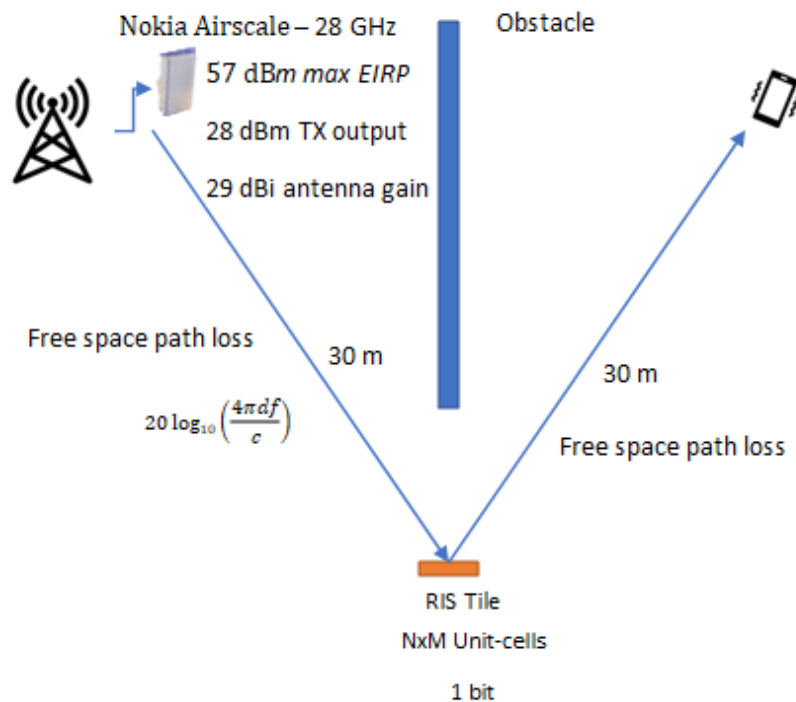


Figure 6: Communication scenario with RIS-assisted channel

5 TECHNICAL INFORMATION

5.1 ABOUT 6G-SANDBOX

6G-SANDBOX is a HE funded research project (HORIZON-JU-SNS-2022-STREAM-C-01-01). The project brings a complete and modular facility for the European experimentation ecosystem (in line and under the directions set by SNS JU), which is expected to provide support for the next decade for technology and research validation processes needed in the pathway towards 6G.

The project target is to technologies and research advances, that span over the entire service provisioning chain, and refer to user/data, control and management planes. In this direction, 6G-SANDBOX introduces the concept of Trial Networks, which refers to fully configurable, manageable and controlled end-to-end networks, composed of both digital and physical nodes.

The 6G-SANDBOX Trial Networks incorporate infrastructures distributed in EU (namely in Malaga, Athens, Berlin and Oulu) and offer to third parties (including experimenters from open calls) automated experimentation capabilities through a rich and extensible toolbox. Meant to create tangible and long-term impact, the 6G KPIs and KVIs that will be quantified with the facility, will be released to any interested party; while the set of developments and APIs that will be produced, will feed an open repository as an initial step to move the contributions and the lessons learned beyond the project borders and define a European 6G library.

A description of the 6G-SANDBOX facilities can be found on the project website at <https://6g-sandbox.eu/pilot-6g-sites/>. Further documentation can be found in the [deliverables](#) and in the [Guide for Applicants](#).

Technical scope of the Call

In respect to the **new infrastructures and functionalities** we are looking for the following implementations:

- Integrated Sensing & Communication (ISAC or JCAS) to save energy.
- Technology for use cases in Internet of Sense
- RIS infrastructure to expand the 6G-SANDBOX capabilities in FR1 and or FR2
- Expanding the 6G-Sandbox testbed With Content Distribution Networks for Quality of Experience
- Portable data center / smart furniture for 6G AI/ML workloads
- Self-learning, evolving Digital Twin. Based on real time data
- Testbed network operation center //Experimentation / "experimental load balancer" front end for optimal experimentation (PORTAL)
- Stand-alone mmWave early modules & infrastructure
- Dynamic slice allocation, entitlement server
- 5GPPP final results integration in 6GSANDBOX
- 5G Multicast-Broadcast Services (MBS)
- Use explainable AI (XAI) to improve O-RAN functionality in 6G networks.
- provision system for eSIM
- AI techniques for autonomous network management / Zero touch
- Support of Ambient IoT devices
- Expanding 6G capabilities

... as well as further topics of community interest.

All activities performed in the Open Call must be made available to other experimenters during the rest of the project duration. Any approved extension and or experimentation are seen as building blocks that may require maintenance during the rest of the project period.

Innovative experiments - In alignment with the overall project objectives 6GSANDBOX is organizing a competitive open call targeting external organizations, including industry, SMEs, research institutions, and academia, interested in performing experiments on the top of the infrastructure provided by the 6GSANDBOX. This open call invites experimenters to use the 6GSANDBOX experimental facilities, by taking advantage of the provided testbed features, in order to deploy and test broad scope of applications, e.g., coming from various vertical sectors, tailored for the future 6G communications networks.

5.2 DETAILED DESCRIPTION OF INDICATED IMPLEMENTATIONS (NEW INFRASTRUCTURES AND FUNCTIONALITIES)

Integrated Sensing & Communication (ISAC or JCAS) to save energy

Integrated sensing and communication (ISAC), also called Joint Communication and Sensing (JCAS), is an emerging technology in the field of wireless communication networks that aims to combine sensing and communication functionalities within a single device or system. In ISAC, the same hardware, such as antennas, transceivers, and signal processing units, is used for both detecting and monitoring the surrounding environment (sensing) and transmitting data or information about the observed phenomena (communication). ISAC is one of the topics investigated by 3GPP in the context of Rel-19. By using RF signals emitted by gNBs, ISAC systems can detect and locate people by analyzing changes in the signal characteristics caused by the presence of humans. For example, the received signal strength (RSS) or time of arrival (ToA) may vary as people move around, reflecting their position or presence.

Once the ISAC system detects and locates people, it can communicate the information to a central server, nearby devices, or other parts of the network. This data can be used for various purposes, such as security, smart home or building automation, crowd monitoring, or emergency response.

- The 3rd parties are expected to design, integrate, and test a prototype of passive radar that analyzes reflection of 5G signals to detect the presence of people in a given area, e.g., to control lighting.
- Alternatively open callers are requested to provide innovative means and methodologies of sensing objects in the 3D environment. Potential extension is “fiber as a sensor” where consortium extends the understanding of JCAS towards using appropriate metrics and measurement methods in order to be able to detect objects (small/big, static/moving) in vicinity of a fiber that is deployed under the ground. The main target is providing a kind of “sensor fusion” that would improve identification of the context.

Involved testbeds/platforms: Malaga and Athens

Technology for use cases in Internet of Sense

Use cases of Internet of Senses, with special focus on the application that will enable the public event committed for the project. In particular, the application is centered on telepresence: a real-world scenario is captured in real-time to provide to remote participants the multimodal feeling (audio, video and haptics) of being present there and communicating with people.

- The Goal is to enrich the combination of XR technologies for the use case and analyze potential additional requirements for the network, and associated KPIs/KVIs
- The Requirement: Technology which can be used to provide a realistic feeling of presence for remote people in the real environment being captured, so the people there have a better feeling of having those remote users effectively present there. Possible technologies usable with this goal:
 - Large volumetric displays capable of representing in real time the remote participants, either as 3D video or avatars
 - Any kind of holographic-like devices
 - Realistic avatar technology capable of animating photorealistic models of remote participants (ideally presenting their real aspect), including clothes.
 - Body sensors for capturing different parts of the remote participants, used to animate the avatars.
 - Volumetric capture setups, capable of capturing and transmitting point clouds representing the remote participants.
 - Visual pointers or actuators which can reflect in the local scenario the actions of remote participants (robotic arms, laser pointers, etc.)
 - 360 or 180 video streaming in real-time and bidirectional.
- Specific requirement for using Malaga testbed: Use of the KPIs API and XR extension for 5G provided by the project.

Involved testbeds/platforms: Malaga and Athens

RIS infrastructure to expand the 6G-SANDBOX capabilities in FR1 and or FR2

Description: 6G-SANDBOX would like to expand the experimental networks by adding RIS (reflective Intelligent Surface) to the deployment. The RIS can be targeting FR1 and or FR2 bands. Components proposed need to have a good level of maturity to be deployable in public spaces (RIS that are only available for lab demonstration will not be considered). The purpose of the deployment is to enable RIS experimentation until the end of the 6G-SANDBOX project. The Open Caller can propose hardware and software, can include deployment activities and should include a validation measurement campaign. The solution needs to be integrated with the platform and propose the necessary API to be driven by the 6G-SANDBOX experimental framework.

Involved testbeds/platforms: all.

Expanding the 6G-Sandbox testbed With Content Distribution Networks for Quality of Experience

The delivery of digital content over the Internet is critical. Content Distribution Networks (CDNs) are essential to ensure optimal Quality of Experience (QoE) for end-users. We are looking for technology providers to enhance our testbed with CDN capabilities to investigate the impact of cellular networks (5G & 6G) in the QoE.

Specific Requirements:

- The CDN shall be able to provide analytics that allows monitoring of the QoS (and potentially QoE) in real-time or near-real-time.
- The solution shall be compatible with 5G and mobile edge computing (MEC) architecture.

Optional Requirements:

- Remote API to control the CDN capabilities and configuration is a plus.
- Providing a content library (videos) of different qualities (4K and beyond) is a plus.

Involved testbeds/platforms: All platforms.

Portable data center / smart furniture for 6G AI/ML workloads

6G-SANDBOX welcomes physical HW providers that deliver edge servers which are highly configurable and provide number of various processor types (e.g. ARM, AMD, Intel, FPGA, etc), dedicated RAM and disc space, under operation of a middleware that provides manageability of applications and configurations, in order to support novel 6G use-cases that would benefit from such dedicated HW.

- Optional Requirements: Existing API or middleware that provides services deployment, management, and configuration.
- Specific Requirements: The HW should be able to operate at same time multiple independent workloads, including workloads with strict low-latency requirements, provide interfaces for monitoring energy consumption, checking the state of internal machine modules, provide hot-swap of the HW modules and very low energy cooling. Optimally the solution should be able to operate some kind of cognitive plane (or selected components), where it is feasible to manage workload deployment and scheduling in smart fashion.

Involved testbeds/platforms: All platforms.

Self-learning, evolving Digital Twin. Based on real time data

6G-SANDBOX has deployed a Digital twin platform for the testbeds. The Digital Twin platform relies on models that are: or created purely in software by modelling functionalities and impairments or are based on a set of measurements actually reflecting the device's actual performance. The work we expect to take place here will be to add additional models to the toolchain and library, leveraging the existing API and ability of the tool to accommodate additional functionality. The models requested are created from the 6G-SANDBOX actual infrastructure and can be extracted through on-site measurement campaigns. The deliverables are actual models where a match between actual performance and the digital twin can be demonstrated.

- Specific Requirements: Understanding and past experience with modelling of network elements needs to be demonstrated. Experience with Digital twin platforms and validation is also needed.

Involved testbeds/platforms: All platforms.

Testbed network operation center //Experimentation / "experimental load balancer" front end for optimal experimentation (PORTAL)

With the advent of software networks, resources can be allocated in a very flexible way. 6G-SANDBOX is composed of 4 facilities which can be used to experiment. At the same time, the infrastructure is designed to allow multiple users to benefit from it. One issue in the case of experimentation is the need to control the exact state of the infrastructure while running the experimentation. The reason being that the results of one experimentation could be influenced by another concurrent running experiment. To solve this problem, a load balancer is needed to control and allow experimentation to run. This component is part of the network operation center which allows a user to run an experimentation or to schedule it at a point in time that it can run in proper conditions. This condition takes into account the use of the infrastructure by the other experimenters. This task is to design the experimental load balancer.

Involved testbeds/platforms: All platforms.

Stand-alone mmWave early modules & infrastructure

Current deployments of mmWave gNBs in 6G-SADNBOX require 4G connectivity in order to support Non-SatandAlone mode, using 26GHz or 28GHz for the mmWave part. Some vendors are now introducing pre-commercial Stand-alone mmWave gNBs that will evolve in terms of bandwidth and other features in 2024. However, they are not still in the normal procurement channels. For this reason, the project is requesting prototypes or pre-commercial equipment to be deployed as part of the testbeds.

- **Specific Requirements:** full radio components (all needed hardware, software and some compatible User Equipment) to be connected to standard 5G Core networks that support Release 16 and/or Release 17. Outdoor and/or indoor solutions are acceptable. Installation and initial testing should be part of the proposal (including documents to be presented to regulators to obtain spectrum). A minimum of two gNBs and two EUs is required.

Involved testbeds/platforms: Malaga.

Dynamic slice allocation, entitlement server

A new functionality in the upcoming release of Android 14, will enable users to request a 5G network slice for enhanced performance for specific times for any application that can use a 5G network slice provisioned by the communications service provider (CSP).

The new functionality is meant for service providers to offer their consumer subscribers the choice of enhanced performance for applications via a 5G network slice as part of their 5G Standalone equipped subscription plans.

For devices running Android 12 or higher, Android already provides support for 5G network slicing. From Android 13, app developers can include functions and capabilities in their applications to align with certain network characteristics (such as lower latency, higher bandwidth or other characteristics) offered by a CSP-provisioned network slice. If the CSP offers a slice with those particular characteristics, and the ability to use the slice is included in the application, the subscriber can purchase access to it for a unique 5G experience.

We are requesting On-demand network slicing functionality to boost customer experience:

- New solution enables Android smartphone users to activate a network slice on-demand in real-time boosting network performance and latency across different applications such as high-quality streaming and gaming.
- Enables operators to create new 5G services based on new network slicing capabilities on Android 14 release devices and 5G networks.

The proposed solution should be based on entitlement and policy control servers and UE Route Selection Policy (URSP) technology implemented in Android 14. The standard-compliant entitlement server should verify the network slice service availability, promote service packages for the end user, and send purchased service options to the operator Business Support System (BSS), which will activate the selected dynamic network slice policy for the user using URSP.

- **Specific Requirements:** The solution need to be integrated with Nokia's Aircscale 5G basebands. Android devices and/or specific firmware configuration should be provided as part of the solution if needed. Android 14 devices will be available at S6GSANDBOX sites.

Involved testbeds/platforms: Malaga

5GPPP final results integration in 6GSANDBOX

5GPPP has created a rich set of technologies and demonstrators as part of its successful program. Now that the SNS-JU program has fully started and the 5GPPP projects are finishing, we open the opportunity for 5GPPP projects to contribute their technology and demonstrators to be deployed/used in the 6G-SANDBOX. The 5GPPP technologies will then be made available as capabilities to be shared for experimentation.

- **Specific Requirements:** Be an outcome of a 5GPPP project, with a technology demonstrator that can be integrated in the 6G-SANDBOX infrastructure for experimentation.

Involved testbeds/platforms: All platforms.

5G Multicast-Broadcast Services (MBS)

The use of Multicast–Broadcast Services (MBS) in 5G is still under construction. The support of this feature includes upgrades in the UE, the gNB, the 5G Core network as well as end to end specific services. For this reason, the project is requesting prototypes or pre-commercial developments in this area to be deployed as part of the testbeds.

- **Specific Requirements:** all the components needed to demonstrate end-to-end MBS with some example service reusing existing network in 6G-SANDBOX. As far as the 6G-SANDBOX platforms components can be enhanced or connected to new elements, proposers are not expected to provide a full 5G chain, but to install what is available to demonstrate MBS. Additionally, proposers should expose open APIs to create new services during the project. The proposers can complete their current solutions within the project as part of the work, provided that they will be available by the end of OC2 execution.

Involved testbeds/platforms: Malaga.

Use explainable AI (XAI) to improve O-RAN functionality in 6G networks.

AI-based RICs aim to tackle traditionally hard-to-solve aspects of the RAN domain, such as spectrum management, mobility, radio resource assignment and scheduling, admission control, link management, and power allocation. Explainable AI (XAI) is an emerging paradigm that aims to shed light on the decision process that is performed by closed (black box) AI models. XAI techniques should be incorporated into the running AI-based rApps/xApps to provide transparent explanations of their outputs. We are looking for technology providers to enhance the 6G-SANDBOX testbed with XAI capabilities to improve O-RAN functionality in 6G networks.

- **Specific Requirements:** There is a need to integrate XAI solutions into the O-RAN management operations in order to gain more detailed information about the decision-making processes of ML and DL algorithms. This solution needs to be integrated with the O-RAN solution provided by IS-Wireless in the UMA testbed. Develop XAI xApps/rApps for the RIC.

Involved testbeds/platforms: Malaga.

Provision system for eSIM

6GSANDBOX is requesting a solution for provisioning eSIMs in Trial Networks devices. eSIMs can be hosted in the cloud (external server) but should be downloadable by devices at 6GSANDBOX facilities.

Specific 5G Core Network configuration will be provided for the company to generate the eSIMs. Those should be re-usable during the Open Call period, and it should be possible to switch the eSIMs between devices.

- **Optional Requirements:** Total of 500 eSIMs should be included in the proposal. eSIMs should be active until the end of 6G-SANDBOX project (currently end of 2025).
- **Specific Requirements:** eSIMs will be used in Release 16/Release17 networks. eSIMs will need to support network slicing. Roaming will not be required in the eSIMs.

Involved testbeds/platforms: All platforms.

AI techniques for autonomous network management / Zero touch

The operation of autonomous zero-touch networks is expected to change thanks to 6G technology. These networks will save costs and free up resources for important activities and income production. 6G-SANDBOX is

seeking solutions to have the capacity to self-configure, self-heal, self-optimize, and self-protect the 6G system with little human participation.

- **Specific Requirements:** Contributors should offer solutions that support AI techniques for self-configuration, self-healing, self-optimization, self-protection towards realizing intents in cognitive networks. Compatibility with existing cloud computing platforms and 5G/6G systems of 6G-SANDBOX platforms is a prerequisite.

Involved testbeds/platforms: All platforms.

Support of Ambient IoT devices

Contributions are solicited to enable support for Ambient IoT devices within the 6G-SANDBOX platform. Ambient IoT refers to a sub-set of IoT devices that operate without a dedicated power source, harvesting energy from ambient radio frequency (RF) signals to transmit data. These battery-less, self-sustaining devices have been gaining attention for their potential to revolutionize energy-efficient communication and are considered an integral part of upcoming 3GPP Release 19 standards.

- **Specific Requirements:** Contributors must offer a seamless end-to-end solution that supports (a) provisioning of Ambient IoT devices, (b) energizing Ambient IoT devices via RF transmission, (c) receiving and authenticating of data from Ambient IoT devices and (d) forwarding received data to suitable application functions (AFs), e.g., via NEF. An integration plan must be provided, detailing the alignment of the contributed technology with the 6G-SANDBOX platform's existing architecture, API structures, and security protocols. The solution provided should consider the requirements and use cases defined in the applicable stage-1 specifications of 3GPP Release 19 for Ambient IoT.
- **Optional Requirements:** While not strictly required, the contribution will be more valuable if it also includes features for real-time data analytics, energy-efficient data transmission, or advanced security protocols. These would not only enhance the functionality but also contribute to the robustness of the 6G-SANDBOX platform.

Involved testbeds/platforms: All platforms.

Expanding 6G capabilities and/or experimenting with the 6G capabilities

6G-SANDBOX welcomes any extension or experimentation proposals with a high 6G content which is not called for specifically in this call. The proposed activity must leverage the current 6G-SANDBOX testbed capabilities.

Involved testbeds/platforms: All platforms.

End of document.