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D2.1 Requirements analysis for exposing the RI

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Scientific Large-scale Infrastructure for Computing Communication Experimental Studies **Starting Communities**

www.slices-sc.eu

Executive summary

This deliverable aims to present the requirements for exposing the Research Infrastructures to the research community. These requirements concern the existing research infrastructures, the ones inherited by previous research projects, as well as the interfaces and the intercommunications between the current infrastructures, in order to organize how all the different experimental components in SLICES-SC are exposed for users.

Having in mind the ongoing digital transformation of the human societies, it is more than certain that the Digital Infrastructures will pave the way for significant improvements in the industrial, economic and political dimensions. In order to create fully exploitable infrastructures, the research community needs to address significant challenges regarding their efficiency, trust, availability, reliability, range, end-to-end latency, security and privacy. A requirement analysis on the needs of the community for the SLICES-RI infrastructure has been completed through a survey, which is presented analytically in this deliverable. The results of this survey indicate the main research directions that should be assisted by SLICES.

Moreover, SLICES ambitions to exploit several of the existing assets at the European level of research infrastructures. SLICES-SC will rely on the current resources to enhance their utilization and incorporate them in order to create a European-wide test-platform with advanced compute, storage and network components, which are interconnected by dedicated high-speed links. This deliverable presents analytically the current infrastructure resources and the services that are offered nowadays by the European research community, as well as the current tools and APIs that exist across the different testbeds that comprise SLICES-SC. Future directions for each facility, as well as requirements analysis at the node level and as a whole are presented. The present requirements analysis is realized into tangible results with the SLICES-SC portal, which provides access to resources for Transnational Access.

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Acronyms

API	Application Programming Interface
ASIC	Application Specific Integrated Circuit
CI/CD	Continuous Integration/Continuous Development
CN	Core Network
CNF	Containerized Network Function
CP	Control Plane
CU	Central Unit
CUPS	Control/User Plane Separation
DU	Distributed Unit
eNB	evolved NodeB
EPC	Evolved Packet Core
FPGA	Field Programmable Gate Array
FRCP	Federated Resource Control Protocol
FTTH	Fiber to the Home
gNB	gigabit NodeB
GPP	General Purpose Processor
GPU	Graphics Processing Unit
HPC	High Performance Computing
IaaS	Infrastructure as a Service
ICT	Information and Comunication Technology
IoT	Internet of Things
KPI	Key Performance Indicator
LTE	Long Term Evolution
MANO	Management and Orchestration
MEC	Multi-Access Edge Computing
ML	Machine Learning
NEF	Network Exposure Function
NFV	Network Functions Virtualization
NFVI	NFV Infrastructure
NIC	Network Interface Card
NRF	Network Repository Function
NSI	Network Service instance
NSSF	Network Slicing Selection Function
ODL	OpenDayLight (SDN controller)
ONAP	Open Networking Automation Platform
ONF	Open Networking Foundation
O-RAN	Open-RAN
OSM	Open Source MANO
PCF	Policy Control Function
RAN	Radio Access Network
RIC	RAN Intelligent Controller
RU	Radio Unit
SBA	Service Based Architecture
SDN	Software Defined Networking
SDR	Software Defined Radio
SD-RAN	Software Defined RAN
SFA	Slice Federation Architecture
SMF	Session Management Function
UAV	Unmanned Aerial Vehicle
UDM	Unified Data Management
UP	User Plane
UPF	User Plane Function
V2X	Vehicle to Everything
VNF	Virtual Network Function

1. Introduction

Digital Infrastructures and the Internet technologies lie at the heart of the digital transformation of our society. The recent global crisis caused by the COVID-19 pandemic pinpoints the important role of Digital Infrastructures, and outlines how they should be reinforced for the coming years. SLICES aspires to design, deploy and operate a heterogeneous highly distributed infrastructure that will drive experimentally-driven research over real, scalable Digital Infrastructures. Nevertheless, as the research in the sector covers simultaneously different fields, the principles need to be identified and prioritized, based on the requirements that have been given by the respective community.

This document provides the requirement analysis for exposing the RIs of SLICES. It presents whatever is identified as demand of the research community and concludes to a set of research fields, which will be assisted by SLICES. Towards collecting the real demands of the research community working for beyond 5G and 6G technologies, we conducted a survey in the relevant ICT communities for assessing their needs. The detailed results of this survey are reported in this deliverable. The responses of the research communities to this survey allowed SLICES to determine the demands for the future testbed infrastructures. The SLICES infrastructure will be focused on the most interesting of the aforementioned topics, and the use cases that are mostly related to these topics will be identified and supported. The new research infrastructure will prioritize topics such as Cybersecurity, telecommunications and network technologies, privacy and data protection, but will also take care of other topics, such as Artificial Intelligence, e-Health, mobility and connected vehicles, clean and sustainable energy. These outcomes will be reviewed and continuously monitored during the journey of the project.

In addition, the capabilities of the current research infrastructures are analysed considering all possible alternatives and converging to the most optimal exploitation of them. While there is a rich variety of European research infrastructures which are partially satisfying most of the current research requirements, they need to be redesigned and reorganized in a centralized manner to unleash their hidden potential and deal also with the future research necessities. In this report, SLICES analyses the current status of the European infrastructures and designs the new SLICES infrastructure, based on the enriched experience gained by all relative European research initiatives run until now.

The document is organized as follows. Section 2 provides a brief overview of the demand analysis for the SLICES research infrastructure. Section 3 presents the current status, future plans, and dedicated requirements analysis at a node level of the existing European infrastructures, outlining their capabilities and drawing plans for their future operation. Section 4 presents the requirements for computing and connectivity towards experimenting with key technologies for 6G, transport network and cloud computing, as outlined from the requirements derived from the testbeds. Section 5 builds on top of the requirements and briefly presents the interfaces used by the existing infrastructures, as well as their interconnections that are used in order to integrate the distributed experimental islands into a single SLICES-SC facility, used for providing Transnational and Virtual Access to the community. Finally, in section 6 we conclude the document and present future directions in deploying and operating the SLICES research infrastructure.

2. Demand Analysis

Wide network softwarization, taking place already in 5G and beyond 5G network deployments, is enabling the extension of existing testing platforms and new RIs to provide a wide range of resources to the experimenters. As such, several technologies can be offered simultaneously within an experimental node (testbed), including wireless networking, Cloud and Edge Computing, High Performance Computing (HPC), as well as managing the experimental components through the application of Machine Learning (ML). One of the project contributions reported to this deliverable is the collection of the market and research community demands and expectations for these research infrastructures, so as to extract the requirements for each of the platform for connecting/integrating with the overarching SLICES-SC framework.

During the long evolution of mobile communication systems from 1G to 5G, the industry has succeeded significant advances in supporting outstanding applications that will be further improved, if and only if they are evaluated on real deployments with use of testbeds. These applications include high-definition media streaming, low-latency V2X communication, reliable-critical emergency networks, power-efficient IoT communications and unmanned aerial vehicles. There is still a significant amount of research, which is necessary to unleash the full potential of all these applications. The commercial rollout of 5G is underway, but the outcomes of the research on these testbeds will constitute the fertile ground for the 6G foundation, which will most probably be commercialized by 2030.

6G is expected to significantly extend the mobile communication capabilities compared to 5G, enabling a vast variety of advanced verticals and use cases that are not yet realized. The current and upcoming technological developments and advancements will be able to support new use cases requiring wireless communication. For example, the wireless connectivity for Oceans, Space, Air-to-ground (including aerial vehicles), High-speed trains (supporting more than 500 kms/h) and satellite networks are paving the way for 6G. Moreover, the exploitation of the Terahertz frequencies will be a significant boost towards 6G. The maturation of all these technologies requires their comprehensive evaluation on testbeds, in order to check if the 6G KPIs are satisfied, which will be 10 to 20-fold stricter than the 5G ones. In the next section, we present the SLICES-SC methodology for collecting the real demands of the research community working for 6G.

2.1. Methodology

In the context of the SLICES-DS project, a complete analysis of the demand from the scientific communities was undertaken and reported in the SLICES-DS deliverable D1.2 "Requirements and needs of scientific communities from ICT-based Research Infrastructures"[1]. This deliverable collected the needs, the requirements and the expectations coming from the potential SLICES users from the research community, by using a survey. The analysis conducted in the previous deliverable was global and covered all the aspects of the future research infrastructure, including the technical and operational requirements from the scientific community. To provide some background information, the survey was conducted in **December 2020 and January 2021** with **226 participants**; 67 of them completed all the survey questions. Most of the participants (70%) were from academia, followed by SME/industry (25%), public administration (2%) and NGOs and public-private foundations

(3%). The survey was distributed through several mailing lists from the SLICES partners, including the one from the Fed4FIRE+ project.

2.2. Demand Analysis from the Survey

The purpose of the survey was to determine which best practices/supported technologies/key subjects the infrastructure must support. Respondents said that the SLICES infrastructure should be able to simultaneously manage the distribution of computing (cloud, fog, edge) and the processes running on top of computing, which should be optimised through the use of Artificial Intelligence (AI) and Machine Learning (ML). AI and ML will also play a significant role in managing the underlying layers, particularly to increase the performance and energy efficiency of wireless and network technologies (SDN/NFV) in 5G networks and beyond. Security, privacy, and scalability are crucial elements that must be addressed by the research infrastructure, with the opportunity to evaluate them directly within the RI. The ability for researchers to configure the network used for different types of studies via open APIs is an additional significant feature that the future RI will need to support. Below, we break down the summary of their responds, based on the survey questions.

2.2.1. Supported Technologies for SLICES

The functionality suggested permits a basic description of the new SLICES infrastructure for research. The research infrastructure should utilize the most recent communication technologies, such as 5G and beyond 5G/6G, in a genuine environment that includes cloud, fog, and edge components. Researchers also want more ease of use from the research infrastructure (RI) and the ability to conduct experiments that are more relevant to industry; this implies that the scale and scalability of existing testbeds should be enhanced. The configuration of the research infrastructure and the availability of open access are crucial to the research community. The new RI should contain new tools, such as traffic generators and actual data sets. These instruments should ultimately aid in the development of AI and ML during experiments.

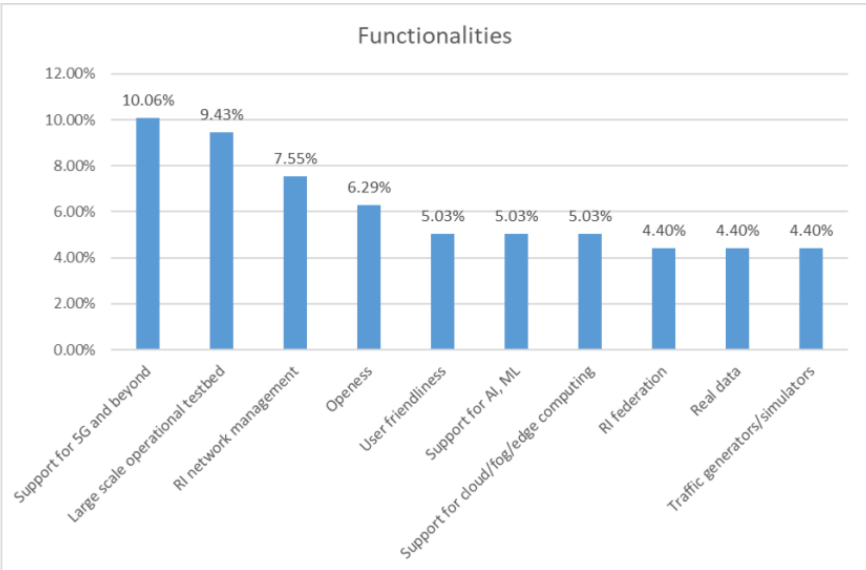


Figure 1: Desired functionalities from SLICES-RI

2.2.2. Supported Use Cases for SLICES

Respondents have provided a variety of supported use cases, which can be split into two categories: core network and verticals. The core network covers the communications technologies and the interactions between the components interconnected by these technologies. Use cases related with verticals (e.g., connected vehicles, smart grid, etc.) should also be supported by the research infrastructure, even though it is acknowledged that the expectations placed on the RI vary (a stable operation is necessary). It implies that the new SLICES RI will first concentrate on the core technologies, but will be able to enable their applications in the many ICT areas, taking into account the particular requirements and needs of each use case. Combining the most relevant use cases is possible. AI and ML are utilized in the context of IoT and 5G to optimize the collection and analysis of data, for instance. Using AI and ML, the network layer can be better managed in SDN/NFV implementations. Some of the use cases described in the study are horizontal and relate to energy efficiency, scalability, security, and privacy.

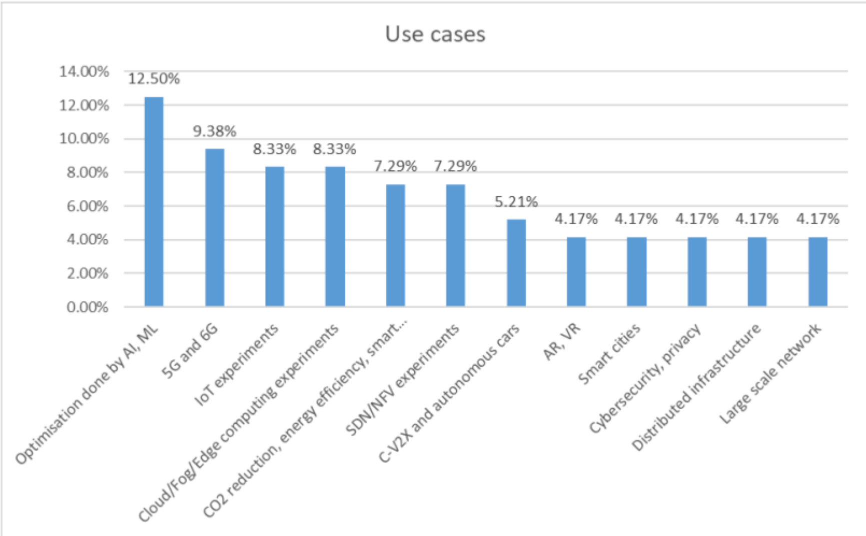


Figure 2: Use cases supported by SLICES-RI

2.2.3. Industrial participation and standardization

The research community has no reservations regarding the utility of the new European ICT research infrastructure and the involvement of the European business sector. The survey results indicate that the collaboration between the research infrastructure and the industry will result in a win-win situation. The exchanges and technological transfers, as well as the technical expertise of the people, will be enhanced. In parallel, the research infrastructures should try to address the needs and requirements of the industry. In the experiments conducted at the RI, more realistic use cases may be simulated, thanks to a tight relationship with the industry's target market and customers. Additionally, the industry should offer the components of the research infrastructure to ensure that the RI is aligned with actual industrial deployments. The industry could also contribute to the sustainability of the research infrastructure, as the advantages of the experiments conducted within the RI are shared with industry. In fact, the new ICT research infrastructure is seen as an innovation engine for Europe's industry and SME sector.

Numerous proposals were provided during the consultation with the European research community, allowing us to identify new features and needs for the new SLICES research infrastructure. The research infrastructure should pay special attention to industry, start-ups and small and medium-sized enterprises. Researchers should have easy and unrestricted access to the RI. The utilization of RI resources should be made easier for researchers. Notably, the experimenters should be allowed to configure the network used for the tests. In addition to supporting 5G and 6G experiments with SDN/NFV, the future RI should incorporate a cluster of GPUs and FPGAs. The received suggestions and recommendations can be combined: for instance, the close involvement of the industry and the openness of the RI can be applied in conjunction with the use of open-source solutions already utilized by the industry, such as ONAP (Open Network Automation Platform) and OAI (Open Air Interface) in the context of 5G.

Regarding standardization, the research community consulted for the survey cites a lack of standardization in various domains, including AI, ML, cloud, fog, edge computing, and security. The research infrastructure can be utilized to do standardization-related work and hence contribute to major SDOs such as ETSI.

The European research community has also appraised the importance of SLICES research infrastructure requirements. The most significant needs are remote access, data analytics tools, and scalability, followed by user-friendliness, a variety of connection protocols, and finally security and secrecy. All of these needs will be considered during the development of the SLICES research infrastructure, particularly during the architectural design.

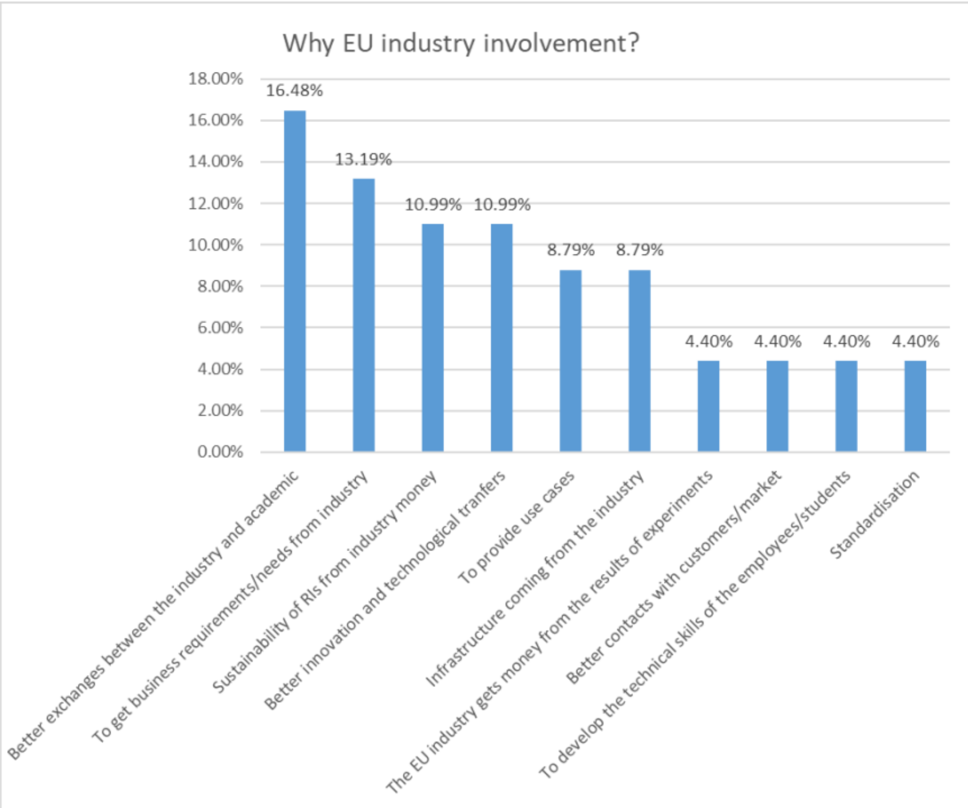


Figure 3: Reasons to involve the industrial participation in SLICES-RI as provided by the survey participants

2.2.4. Prioritization of research topics

The research community has weighed in on the significance of the study fields that will be conducted within the research infrastructure. Artificial Intelligence and edge computing are the most important fields of research. Therefore, the RI must prioritize both. They are followed by data analytics and the Internet of Things, which comprise the second tier of importance. The third tier of importance includes cellular networks, future network architecture, and cloud computing. Finally, green and energy-efficient ICT and blockchain are the lowest priority topics, scoring below 50%. However, SLICES will still address them because we want a broad offering and because SLICES aspires to become an influential RI platform in Digital Sciences, which includes concerns about energy consumption and the implementation of the green deal.

In response to the usefulness and necessity of the RI from the research community, the results enable the identification of use cases for the core network and verticals based on the estimated usefulness of the RI. Therefore, cybersecurity, telecommunications and network technologies, privacy, and data protection are the most valuable topics for respondents within the context of a dedicated research infrastructure. The new research infrastructure should prioritize these areas before addressing the ones that follow: artificial intelligence, e-health, mobility and connected cars, and clean and sustainable energy. In conclusion, respondents estimate that the need for RI in fields such as intelligent manufacturing and supply chains, intelligent agriculture, nanotechnology, and electronic components is somewhat less apparent.

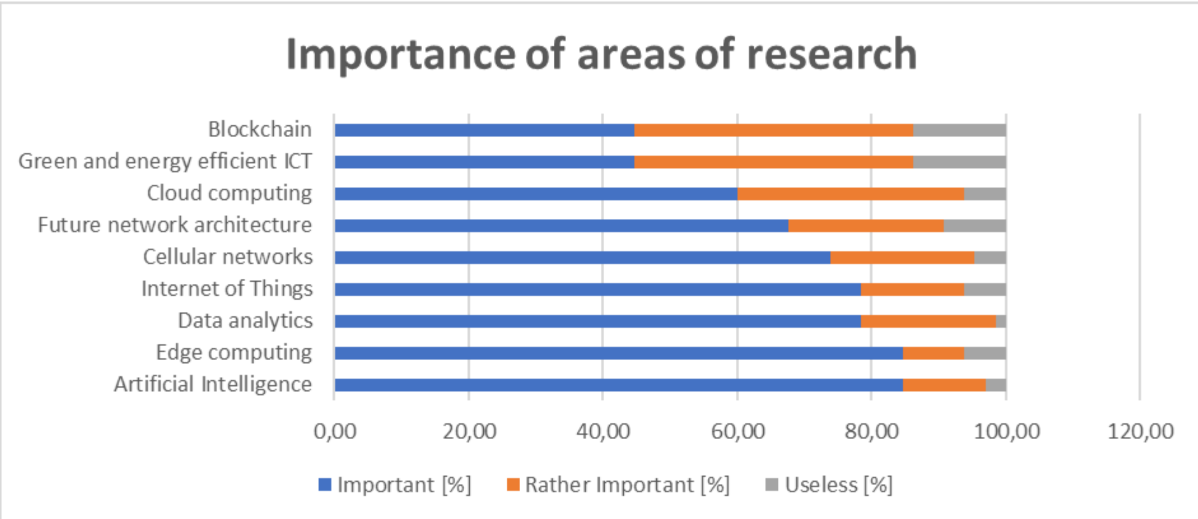


Figure 4: Prioritization of topics of interest in SLICES-RI as responded by the survey participants

2.2.5. Requirements Analysis for SLICES

Some requirements were evaluated in the survey by the research community to determine their importance with the point of view of the future users. These requirements are namely the scalability of the research infrastructure, the user-friendliness of the user interface, the data analytics tools and functions, the diversity of the communication protocols supported, the security and confidentiality of the experiment and finally, the remote access.

75.38% of the responders determine that the scalability of the research infrastructure is important. Concerning the user-friendliness, 73.85% of the responders think it is an important requirement. The data analytics tools and functions are important for 78.46% of the responders. The diversity of communication protocols is evaluated by 70.77% of the responders as important. 61.54% of the potential users estimate that the security and the confidentiality in the research infrastructure are an important requirement. Finally, the remote access is considered by 87.69% of the future users as important. The following table contains the requirements classified by their importance:

Table 1: Importance of the requirements for SLICES-RI

Requirements	Important [%]
Remote access	87.69
Data analytics tools and functions	78.46
Scalability	75.38
User-friendliness	73.85
Diversity of communication protocols	70.77
Security and confidentiality	61.54

So, the **remote access** is the most important requirement for the potential users of the envisioned SLICES research infrastructure. These requirements are currently studied within SLICES-SC, exploring different options for Transnational Access.

3. SLICES-SC Node Status

In this section, we briefly present the main technologies that each testbed currently provides, as well as envisioned future extensions. Each testbed provider has extracted sample requirements from their experience in hosting experiments/operating the dedicated testbed equipment, on the different fields and expansion of the testbed, as well as for the integration in the portal of the project. **Details on the** exact **offering of each node (equipment, tools, locations, annual operating costs) are provided in Annex I.**

3.1. Current SLICES-SC Node Status

The 13 different facilities within SLICES-SC offer several technologies for experimenting with, both off-the-shelf commercial as well as custom research prototypes, for dedicated purposes (e.g. new band testing equipment for beyond 5G). The different capabilities clustered around the most used technologies of the involved RIs are listed below.

Table 2: Current supported technologies in SLICES-SC facilities

Testbed	Country Location	WiFi	4G LTE	5G NR	IoT	HPC	Cloud	SDN	Open-Flow	Optical networks
SILECS-FIT/OneLab	SU/FR						√			
NITOS	UTH/GR	√	√	√	√		√	√	√	
Open5GLab	EUR/FR		√	√						
PIONIER-LAB	PSNC/PL						√			√
5GTN	OULU/FI		√	√	√					

LeonR&Do	COSM/GR				√					
CNR-IIT Lab	CNR/IT				√	√				
imec iLab.t	IMEC/BE	√	√	√	√	√	√	√	√	
ELKH Cloud	SZTAKI/HU						√			
R2Lab	INRIA/FR	√	√	√		√	√	√		
IoT Lab	MI/CH				√					
SLICES Virtual pos	TUM/DE						√			
5TONIC	IMDEA/ES		√	√	√			√		

As the environments that each of the facilities provide can be highly heterogeneous, hence different APIs for configuring the equipment from different in many cases vendors, a common high-level API needs to be deployed in order to manage all of them in an organized manner. The API builds on abstractions of the underlying equipment components, and a common tool for provisioning the equipment shall be employed. Existing APIs are discussed in detail in Section 5 of the present document.

3.2. Foreseen Extensions per SLICES-SC node

3.2.1. SU Node

The SILECS-FIT Infrastructure is continuously being monitored to evaluate the need to extend the infrastructure with additional resources (sensors, devices, servers).

The testbed will integrate new hardware to meet the requirements of the scientific community and also in order to deploy and experiment with the Open Source Core Network and Edge computing solutions. A P4 switch and LTE Small Cells are being deployed and operated for such experiments.

3.2.2. UTH Node

The UTH NITOS infrastructure is constantly being upgraded with latest cutting-edge equipment. Foreseen extensions in the near future include the following:

- Extension of the Cloud and Edge infrastructure, with latest technology compute components, towards offering more resources for assisting network-softwarization driven experiments.
- Extension of the RF devices, towards adopting bleeding-edge prototypes operating in new bands (THz and visible light communications), as well as the operation of 5G-NR FR2 (mmWave) base stations.
- Extension of the IoT devices offered for experimentation, with both urban (dense) and rural deployments for monitoring purposes and testing Low Power WAN networks.
- The acquisition of research spectrum for operating 5G-NR macrocells. UTH team is in discussions with the spectrum regulator agency in Greece for finalizing access to part of spectrum in band N78.
- The deployment of a city-wide testbed across different buildings of UTH, in different locations, interconnected through fiber-based links and mmWave links.

Figure 5: Future extension to a city-wide NITOS testbed in UTH

3.2.3. EURECOM Node

EURECOM will keep maintaining and upgrading the offering around the OpenAirInterface platform. The disaggregation of the CU-C and CU-U planes is in the process of being finalized, along with the integration of new E2 termination points for integrating with the O-RAN architecture. In this context, EURECOM is investigating the UPF implementation on NVidia DPUs (SmartNICs) that will be used as accelerators for the network. Moreover, employing GPUs at the network edge as experimental resource is being investigated, towards accelerating the execution of AI/ML models.

3.2.4. PSNC Node

The extensions foreseen for each of the foreseen laboratories of PSNC are detailed below.

Laboratory 1 - Laboratory of innovative network technologies

The laboratory will be equipped with advanced network devices, including transmission systems, backbone and access switches, measuring instruments, and management software.

This equipment will be connected with the PIONIER fiber optic infrastructure and will constitute a connected network ecosystem. The laboratory will be able to test and verify new network protocols, software for control and management of network devices and network applications. The laboratory will also be used to verify solutions for cooperation with individual network elements (such as long-distance optical transmission systems, packet transmission systems or passive infrastructure monitoring elements) or service applications (e.g., distributed services provided by cloud systems).

Laboratory 2 - Distributed Time and Frequency Laboratory

The main aim of the construction of the Time and Frequency Distributed Laboratory is: i) to provide access to ultra-precise time and frequency signals to all PIONIER-LAB users regardless of their geographical location; ii) to build a time and frequency transmission network that will enable the development of a number of modern services. The Laboratory will be equipped with atomic clocks for generating standard time and frequency, satellite transmission systems for synchronization of individual clocks placed in different MAN, as well as a set of auxiliary devices for transmission, switching and supervision, and measurement of time and frequency signals. Atomic clocks of the highest possible accuracy - active hydrogen masers will be located in 3 locations (Poznań, Warsaw, Gdańsk), and in 8 locations (Koszalin, Olsztyn, Bydgoszcz, Białystok, Łódź, Puławy, Kielce and Rzeszów) there will be atomic clocks - passive hydrogen masers or caesium clocks. The whole distributed laboratory will provide users with access to time and frequency patterns.

Laboratory 3 - Smart Campus as a Smart City laboratory

The Laboratory is designed as an interactive research platform installed in the Student Campus, allowing the testing of functions in the real world, and then it is possible to disseminate the results of the tested functionalities (implementing them for universal use, within the Smart City). The purpose of building the laboratory is, among others: i) to enable research on the development of innovative campus services based on the latest Internet of Things (IoT) technologies; ii) to develop an ecosystem enabling R&D work in the field of Internet of Things and Smart City infrastructure in various areas of human activity (e.g. work, study, information acquisition, mobility); iii) to develop a controlled environment enabling the development of network applications and services using Internet of Things infrastructure in the context of Smart City.

Laboratory 4 - Regional "Living" Innovation Laboratories inspired by ICT

The living laboratory is creating the conditions for future research and development using advanced technologies for data capturing (through sensors and wired/wireless networks) and information processing. Equipment installed in the laboratory will be available to end users to carry out experiments in different fields of disciplines, including (but not limited to): multimedia, e-health, social networking, security and gaming.

Laboratory 5 - Cloud Services Laboratory

The Laboratory will constitute a platform for conducting research on the construction and management of a reliable, scalable and economically efficient cloud infrastructure and providing cloud services on its basis, including IaaS (Infrastructure as a Service) and PaaS (Platform as a Service) mechanisms.

Laboratory 6 - Multi-Scale Simulation Laboratory

The laboratory will be used to perform large-scale and multi-scale simulations of research problems with different time and space scales. Simulations will be possible thanks to the use of High Power Computers (HPC) and data transmission within the PIONIER fibber optic network. The functionality of the laboratory will also be made available in a cloud model.

Laboratory 7 - Laboratory of e-training services

The laboratory will enable research on increasing the effectiveness of the educational process (acquiring knowledge) based on e-training. In their case, due to the lack of teacher-pupil interaction of the nature of the traditional learning model, it is necessary to select appropriate training instruments so that the content is assimilated in an optimal way. The laboratory will enable testing solutions in order to improve the quality of education based on educational Internet services, thus addressing the problem of "mismatch" as is still the case with e-training.

Laboratory 8 - Pre-incubation laboratory

The construction of the laboratory will enable the study of new trends and models of cooperation between science and business, with particular emphasis on the impact of the availability of advanced ICT infrastructure and related R&D services on the innovativeness of companies and regions.

3.2.5. OULU Node

5GTN is an essential part of the 6G Flagship Program as thus is to evolve from 5G Test Network to 6G Test Network during 2020's. 5GTN has been, still is and also will be under constant development and evolution towards more comprehensive 5G and future 6G Test Network. Current plans include but is not limited to following technologies:

- Introduction of mmW technology in FR2 in several phases
    - Indoor first (February 2023)
    - Outdoor in second phase (2023)
- Newest UE's available: smartphones, modems, routers, sensors
- Renewal of 5G base stations (baseband and radios) for improved performance
- 5G core renewal
- cRAN/o-RAN capable HW (under implementation)
- Introduction of larger OAI (Open Air Interface) capability (under implementation)
- Introduction of newest MEC and MEC application technologies
- 100Gbit/s backbone network
- SDN based core network infra
- Enlarge 5G coverage in the Oulu area
- More dynamic 5G network slicing

3.2.6. COSMOTE Node

The LeonR&Do IoT testbed is a comprehensive, end-to-end solution for Internet of Things (IoT) use cases, developed by COSMOTE using open-source tools. It supports a wide range of sensors and devices, regardless of the access technology they utilize, including Zigbee, Z-wave, WiFi, 2G/3G/4G/5G, NB-IoT, LoRaWAN, Sigfox, Ethernet, and more. The testbed includes a cloud-based infrastructure for device management, data storage, data processing, data visualization, and remote access from anywhere at any time. The platform is also flexible and scalable, offering APIs for real-time and offline data acquisition, integration with third-party tools, and customizable dashboards for end-users. The testbed is designed to support any IoT use case, with a wide range of sensors already integrated into the platform, including power/energy meters, smart plugs/switches/relays, activity/motion/presence sensors, temperature, humidity, and pressure sensors, GPS sensors, smoke/fire sensors, flood sensors, gas sensors, air-quality sensors, and more. The backend/cloud segment of the testbed is deployed at OTE ACADEMY premises, while a large number of IoT sensors (>250) have been deployed in various locations, including houses and telco sites in Athens and Thessaloniki greater areas, providing a diverse range of environments for testing and experimentation. Currently, the testbed supports four IoT use cases: energy monitoring/management, home comfort, security, and smart cities (air-quality/pollution monitoring). The testbed offers three APIs to third-party integrators for data acquisition (subscribe to MQTT, curl command to InfluxDB and CSV extraction from Grafana), allowing them to access real-time and historical data for their specific use cases. The LeonR&Do IoT testbed has been in use since 2014 in various R&D EU-funded innovative projects, as well as internal COSMOTE projects, resulting in the development of a stable and complete IoT platform that is constantly being evolved with state-of-the-art capabilities.

3.2.7. CNR Node

The CNR-IIT Lab testbed is intended to be part the Italian node of the SLICES Research Infrastructure, with a specialisation in the domain of decentralised AI, serverless computing, network and service orchestration in software-defined mobile networks, and user-centric networking. It will be extended with new hardware and software to meet the requirements of the scientific community in those research domains. Specifically, we will deploy specialised hardware to support software-defined networking (P4-based programmable switches and SmartNics), software-defined radios, new GPU accelerated servers, and NR/LTE network simulators. In addition, we also plan to extend the CNR-IIT Lab testbed to support V2V and V2I scenarios by deploying two road-side unit (RSUs) and a small fleet (from 5 to 10) of AVGs with customised on-board units (OBUs). The new hardware will be used to deploy the first SLICES Blueprint, in collaboration with the French and Greek nodes of the RI (initially), consisting primarily of the 5G component of the RI. We will use this initial deployment (planned in 2023) to also test different types of management control architectures for the split of the 5G functions. We will test integration with the French and Greek nodes under the different configurations. Finally, we plan to adopt the POS framework (developed by TUM in the German node) for replicability of experiments.

3.2.8. IMEC Node

In the coming years, the node will be extended on the cloud, wireless and IoT domain. Exact requirements are still be defined, but in the first year we will extend at least the GPULab testbed with more and faster GPUs and storage. Also, the wireless testbed will be extended towards more programmability and 5G/6G.

3.2.9. SZTAKI Node

The ELKH Cloud in terms of capacity is continuously monitored and regularly revised in order to investigate the balance between the utilisation and capacity. In case of over-utilisation of the cloud resources the management team of ELKH Cloud applies for further extension of hardware resources towards the ELKH secretary providing financial support for operational and maintenance costs.

One of the most significant software supports of ELKH cloud is the reference architectures providing easy-to-deploy complex software environment to support research activities. In the future the reference architectures will be further extended with the latest developments. Moreover, new reference architectures will be developed based on the user feedbacks.

In the near future, we would like to focus on supporting quantum computing by further developing our existing quantum reference architecture. We plan to extend the quantum reference architecture with support for emerging quantum resources and development frameworks. We will also introduce a generic programming API to access all the major providers through a unified programming interface. Regarding hybrid reference architectures, we plan to update to the latest orchestrator versions, and to incorporate additional cloud resource support to widen the extensibility of these reference architectures.

As a short-term future extension, the ELKH Cloud is currently being integrated to the EGI Cloud Compute infrastructure within the EGI-ACE European project to support the users of the European Open Science Cloud (EOSC) program. Furthermore, the ELKH Cloud becomes integrated shortly into the SLICES infrastructure as a testbed of the Hungarian node.

3.2.10. INRIA Node

Inria collaborates with Eurecom to deploy and operate an open programmable platform to test post-5G services. In 2022, R2lab was connected to sister site at Eurecom with 600 Gbps fibers forming together the so-called SophiaNode of the SLICES-RI project. We also enriched R2lab with 5G professional radio units and compute resources managed by Kubernetes clusters to provide an experimental cloud-native environment to test with open source (OAI, SrsLTE) software and some commercially licensed software (e.g., Amarisoft) for 5G/6G networks supporting for example scenarios with disaggregated 5G networks elements. Fully automated deployments of the infrastructure are on their way and in 2023 it is expected to provide a first public version of a full DevOps stack to experimenters to deploy complex experiments on the SophiaNode.

3.2.11. IoTLab Node

The IoT Lab testbed is intended to join the Swiss node of the SLICES Research Infrastructure, with a specialisation in the domain of the Internet of Things. It will be extended with new hardware and software to meet the requirements of the scientific community in the area of IoT. Furthermore, IoT Lab will use the services to be developed in the context of SLICES.

3.2.12. TUM Node

TUM is in the process of extending the pos controller to run on top of other testbeds. Currently, the pos experimental workflow relies on the availability of a pos controller that manages the resources of a testbed. A widely used resource management system is the geni-lib. International testbeds, such as, CloudLab, Chameleon or other European testbeds, for instance, the IMEC virtual wall, Grid 5000, or OneLab rely on the geni-lib. Our extension of the pos controller would allow the execution of the pos controller inside the other testbeds. Based on this controller, other testbeds will be able to run experiments according to the reproducible pos workflow. This way, the other testbeds can profit from the reproducibility-by-design feature supported by the pos experiment workflow.

TUM team plans to regularly upgrade our hardware-based testbed with current hardware, such as new CPUs or updated network cards to keep up with the growing demand for resources from our users. The virtual testbed is currently able to host up to four experiments simultaneously. In the case that the TUM virtual infrastructure runs into capacity problems, TUM team plans to shift resources from the hardware-based testbeds to the virtual infrastructure.

3.2.13. IMDEA Node

5TONIC is expected to extend the lab infrastructure in several directions:

- Updating the network functionalities deployed to the latest 3GPP releases, mainly in areas like network slicing, uRLLC, TSN, RedCap… that may help to support new use cases.
- Extending the coverage area to other sites, mainly the University Carlos III Madrid. This would allow the support of new use cases related to teaching and research by students and teaching staff of the university.
- Preparing the lab for evolution towards 6G, incorporating new technologies that help to increase spectral efficiency and meet the requirements of future communications. They include the operation at high frequency bands (sub-THz), support of RIS and ISAC, incorporation of AI based radio functionalities, etc.
- Incorporating other elements network elements and functionalities that will allow to emulate the behaviour of real-world networks in a more realistic ways, making the results of tests and experiments more relevant for stakeholders.
- Preparing the lab for facilitating its use by researchers, incorporating mechanisms for the remote configuration and launch of experiments, and the automation of results' collection and analysis.

3.2.14. Summary on future extensions of each SLICES-SC node

The different facilities foresee different directions for their future extensions. As such, most of them foresee the extension of their compute infrastructure, towards providing access to more experimenters as well as supporting Edge/Core Cloud related experiments. Similar extensions are foreseen for the telecommunication network operation, through the integration of fully softwarized and open source solutions for 5G networks, extensible towards supporting beyond 5G and 6G research, as well as new RF devices, allowing the operation in new bands (e.g. THz communications).

The following table is summarizing the foreseen extensions at each node, based on the most common listed technologies.

Table 3: Foreseen extensions to SLICES-SC nodes

Testbed	RF Devices (new Bands)	IoT Devices	Cloud/ Edge	Wired Networking (SDN)	HPC	5G Software	B5G/6G Extensions
SILECS-FIT/OneLab	√	√	√	√		√	√
NITOS	√		√	√		√	√
Open5GLab	√	√	√	√			√
PIONIER-LAB	√	√	√	√	√	√	√
5GTN	√	√	√	√	√	√	√
LeonR&Do		√	√			√	√
CNR-IIT Lab	√	√	√	√	√	√	√
imec iLab.t	√	√	√	√	√		√
ELKH Cloud			√		√		
R2Lab	√	√	√	√		√	√
IoT Lab		√	√				
SLICES Virtual pos			√	√			
5TONIC	√		√	√			√

3.3. Node level requirements analysis

In this section, we detail on the specific requirements that each node outputs for the future extension in tools and integration with the SLICES-SC portal (presented in detail in D2.2).

3.3.1. SU Node

The testbed managing tool that is currently deployed to operate the infrastructure is the extended version of Slice-Based Federation Architecture (SFA) (more details on the framework and APIs are provided in Sect. 5). The testbed managing tool provides an API which returns a XML-RPC struct and fully supports the Resource Specification (RSpec) schema. This RSpec schema is also used in the GENI and Fed4Fire API as the default mean to describe resources. However, a wrapper for the testbed managing tool is necessary to be fully integrated in the SLICES portal.

In the current stage of the integration, the SILECS-FIT Infrastructure is partly integrated to the SLICES portal (FIT CloudLab and Grid'5000).

The other sites will be integrated following the light federation procedure described in http://doc.slices-sc.eu/#light-federation. This requires an upgrade of the current management tool to support the OpenID Connect authentication method.

3.3.2. UTH Node

As network softwarization is key for success of the infrastructure, UTH and NITOS testbed promote the parallel usage of virtualized infrastructure to experimenters. The 5G telecommunications network is the best paradigm for this, since it is highly softwarized, and this drives further innovations towards beyond 5G and 6G technologies. As such, NITOS testbed is concurrently providing access to its resources beyond existing Metal as a Service approaches, and adopts several APIs for the future provisioning of resources (OpenSourceMANO, Kubernetes API, etc.). These are provisioned in parallel with the existing bare metal approaches, and are continuously extended towards supporting access to federated/integrated clusters under such APIs.

Such APIs are inherently compatible with the ongoing research for the 5G and beyond telecommunication network, as e.g., the Open-RAN agents are commonly deployed and exposed using such APIs and tools. Towards easing the access to groups coming from different backgrounds, and lowering the barrier for new users to use the infrastructure, the system is constantly expanded to cover resources that are not yet offered in such a virtualized setup, e.g., dedicated hardware prototypes. The aforementioned setup is exposed for SLICES-SC in parallel with existing bare metal access.

3.3.3. EURECOM Node

EURECOM infrastructure is using Redhat OpenShift for the deployment of networking related workloads (e.g., OAI) on the infrastructure. The compute infrastructure will be exposed using the respective APIs that Openshift provides (K8s based APIs) in order to enable orchestration of workloads on top of the compute infrastructure. Dedicated APIs (e.g., the Mosaic 5G operator) are also in place and can be used for easing the deployment of different functions of the OAI network. EURECOM follows a fully softwarized approach for the network.

3.3.4. PSNC Node

The management platform for the RI in Poland is currently under development. The design takes into account possible integration with external tools, including SLICES-RI management platform. The projects from National Roadmap of RIs are highly distributed, therefore the management platform already takes into account the problem of federating/integrating resources from different locations and managed by different entities. Lessons learned from deploying the central platform to manage distributed local testbeds from different universities and research centers in Poland can be used in the process of designing and developing the management platform for SLICES.

3.3.5. OULU Node

Due to the wireless nature of the 5G Test Network it needs human interaction when operating. Several of the features, including the use of the base stations and smartphones, can't currently be automated. Thus, human interaction is needed.

Some of the features of 5GTN has been automated or can be remotely controlled:

- Main test tools are automated, but the configuration needs to be done manually due to the dynamic nature of the network.
- 3D scanner can be remotely controlled by using SW that is installed on a Pad.
- Virtual computing is remotely usable as is the possibility to install SW containers

5GTN is protected by Firewall so to access it from outside the network itself requires the use of a VPN connection.

3.3.6. COSMOTE Node

Access to the LeonR&Do IoT testbed requires a user to be granted access to: (a) the Cloud graphical environment (WebGUI) via which he will be able to visualize, control, automate and manipulate (add, remove, modify) his IoT sensors/end-devices remotely, anytime and via any device (smartphone, smartwatch, laptop) and (b) the Grafana dashboard, which provides visualization of his own real-time and historical measurements.

3.3.7. CNR Node

Since the CNR-IIT Lab tested does not yet implement a management framework that allows users to set up the testbed environment according to Testbed-as-a-Service paradigm, it will use the services and tools to be developed in the context of SLICES for the experimental plane and for experimentation reproducibility. To this end, the main requirements are as follows:

- Definition of the SLICES Blueprint (currently under finalisation) so as to use it as an operation tool to guide the deployment.
- Identification, following the Blueprint, of specific HW to be acquired, based on the operational constraints identified by the nodes participating to this initial deployment phase
- Identification of the tools supporting the experimental plane, starting from those related to the connection across different nodes, and then those related to the specific operations of the local testbed
- Identification of the best architecture supporting the operation of the disaggregated 5G component, as a required input for the characteristic of the connectivity through the national NREN (and thus GEANT) supporting joint operations across the testbeds.

3.3.8. IMEC Node

All testbeds are integrated with Slices-SC portal, of which the GPULab testbed is web based, so is lightly federated with using the same accounts. The other testbeds are supporting the GENI/Fed4FIRE AM API and jFed.

No extra requirements to the portal or tools are needed.

3.3.9. SZTAKI Node

At the current phase of the ELKH cloud integration to the SLICES portal and infrastructure, the most appropriate integration mode is the Light federation described at https://doc.slices-sc.eu/#testbed-owner-getting-started. This level of integration requires ELKH Cloud to be upgraded with the authentication support for OpenID Connect layer on top of the OAuth protocol. In ELKH Cloud the users are working in projects as described in the introduction. Mapping of SLICES users into projects, harmonising the project creation, management at the level of SLICES and ELKH Cloud is needed to be designed and implemented.

3.3.10. Inria Node

R2Lab was first deployed in 2015 as part of the FIT Equipex Project, funded by ANR, that offers a range of testbeds oriented towards research in networking. As such, it is part of the OneLab federation of testbeds - a consortium of higher education and research institutions. This ecosystem features a variety of networking and communication environments and testbeds, that offer a wide spectrum of services: internet-overlaid testbeds; wireless, sensing and mobility testbeds; broadband access; core testbeds and network emulation environments. R2lab was part of the Fed4Fire+ federation and will be connected to the SLICES-RI portal in 2023 with the SophiaNode extension currently being deployed jointly with Eurecom.

3.3.11. MI Node

Concerning the requirements for the testbed managing tools, IoT Lab is currently using the GENI Aggregate Manager (AM) API version 3 which is also employed in the Fed4FIRE testbed federation. In this context, the status of the IoT Lab testbed can be retrieved online through Fedmon at https://fedmon.fed4fire.eu/testbed/iotlab. It provides the necessary means to monitor the daily operation of the IoT Lab research infrastructure. The main calls of the GENI Aggregate Manager (AM) API are described at the following URL: https://gitlab.distantaccess.com/iotlab-fed4fire/fed4fire-documentation#fed4fire-iot-lab-api. It signifies that the requirements for the operation of the IoT Lab testbed are derived from the generic requirements defined in Fed4FIRE.

3.3.12. TUM Node

The main goal of the testbed is the development and demonstration of the previously described reproducible experiment workflow. This workflow should be compatible across all testbeds running a pos controller laying the foundation to Reproducibility-as-a-Service (RaaS). This service allows us to automatically execute pos experiments on different testbeds, i.e., users can hand in their experiment that were created in the virtual pos testbed and can be reproduced on one of the TUM bare-metal testbeds.

Despite the virtual resources the virtual testbed was designed to provide a similar performance to bare-metal deployments. This was achieved through the usage of Single-Root IO-Virtualization (SR-IOV). SR-IOV allows partitioning the network cards on a hardware into separate, isolated virtual functions (VFs). The performance and latency of these VFs is similar to real hardware, whereas a typical, purely software-based virtualization performs worse. Therefore, experimenters can expect a similar performance of virtual and non-virtualized testbed instances, i.e., experiment results created through RaaS are more similar.

TUM team plans to integrate the virtual testbed into the SLICES portal using the light federation model. Therefore, pos will be integrated to the SLICES portal as an additional OpenID Connect provider. The current solution already uses the OpenID protocol; however, TUM currently relies on a local provider for user authentication.

3.3.13. IMDEA Node

From the experience that 5TONIC has obtained in the support of Horizon 2020 projects looking at the deployment of a testing infrastructure for 5G industrial use cases (5TONIC was involved in 5G EVE and 5G VINNI projects), some requirements that may be applicable for SLICES were identified:

- There is the need to maintain a stable testing definition and execution in the context of a network infrastructure that is evolving, updating functionalities and incorporating new ones, while potentially changing the coverage area and the topology.
- There is also the need to simplify the procedures for the definition of tests and experiments, in such a way that a deep knowledge of the procedures to activate different functionalities in the testbed is not required. The use of AI may help in this area, requiring from the experimenter to describe the test rather than programming or scripting it.
- There is a gap that needs to be addressed when deriving use case’s KPIs (which can be very numerous, considering the variety of applications that can be supported with 5G and 6G) from network performance’s KPIs.

- Having a clear and well-defined framework that regulates aspects like IP is mandatory when multiple parties are involved in the implementation of tests and experiments.

3.3.14. Summary on Requirements Analysis from nodes

From the analysis conducted at a node level, we conclude that it is of utmost importance that the facilities are controlled through a common API, and a portal interface running on top of that. It is clear that the facilities want to harmonize their APIs towards creating a stable experimentation environment, while also extend the APIs towards adopting many common practices and methodologies on resource management, stemming from research outcomes (e.g., SDN/NFV adoption and exposure to experimenters, network disaggregation and softwarization, etc.). In the next section, we detail the key components as found in relevant literature on such aspects that the infrastructure should adopt, based on the requirements analysis.

4. Requirements for Connectivity and Computing

In this section we present the most recent trends on technology evolution and experimentation needs that the SLICES-SC architecture will evolve around, based on the requirements extracted from the different node providers. These are clustered and detailed to the following:

- Provisioning of beyond 5G Radio Access Networks;
- Providing access to 5G and beyond Core Networks;
- Provisioning large clusters of cloud computing resources;
- Network stitching among the different islands and experimental components.

4.1. Radio Access Network (RAN)

5G RAN [2] has evolved from the previous generations with significant improvements in capabilities, supported functionalities, and innovation potential. Access to higher carrier frequencies, including millimeter Wave (mmWave) frequency spectrum, and flexible frame structure with variable number of symbols per subframe, 5G NR can provide high bandwidth connections, allowing several innovative applications to be supported over the top. Wide softwarization that has been witnessed for different types of services in the recent years has expanded at the 5G RAN level, allowing several of the functions that have been running in monolithic hardware implementations of base stations to run as cloud-native functions. In terms of experimentation platforms, several tools exist that implement the 5G stack fully in software. Such platforms rely on Software Defined Radio (SDR) frontends, and can turn commodity equipment (e.g., with General Purpose Processors) to fully functional base stations. Two are the most prominent solutions in open source to implement such functionality as follows: 1) the OpenAirInterface5G platform (OAI) [3], and 2) the srsRAN platform [4]. Both platforms support the basic operations for the 5G-NR, though OAI has a wider user base and implements more features, such as disaggregated operation for the RAN, several different supported SDRs, etc. From an architecture perspective, 3GPP Release-15 has introduced CU/DU split (3GPP Option 2 split)[5] along with Virtualized RAN architecture. By splitting the higher layers of 3GPP software stack (SDAP, PDCP and RRC) and lower layers (RLC, MAC and PHY) into separate logical units, known as Centralized Unit (CU), Distributed Unit (DU) and Radio Unit (RU)[6], which can be deployed at separate locations. Further split of gNB-CU is induced by separation between the Control Plane (CP) and User Plane (UP) named as gNB-CU-CP and gNB-CU-UP.

Apart from the 3GPP Option 2 split, in total, eight options have been studied[6], decomposing the RAN at different levels (closer/higher from the radio part). Building on top of the different disaggregation options, and especially delving into the CP/UP separation (CUPS), Open RAN (O-RAN)[7][8] architecture defines open and standardized interfaces among the different elements of the disaggregated RAN. Through the use of such standardized interfaces, interoperability of functions between different vendors is enabled, while programmability of the RAN through dedicated interfaces is facilitated. O-RAN Alliance is responsible for an additional split of the CU-CP into Radio Intelligence Controller (RIC) and remaining part of CU-CP. O-RAN defines the specifications for interface definitions between CU, DU, RU and RAN intelligent controller (RIC) that can be deployed at the edge of the network. Depending on the operation of the RIC and the programmable functions in the gNB, the RIC can operate in real-time mode (<1ms latency for programming the different functions, e.g., for Radio Resource Management) or near-real-time/non-real time mode (e.g., for the application and integration of Machine Learning models to the operation of the RAN)[9].

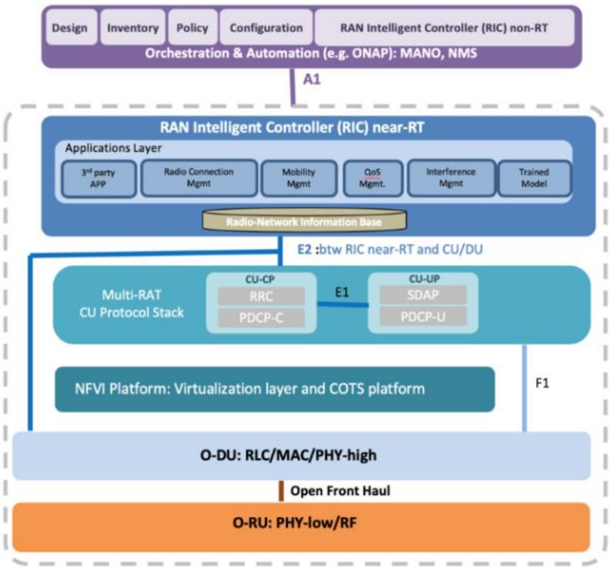


Figure 6: Open-RAN deployment and programmable interfaces

Similar to the O-RAN programmable interfaces, dedicated solutions for specific platforms exist, that open up the programmability of the RAN functions in practice. For example, the FlexRIC platform [10] (also called as FlexRAN), developed by Eurecom for OAI, allows the programmability of the OAI RAN in real-time, by exposing a REST interface. The FlexRAN controller is under further extension for becoming compatible with the O-RAN interfaces for programming the network. Similar to the FlexRAN platform, the SD-RAN platform [11] developed by the Open Networking Foundation (ONF) is complimenting O-RAN's focus on architecture and interfaces by building and trialing O-RAN compliant open source components. SD-RAN is developing a near-real-time RIC (nRT-RIC) and a set of exemplar applications that run on top (xApps) [12] for controlling the RAN.

Towards integrating all the above efforts for the end-to-end deployment of the cellular network with extended use of virtualized services, the AETHER framework [13] is currently under development by ONF. AETHER combines three main elements, namely, a control and orchestration interface to the RAN, an edge cloud platform (the AETHER edge), with support for cloud computing APIs, and a central cloud (the AETHER core), for orchestration and management. The AETHER project integrates several ONF efforts, including SD-RAN, ONOS [14], CORD and OMEC[15], for providing a fully-fledged solution for the deployment of the cellular network in an end-to-end manner.

4.2. Core Network

The Core Network (CN) is the central element of the telecommunications network that provides services to customers who are connected by the access network. The 5G core network is referred to as 5GC, it is an evolved version of EPC (LTE Evolved Packet Core network) as cloud-native, taking advantage of the service-based-architecture (SBA) [16]. The main components of the 5GC are the Access and Mobility Function (AMF), Session Management Function (SMF), User Plane Function (UPF), Unified Data Management (UDM), Authentication Server Function (AUSF), Policy Control Function (PCF), Network Exposure Function (NEF), Network Repository Function (NRF) and Network Slicing Selection Function (NSSF). These 5G network functions are cloud-native by design, thanks to the Service Based Architecture (SBA) design of the 5GC. Therefore, their instantiation can take place as Virtual Network Functions (VNFs) or Container Network Functions (CNFs) in any of the available virtualization platforms.

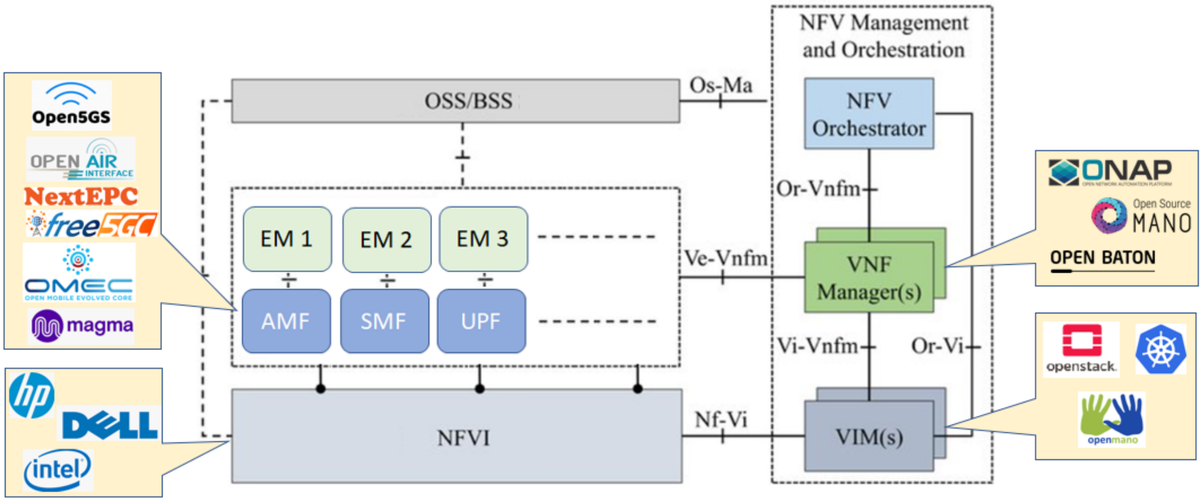


Figure 7: Cloud-native instantiation of the 5G Core Network

The main goal is to adapt them independently when the load increases for any specific service or set of services, which is a major advancement from previous mobile generations. To promote flexibility and reduce cost, it is possible to adopt generic hardware and use an NFV Infrastructure (NFVI) layer in order to host them.

4.3. Cloud/Edge Computing

Computing infrastructure is required across the different sites for either experimentation or management purposes. For the latter, resources are needed in order to support functions such as signal processing, controls and related computational, high performance and data intensive computations; In addition, such resources can provide the programmability framework for the experimenter, APIs, resource access, reservation and slicing, data storage, and the management part of the users, slices and experiments. Regarding the resources dedicated to experimentation, Clusters of compute infrastructure are needed for the cases where ample processing power is required. This is of high importance for several types of experiments, especially the ones involving Artificial Intelligence and Machine Learning, as the computational power needed for training is significantly high, and can be assisted by splitting the load across several interconnected clusters, or using special purpose hardware (e.g., FPGAs, GPUs) for higher computing power. As such, several state-of-the-art platforms exist for experimenting with cloud infrastructure, as detailed below.

OpenStack[17] is a free, open standard cloud computing platform. It is mostly deployed as infrastructure-as-a-service (IaaS) in both public and private clouds where virtual servers and other resources are made available to users. The software platform consists of interrelated components that control diverse, multi-vendor hardware pools of processing, storage, and networking resources throughout a datacentre. Users manage it either through a web-based dashboard, through command-line tools, or through RESTful web services. OpenStack has a modular architecture with various code names for its component. The most important with respect to the SLICES-SC architecture are the following:

- Nova (compute): Nova provides a way to provision compute instances as virtual machines, real hardware servers, and has limited support for system containers (e.g., through the Openstack ZUN[18]).
- Neutron (networking): Neutron provides "network connectivity as a service" between interface devices (e.g., vNICs) managed by other OpenStack services (e.g., Nova). OpenStack Networking enables projects to create advanced virtual network topologies which may include services such as a firewall, and a virtual private network (VPN).
- Cinder (storage): Cinder is the OpenStack Block Storage service for providing volumes to Nova virtual machines, containers and more. Cinder volumes provide persistent storage to guest virtual machines - known as instances, that are managed by OpenStack Compute software.
- Keystone (identity): Keystone is an OpenStack service that provides API client authentication, service discovery, and distributed multi-tenant authorization.
- Glance (image repository): The Image service (glance) project provides a service where users can upload and discover data assets that are meant to be used with other services.
- Horizon (Dashboard): Horizon is the canonical implementation of OpenStack's Dashboard, which provides a web-based user interface to OpenStack services.
- Heat (Orchestration): Heat is a service to orchestrate multiple composite cloud applications using templates, through both an OpenStack-native REST API.

Regarding the networking part of the cloud system, connections for cloud nodes within SLICES-SC are needed for the following:

- In the node itself: for building the clouds and for network experimentation
- connections between clouds are needed to experiment on distributed clouds in different locations or for interconnecting other infrastructure such as edge nodes or RANs

Such state-of-the-art platforms like OpenStack can be used for providing seamless interconnections between different islands, without the need of building testbed specific APIs for communicating with each island.

In the cloud-computing world, containers are an emerging technology and the paradigm is standing between virtual machines and containers now. Although much of the research in the domain has been conducted using Virtual Machines and underlying software like OpenStack, there seems to be a notable steer towards containerized services, which are more lightweight, can be easily instantiated over almost any hardware, and can be managed more efficiently. Containers show high utilization of computing resources and better performance than virtual machines. Multiple containers can be executed on the same host and share the same Operating System (OS) with other containers, each running isolated processes within its own secured space. Because containers share the base OS, the result is being able to run each container using significantly fewer resources than if each was a separate virtual machine (VM). Along with this trend, Network Functions Virtualization (NFV) industry has also been interested in Containerized Network Function (i.e., CNF) instead of conventional Virtualized Network Function (i.e., VNF) due to its scalability and efficiency for operation and management. For those benefits, various mobile operators are trying to replace conventional VM-based NFV platforms with container-based platforms. For low-latency use cases, 5G Core Network (CN) and RAN components are motivated to run as Containerized Network Functions (CNFs), instead of VMs in the case of Virtual Network Functions (VNFs), supported by tools like Kubernetes[19], that can deploy the services directly on bare-metal. Open-source projects are moving towards cloud-native design, but until they become a reality, a mix of VMs and CNFs has been adopted. Edge computing will have requirements for low-latency, cost-efficient infrastructure, secure with AI/ML capabilities. CNFs will be widely considered for the cases of Edge/Fog computing, due to the low complexity and fast instantiation of cloud-native services that can be achieved. Specific to ML tasks, several tools have emerged for managing the deployment of such workloads using containers. The most outstanding effort that is exemplifying this adoption is the Kubeflow framework [20], that can be used for splitting ML pipelines and workflows across several distributed nodes.

4.4. Node Interconnection

In order to support connectivity between currently isolated experimental islands, an efficient interconnection between them should exist, able to facilitate high-speed and reliable data transfer across the different sites. Network programmability for such connections is key in order to create custom experimentation environments, with specific SLAs, as mandated by each experiment configuration.

To this aim, Software Defined Networking (SDN) [21] shall be employed in order to provide fine grained control over the inter-networking aspects between testbed islands. SDN leverages network softwarization to decouple network control from the forwarding (or data) plane, thus separating routing and control procedures from specialized hardware based forwarding operations. SDN is designed to make networks more flexible, controllable and agile. There is a plethora of open source SDN solutions/protocols for managing such networks, with the two most outstanding solutions being OpenFlow and the latest trend of P4 programming, allowing the control of high-speed (multi-Gbps) P4 switches. Details on the operation of each solution is provided below:

- OpenFlow: OpenFlow [22] is a communications protocol that gives access to the forwarding plane of a network switch or router over the network. It enables network controllers to determine the path of network packets across a network of switches. OpenFlow allows remote administration of a layer 3 switch's packet forwarding tables, by adding, modifying and removing packet matching rules and actions. This way, routing decisions can be made periodically or ad hoc by the controller and translated into rules and actions with a configurable lifespan, which are then deployed to a switch's flow table, leaving the actual forwarding of matched packets to the switch at wire speed for the duration of those rules. Packets which are unmatched by the switch can be forwarded to the controller. The controller can then decide to modify existing flow table rules on one or more switches or to deploy new rules, to prevent a structural flow of traffic between switch and controller. It could even decide to forward the traffic itself, provided that it has told the switch to forward entire packets instead of just their header.
- P4 [23] is a programming language for controlling packet forwarding planes in networking devices, such as routers and switches. In contrast to a general-purpose language such as C or Python, P4 is a domain-specific language with a number of constructs optimized for network data forwarding. P4 programs are designed to be implementation-independent: they can be compiled against many different types of execution machines such as general-purpose CPUs, FPGAs, system(s)-on-chip, network processors, and ASICs. P4 is designed to be protocol-independent: the language has no native support for even common protocols such as IP, Ethernet, TCP, VxLAN, or MPLS. Instead, the P4 programmer describes the header formats and field names of the required protocols in the

program, which are in turn interpreted and processed by the compiled program and target device. This functionality allows for complete control over network packets. Moreover, protocol independence and the abstract language model allow for reconfigurability – P4 targets should be able to change the way they process packets (perhaps multiple times) after they are deployed.

Several of the current nodes in SLICES-SC support the reconfiguration of the switching fabric within the node using either OpenFlow or P4 programming. Moreover, such support is provided over their interconnection with other sites, which takes place either over the GEANT network [24], using dedicated virtual circuits, or over the Internet. This process is to a high degree automated for the experimenter that needs to conduct an experiment using multiple sites. For example, the Belgium node at IMEC uses VLANs over virtual circuits to interconnect to other nodes. When an experimenter wants to set up a connection, they can 'stitch' together nodes and VLANs at two locations to set up a layer 2 connection. Currently VLANs are available to University of Amsterdam, Grid5000, Fabric, UTH, GEANT.

5. APIs specific to testbed operations

In this section we present some of the **existing APIs** for supporting the testbed operation and experimentation with the deployed resources. These APIs are already in place on the different nodes, while node providers are in the process of integrating with the central SLICES-SC portal entity. The integration is taking place with two approaches: 1) a loose federation scheme, where parts of the APIs are implemented and reporting to the central portal entity, and 2) a tight federation scheme, where the APIs are implemented in detail, and resources in the testbeds can be fully managed through the central portal. Such APIs are dedicated to resource control, slice reservation (booking of a part of the infrastructure for experimentation), and other testbed specific APIs. The APIs are leveraged by the first version of the portal, and they are in the process of further extension towards supporting more operations (new resources, new control over resources). Testbeds that integrate with the SLICES-SC portal (D2.2) need to implement parts/fully the listed APIs.

5.1. Control Plane Resource Control APIs

APIs under this category are used for contacting the respective management software of a node, and requesting/leasing/releasing resources from the management software. The resources retrieved can be filtered out before presenting them to the user for deciding which will be used.

5.1.1. API for Slice Reservation

The Slice-Based Federation Architecture (SFA) [25] provides a 'thin waist' for secure, distributed resource requests. This effort has been initiated by GENI in the US and Fed4FIRE in EU and fostered the emergence of an ecosystem of tools and services covering a wide range of applications not included in the SFA, such as enriched user interfaces, measurement and monitoring platforms, user registration and authentication services, and experimental management software.

A typical user willing to run an experiment across federated testing facilities Is accommodated by the usage of SFA, releasing the user from switching between many heterogeneous and overlapping tools. With SFA assistance, he does not need to discover various tools, learn their processes and semantics, and often authenticate himself several times and manually make the bridge between them. As a response to this diversity and complexity, the notion of an experimenter's portal is often advanced.

The SFA API is specifically intended for the retrieval of a description of the corresponding testbed. Each SFA API call returns an XML-RPC struct that describes which version of the API is used, the Resource Specification (rSpec) schemas supported, and the URLs where other versions of the API are running. This XML-RPC struct is also extended in some testbeds with information related to both the testbed and the tool directories. SFA is initially designed by GENI and later extended by Fed4FIRE.

5.1.2. GENI/Fed4FIRE APIs

The AM (Aggregate Manager) API (https://fed4fire-testbeds.ilabt.iminds.be/asciidoc/federation-am-api.html) is the default for testbeds (https://doc.fed4fire.eu/#testbed-owner-documentation) in GENI and Fed4FIRE (including the Belgium Slices node at IMEC). The SA (slice authority) and MA (member authority) (https://groups.geni.net/geni/wiki/CommonFederationAPIv2) are the default APIs for the authority. Resource Specifications (rSpecs) are the default to describe resources in GENI and Fed4FIRE as shown in the following link https://fed4fire-testbeds.ilabt.iminds.be/asciidoc/rspec.html.

5.2. Experimental Plane Resource Control APIs

APIs under this category are used for conducting the actual experiment on the testbed/federation of testbeds. They are used by tools already developed (e.g., OMF) towards controlling and orchestrating the experiment over multiple nodes.

5.2.1. FRCP API for Resource Control

The most widely used API for testbeds resource control, adopted by several testbeds around the Globe is the Federated Resource Control Protocol (FRCP) [25]. FRCP is a standardized resource control protocol that permits the control of resources provided by multiple federated facilities in a uniform way, even if they use different management software. It consists of a message being sent by a requester to a component (or resource). The component may accept the message and perform the requested associated actions. For the message exchange with the resources (physical or application resources), the necessary resource controller implementation, supporting the set of defined messages, should be running in the different resources of the facility.

The most significant features of FRCP are enlisted below:

- It is not required by the testbeds to use the same testbed management software.
- The control of any type of resource is feasible if the respective low-level resource control tools are in place.
- It defines a mechanism for signing each message to securely bind the message to a''sende''. While it is outside the scope of the FRCP specification, the recommended ''best practice'' for implementing this is the use of PKI public/private key encryption with X509 credentials.
- It keeps each facility independent in a loose federation with the rest facilities.
- It is not a management software, but provides an interface to control resources.
- Its implementation is sufficiently modular.

Below, the FRCP message syntax is explained. The content of a message is described in an XML format with the following convention.

```
<MSG_NAME xmlns="http://schema.mytestbed.net/omf/X.Y/protocol" msg_id= ID>
….
</MSG_NAME>
```

with:

- X.Y = the version of the protocol

- MSG_NAME = the name of message, eith“r“"cre”te“,“"config”re“,“"requ”st“,“"inf”r”", “r“"rele”s”"
- ID = a globally unique ID for this message

The element may then have child elements, which further describe various message properties specific to the message type. There are two different ways for declaring the value of a message property. The simple version provides the value as a text element with an optional ‘'typ'' attribute if the value is not of type ‘'xsd:strin''.

```
<MSG_NAME ... >
<PROP_NAME type”"TYP”">VALUE</PROP_NAME>
...
</MSG_NAME>
```

The more descriptive way employs a list of child elements to describe the property in more details. Basic elements are ‘'typ'' and ‘'valu'', but can also include ‘'uni'', ‘'precisio'', or ‘'min-valu'', “max-valu'' if the property is used a constraint in a ‘'reques'' message.

```
<MSG_NAME ... >
<PROP_NAME>
<type>TYPE</type>
<value>VALUE</value>
...
</PROP_NAME>
...
</MSG_NAME>
```

FRCP can be used to support control over the hardware provided from a testbed, by using the predefined message format for advertising/controlling the available resources.

5.2.2. Other Custom/Dedicated APIs

Besides APIs that have been defined and adopted by several islands, some provide extended APIs for their dedicated equipment. For example, the 5GTN external APIs are exposed by the 5GTN facility adapter. It translates the generic requests coming from external controller or operator into facility specific requests so that the network performs the desired functions. Based on functionalities, the API interfaces have been divided into two groups:

1. Network Slice Management Interfaces
2. Key Performance Indicators (KPIs) Management Interfaces

The purpose of Network Slice Management Interfaces is to control the life cycle of a network slice in 5GTN. From creation to deletion each functionality is controlled by a respective interface. Currently 5GTN is supporting following interfaces:

- Network Slice Instance (NSI) Feasibility Check Interface: to verify the availability of resources to create a network slice instance.
- NSI Creation Interface: used to create a network slice instance in 5GTN.
- All NSIs View Interface: to retrieve the information of all the NSIs deployed in the 5GTN system.
- NSI View Interface: to get the information of one specific NSI.
- Delete NSI Interface: to delete an NSI and release the resources.

Once the NSI is created, real-time collection of performance data is needed to analyze the behavior of network slice to take appropriate actions. KPIs like throughput, delay, jitter, packet-loss etc. can be collected from two measurement points like source and the destination. Thus, for KPI monitoring 5GTN offers following interfaces:

- Create Measurement Job Interface: to start collecting the KPI data of one specific slice.
- Get Measurement Jobs Interface: to retrieve the information about all the KPI measurement jobs of all the slices.
- Get one Measurement Job Interface: to get the information of one specific measurement job.
- Delete Measurement Job Interface: to delete a measurement job and stop collecting the KPIs from a specific slice.

6. Conclusion

This document focused on analysing the current requirements of ICT stakeholders for the operation of the SLICES-SC facility, as well as the fundamental principles on which developments will be based. These principles, in conjunction with current trends in resource management such as resource programmability, network virtualization, and resource disaggregation, have led to the widespread adoption of various frameworks, interfaces, and resources for deploying experiments and applications over distributed infrastructures. The main interfaces, APIs and frameworks have been analysed accordingly. The purpose of this document is to continue the discussion on the requirement analysis, aiming to produce a sound solution for the long-term deployment of the SLICES-RI during the facility's construction and operation. Based on existing testbed APIs, high resource heterogeneity among the different nodes and the requirements analysis conducted within the consortium and this document, the consortium has decided to leverage existing APIs and extend them where appropriate to enable transnational access to the facilities. Existing APIs are leveraged from new tools that are being added to the facilities (e.g., a new portal design, support for reproducibility of experiments through the POS framework) towards offering more opportunities and rich experimentation tools to the research community. The present document draws the first conclusions based on the requirements fed from current and foreseen extensions of facilities, and will be refined continuously. The service design and architecture are based on the vast experience of the participating members in managing test platform infrastructures.

7. Annex I

In this section, we detail the equipment, locations, as well as main services offered from each of the SLICES-SC nodes.

7.1. SU Node

Name: **SILECS-FIT / OneLab**

Website: https://fit-equipex.fr/, https://onelab.eu/, https://www.silecs.net/

Annual Operating Costs: 3.6 million € (including amortization of investment costs).

Node Description

7.1.1. Technologies/Node offering

SILECS (SILECS Infrastructure for Large-scale Experimental Computer Science) deploys and operates a large-scale infrastructure allowing controlled access to advanced technologies. It responds to the need to support basic research in these areas where access to such instruments is essential. In addition, it creates synergies between university, industrial and commercial players in order to accelerate access to the market for basic ICT technologies, but also in the vertical sectors (application sectors).

SILECS is the French part of the SLICES-RI which is being formed since 2017 and submitted to the ESFRI Roadmap 2021. It is built on two existing French Infrastructures (FIT and Grid’5000). FIT is a French Equipex since 2011, which became a French National Research Infrastructure in 2015, and merged with Grid'5000 in 2018.

FIT is also part of the OneLab federation of testbeds since 2014, which allows connection and experimentation with other testbeds and technologies in Europe and beyond (e.g., with your OneLab account credentials you can now access all CloudLab sites infrastructure including sites in the US).

SILECS-FIT aims to:

- Enable experimentation across a broad range of subject, greatly reduce the cost and time required to design, establish and monitor an experiment, and through testing, the robustness of the solutions is increased.
- Provide a large-scale experimentation environment through the federation of testbeds that are competitive at the worldwide level, allowing to incubate advanced experiments and to stimulate a large base of users coming from the research world as well as industry.
- Offer large-scale state-of-the-art wireless, sensing and mobility infrastructures for any builder of tomorrow's systems and services, who wish to try out, test and validate his/her solution before implementing it in real-life.

- Offer easy access, a library of tools and online support for wireless and wireless sensor networks including robots. The users can even plug their own devices in FIT's testbeds and run their tests there as well.
- Provide a Cloud Infrastructure for experiments related to Cloud design, development of Cloud components and services

SILECS-FIT infrastructure is structured in three pillars:

- FIT Wireless: Highly flexible experimentation on a wide array of wireless networking issues.
- FIT IoT-Lab: A large-scale infrastructure for testing the Future Internet of Things.
- FIT Cloud: A Cloud Infrastructure for development Cloud components and services (FIT CloudLab). It provides compute and storage resources to experimenters (FIT Openstack).

On the IoT side, the FIT IoT-Lab platform, part of the FIT Equipex Initiative, offers a large set of IoT resources, more than 2700 wireless IoT devices and mobile robots are deployed on 6 different sites across France.

The platform provides different types of hardware such as M3, A8 and WSN430 boards and each of these nodes are equipped with various sensors such as ambient light, temperature, atmospheric pressure and temperature sensor, tri-axis accelerometer, tri-axis magnetometer, tri-axis gyrometer.

For the Cloud category, a Cloud Infrastructure is deployed and operated at Sorbonne University and consists of 2 different components, FIT Openstack and FIT Cloudlab, together it allows researchers to run cloud-based experiments related to the development and deployment of Cloud Software Stack, Cloud components and services.

FIT Cloudlab is the collaboration with the innovative project “Cloudlab” of the University of Utah, Clemson University, the University of Wisconsin Madison, the US Ignite, the University of Massachusetts Amherst, and Raytheon BBN Technologies which is part of the National Science Foundation NSFCloud program. CloudLab is a flexible scientific infrastructure for research on the future of cloud computing. Researchers use CloudLab to build their own clouds, experimenting with new architectures that will form the basis for the next generation of computing platforms. It provides researchers with control over compute, storage and network resources and visibility all the way down to the bare metal.

FIT OpenStack runs an underlying OpenStack Cloud that is composed of 9 compute nodes (Supermicro X9DRW and Dell PowerEdge R640) and 2 controller nodes (Dell PowerEdge R740) connected to a 10Gb SFP+ Cisco switch and provides over a hundred of computing cores to experimenters. The testbed enables experimenters to customize their own virtual servers with the CPU, Memory and Storage of their choice and to deploy virtual private servers on the OpenStack Cloud through the OneLab portal.

7.1.2. Locations deployed

The SILECS-FIT infrastructure is distributed in several different sites across France. The Head quarter is located at Sorbonne Université – 4 Place Jussieu, 75005 Paris, France.

The locations for the different sites are described below:

- FIT Wireless: R2 Lab (Inria-Sophia-Antipolis), In Lab (SU-Paris), NC Lab (IMT-Evry), Cortex Lab (Inria-Grenoble).
- FIT IoT-Lab: Inria Grenoble, Inria Lille, ICube Strasbourg, Inria Saclay, Inria Rennes and Institut Mines-Télécom Paris.
- FIT Cloud: FIT OpenStack (SU-Paris), FIT OpenStack NC Lab (IMT-Evry) and FIT CloudLab (SU-Paris).
- Grid'5000's sites through the SILECS merger are located in Lille, Nancy, Grenoble, Lyon, Sophia-Antipolis, Rennes, Nantes, Luxembourg, Toulouse.

7.1.3.Services Offered by the testbed

The SILECS infrastructure provides the following services:

1. On the one hand, it provides a service platform for testing and testing protocols and applications for the Internet (FIT infrastructure). It is organized on the basis of a federation of autonomous platforms, of various technologies, making it possible to stimulate a large base of academic and industrial users. SILECS also provides an environment and tools for accessing this platform, as well as measurement means for collecting data from experiences. It is thus an accelerator for the design of advanced technologies for the Internet of the Future. Open and free, the infrastructure provides the users with an access (regardless of geographic location) via the web interface or via ssh access, for example, in the case of FIT IoT LAB.
2. On the other hand, and thanks to the further integration with Grid'5000, SILECS can be seen as a Hardware-as-a-Service platform, highly reconfigurable and controllable: researchers can experiment with a fully customized software stack thanks to bare-metal deployment features, and can isolate their experiment at the networking layer. It also provides advanced monitoring and measurement features for traces collection of networking and power consumption, providing a deep understanding of experiments. It has been designed to support Open Science and reproducible research, with full traceability of infrastructure and software changes on the testbed. It is a large-scale and versatile testbed for experiment-driven research in all areas of computer science, with a focus on parallel and distributed computing including Cloud, HPC and Big Data.

SILECS has a significant community of 1500+ users supported by a solid technical team. SILECS targets 2,000 users out of an academic and industrial population of more than 10,000 people. We can expect around 20% of users from the industrial world, or around 400 users at European level, including SMEs, very small businesses, and large groups.

SILECS, through FIT and Grid'5000, has been used since the opening of the platform by different types of actors: public actors, industrialists, SMEs, local ecosystems, French research projects and European projects. Partnerships are most often made in the context of research projects. The main target community is French academics but there are also possibilities for academics outside French and private companies.

7.2. UTH Node

Name: **NITOS**

Website: *http://nitlab.inf.uth.gr/NITlab/index.php/nitos.html*

Annual Operating Costs: >350k€

Node Description

7.2.1. Technologies/Node offering

UTH provides in its premises an integrated infrastructure, named the NITOS Facility, which is a union of heterogeneous testbeds focusing on experimentation-based research in the area of wired and wireless networks. NITOS is remotely accessible and open to the research community 24/7 through the NITOS portal, allowing users from around the globe to take advantage of highly programmable equipment. The testbed is based on open-source software that allows the design and implementation of new algorithms, enabling new functionalities on the existing hardware. Parallel experimentation (slicing) of different users is enabled, through the utilization of the NITOS scheduler software. NITOS has an established user base of over 4000 users in the past years, with over 20 researchers using the infrastructure in a daily basis. It is federated with several infrastructures all over the world (Europe, Brazil, South Korea) in the context of various projects, like OpenLab, FLEX, Fed4FIRE, SmartFIRE, MONROE, 5GinFIRE, 5G-XHAUL, 5G-PICTURE, 5G-VICTORI while it is also part of the OneLab federation.

7.2.2. Locations deployed

The testbed is organized in four different clusters, all of which are interconnected through the UTH campus network and therefore resources can be combined from multiple locations. The main locations of the infrastructure are the following:

- An outdoor cluster of approx. 50 nodes, located in the heart of the city of Volos, all of them bound to external uncontrolled interference. The location has been selected as the external interference in the unlicensed spectrum is very high, with very dense deployments of access networks outside the testbed. The environment is very challenging, and has been used for creating new protocols and algorithms for dynamic spectrum management, interference control, power control, rate control, etc.
- An indoor cluster of 50 nodes, in an interference-free environment. Experimenters can setup the exact environment for testing their protocols/algorithms, and can get repeatable experiments. The environment is fully customizable, with programmable attenuators offering fine grained control of the wireless signal. The environment is used for 4G and 5G testing, using either off-the-shelf cells or Software Defined Radio equipment.
- An office cluster of approx. 20 nodes, with mild external interference. The environment is used for testing new resource management tools, before testing in either the indoor/outdoor deployment. The office cluster is also providing access to an LTE microcell, covering approx. the 1/3 of the city when operating in full power.
- A computing edge setup, based on a powerful blade server, offering low latency access from either the indoor cluster (<0.2 ms) or the outdoor setup (<0.5ms).

Resources from all the different locations can be mixed, in order to create endless experimental setups and environments.

NITOS indoor (left) and outdoor (right) testbed

NITOS blade system (edge) and 4G microcell available for experimentation

7.2.3. Services Offered by the testbed

Services currently offered by the infrastructure:

- A **wireless experimentation testbed**, which consists of 100 powerful nodes (some of them mobile) in indoor and outdoor deployments that feature multiple wireless interfaces and allow for experimentation with heterogeneous (Wi-Fi, WiMAX, LTE, Bluetooth) wireless technologies.
- A **wireless sensor network**, consisting of a controllable testbed deployed in an indoor environment, a city-scale sensor network in Volos city and a city-scale mobile sensing infrastructure that relies on bicycles of volunteer users. Most of the sensor platforms are custom-made, developed by UTH, and some others commercial, all supporting open-source and easy to use firmware and exploit several wireless technologies for communication (ZigBee, Wi-Fi, BLE, LoRa and 6LoWPAN).
- A **Software Defined Radio** (SDR) testbed that consists of Universal Software Radio Peripheral (USRP) devices attached to the NITOS wireless nodes. USRPs allow the researcher to program a number of physical layer features (e.g., modulation), thereby enabling dedicated PHY layer or cross-layer research.
- A **mmWave** testbed, consisting of six different nodes supporting multi-Gbps over the air speeds, and beam-steering with 15 degrees step.

- A drone base testbed, consisting of five high-performing drones that are able to carry NITOS nodes and setup wireless mesh setups with different technologies (WiFi, mmWave).
- A **Software Defined Networking** (SDN) testbed that consists of multiple OpenFlow technology enabled switches, connected to the NITOS nodes, thus enabling experimentation with switching and routing networking protocols. Experimentation using the OpenFlow technology can be combined with the wireless networking one, hence enabling the construction of more heterogeneous experimental scenarios.
- A **Cloud infrastructure**, which consists of 7 HP blade servers and 2 rack-mounted ones providing 272 CPU cores, 800 GB of Ram and 22TB of storage capacity, in total. The network connectivity is established via the usage of an HP 5400 series modular OpenFlow switch, which provides 10Gb Ethernet connectivity amongst the cluster's modules and 1Gb amongst the cluster and GEANT.

7.3. EURECOM Node

Name: **Open5GLab**

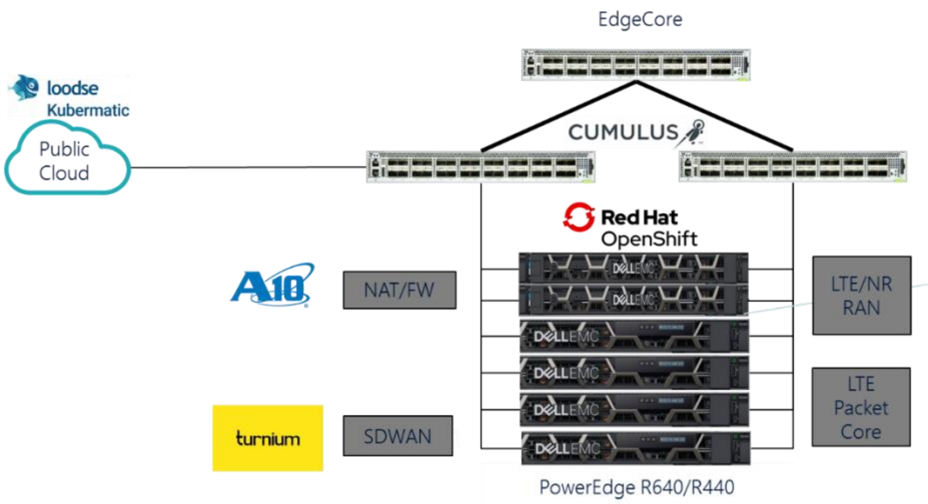
Website: http://open5glab.eurecom.fr/

Annual Operating Costs: 80k€

Node Description

7.3.1. Technologies/Node offering

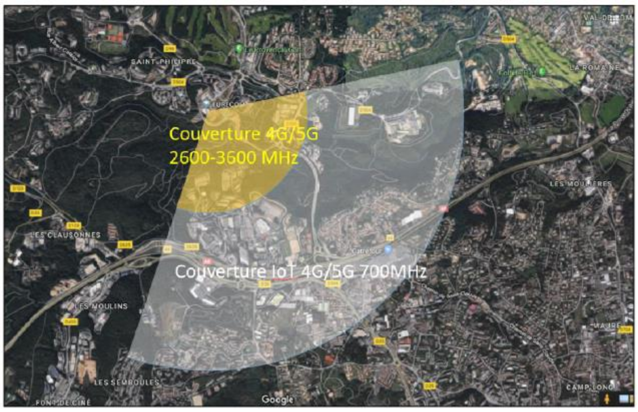
Open5GLab at EURECOM is one of 3 experimental 5G sites in France in the context of the 5G-EVE ICT-17 project. Construction began in July 2018 and 5G experimentation is now available. The site is interconnected with similar sites in Europe in the 5G-EVE network. It is also one of the test sites for the OPNFV VCO 3.0 (Virtual Central Office) project and as such is interconnected with sites in North Carolina, USA and Montreal, Canada.



Open5gLab provides experimental 5G services including so-called Enhanced Mobile Broadband (eMBB) and massive machine-type communications and is based on fully open-source tools and open-architecture design. It is the main experimental playground for OpenAirInterface (OAI) and Mosaic-5g (M5G) software packages. The site's cluster computing resource makes use of RedHat's OpenShift 4.2 Kubernetes container platform and benefits from technical support from RedHat. The cluster is used for radio-access, core network and mobile-edge functions. Some bare-metal nodes with in-lab 5G-capable radio devices can be used by experimenters and developers and are interconnected with the Kubernetes cluster. External access for onboarding software, collecting measurement data and developing basic software for the site is available for partners using secure-shell access. Interfaces for an external orchestrator (e.g., ONAP) is currently being integrated in the Open5GLab. The nodes of the site are also used by OpenAirInterface Jenkins-based continuous integration / continuous delivery (CI/CD) framework.

7.3.2. Locations deployed

Open5GLab's radio infrastructure includes indoor and high-power outdoor radio-units operating in several 4G and 5G bands in the immediate vicinity of the test site, specifically Band 28 (700 MHz), Band n38 (2.6 GHz TDD), Band n78 (3.5 GHz TDD), Band n258 (25 GHz TDD). The outdoor units are interconnected with the switching fabric using 300m fiber (10/25 Gbit/s). The units are a combination of in-house designs and commercial remote radio-units.



Open5GLab provides remotely-controllable 4G and 5G user-equipment, including both off-the-shelf smartphones and cellular IoT modules. This allows experimenters to control and extract measurements from the user-equipment in a running experiment. With the help of regional partners, Open5GLab provides embedded vehicular user-equipment nodes. Two drones are also equipped with 4G and soon 5G user-equipment and OAI-based 4G radios for mobile base station experiments. With the help of EURECOM, software can be on-boarded into the user-equipment devices.

7.3.3. Services Offered by the testbed

The Open5GLab site provides the means to on-board new network functions to a running 5G infrastructure and test them in both a controlled laboratory setting and in a deployed live network. Experimenters can either make use of existing network functions and basic applications or choose to on-board their own software to test with Open5GLabs infrastructure. This allows scientists to focus on their function of interest and its interconnection with a full network and collect measurements of the new design. In addition, if the network function enhances either the OAI or M5G implementation, it will automatically be reusable by a global network of researchers using OAI/M5G since it will be redistributable with OAI/M5G.

OAI and M5G software packages are used extensively around the globe. The Open5GLab site allows this community to have access to the laboratory used by the main developers of OAI and M5G. It is thus a crucial infrastructure for testing OAI and M5G in both laboratory and outdoor deployments. Since the site is used in OAI's CI/CD framework the entire OAI/M5G communities will be using the site automatically when committing code. The site is already used by the Linux Networking Foundation

VCO project and benefits from software resources from this community. The greater research community can thus benefit from.

7.4. PSNC Node

Name: **PIONIER-LAB**

Website: http://pionier-lab.pcss.pl, https://www.fed4fire.eu/testbeds/pl-lab/, http://pl-lab.pl

Annual Operating Costs: Estimated at 250k€

Node Description

7.4.1. Technologies/Node offering

SLICES Research Infrastructure in Poland is currently being developed as part of national projects from Polish Roadmap of Research Infrastructures. Therefore, at this moment only limited research services and resources are available for Open Calls for Experiments in SLICES-SC.

7.4.2. Locations deployed

The testbed is located in the CBPIO headquarters, located in the Poznan Supercomputing and Networking center. In the next section, we detail on the services offered per location (lab) within PSNC.

CBPIO – headquaters

Poznan Supercomputing and Networking Center

Polish Optical Internet Research Center
Street Jana Pawla II 10
61-139 Poznan

7.4.3. Services Offered by the testbed

Below we present the list of research services and resources currently available through remote access:

- **Cloud services**
    - Total: 512 vCPU, 2 TB RAM, 40 TB of disk space
    - Single reservation max 16 vCPU, 64 GB RAM, 1,25 TB of disk space
- **Optical and measurement equipment**
    - SPIRENT N11U IP Tester (full set of protocols), QSFP, 100G (CFP2), 10G, 1G interfaces

All these elements are accessible remotely by potential users of the RI from Member States.

On-site availability:

- **Multimedia services**
    - 8K Visualization Lab. A 6-meter-wide screen with native 8K resolution using 12 blended BARCO projectors supporting 2D and 3D display at 60 fps. It enables

visualization of advanced graphics and animation, as well as 8K and 8K 3D video projection.
    - 8K recording set, consisting of 4 SONY F65 cameras with the ability to record and live stream of 8K signal. The set is also equipped with a 3D rig for recording 8K 3D content. The set is also equipped with a programmable robotic arm and auxiliary devices for post-production and streaming.
    - Motion-capture equipment based on OptiTrack system enables acquiring of actors' movements in order to create advanced 3D animations.
    - 3D scanning station equipped with a Faro scanner. It enables scanning of landscapes and buildings to point clouds. The station allows for visualisation of effects in high resolution. The set is also equipped with hand-scanners for scanning smaller objects and artefacts.
    - High-order ambisonic sound equipment. The stand is equipped with 48 speakers in two portable installations and enables ambisonic and multi-channel sound reproduction with VR support.
- **Optical equipment and software:**
    - ADVA FSP3000 R7 three DWDM nodes – 10G, 100G, 400G transponders, HD-SDI transponders
    - FTTx node
        - 2 x OLT (Optical Line Terminal)
            - 4 x GPON C+ (support of up to 128 ONT on each port)
            - 2 x 10 GE
            - 4 x 1 GE
            - GPON (ITU-T G.984.4)
            - Active Ethernet
            - routing and switching (BGP, OSPF, IGMP, PIM, Ethernet, VLAN)
        - 20 x ONT (Optical Network Terminal)
            - 1 x GPON
            - 4 x 1 GE
            - 1 x FxS (VoIP)
            - 1 x RF Video
            - 802.11 b/g/n
        - 1 x ODN (Optical Distribution Network)
            - PLC Splitters (1:2, 1:8, 1:16)
            - Fiber modules (5 km, 10 km, 15 km)
    - 650 km of optical fibers in different segments for the DWDM and FTTx system transmission
    - EXFO PSO 200 optical modulation analyzer (up 1 Tb/s)
    - BOSA High Resolution Optical Spectrum Analyzer – 10 MHz, 80 fm
    - Optical Modulation Transmission system
        - Transmit: Keysight 65 Gsa/s 4 channel AWG combined with ID Photonics Multiformat Optical Transmitter
        - Receive: Dual Keysight 63 GHz oscilloscopes with optical frontend, 4 x 63 GHz channels
    - EXFO FTB-5500B Polarization Dispersion Analyzer.
    - EXFO FTB-5800 Chromatic Dispersion Analyzer.
    - EXFO FLS-5800A Broadband Light

- FINISAR Waveshaper 16000S Programmable Optical Processors (C band), 3 units, Waveshaper 4000S – 1 unit
- SPIRENT N11U IP Tester (full set of protocols), QSFP, 100G (CFP2), 10G, 1G interfaces

Synopsys R-Soft optical simulation CAD suite software

The research infrastructure within projects from the National Roadmap of RIs (PIONIER-LAB, PL-5G, NLPQT) is under construction and will be available to end users in 2024.

The list of laboratories to be offered from 2024 includes (among the others):

- Laboratory 1 - Laboratory of innovative network technologies,
- Laboratory 2 - Distributed Time and Frequency Laboratory,
- Laboratory 3 - Smart Campus as a Smart City laboratory,
- Laboratory 4 - Regional "Living" Innovation Laboratories inspired by ICT,
- Laboratory 5 - Cloud Services Laboratory,
- Laboratory 6 - Multi-Scale Simulation Laboratory,
- Laboratory 7 - Laboratory and e-training services,
- Laboratory 8 - Pre-incubation laboratory.

7.5. OULU Node

Name: **5GTN**

Website: *https://5gtn.fi/*

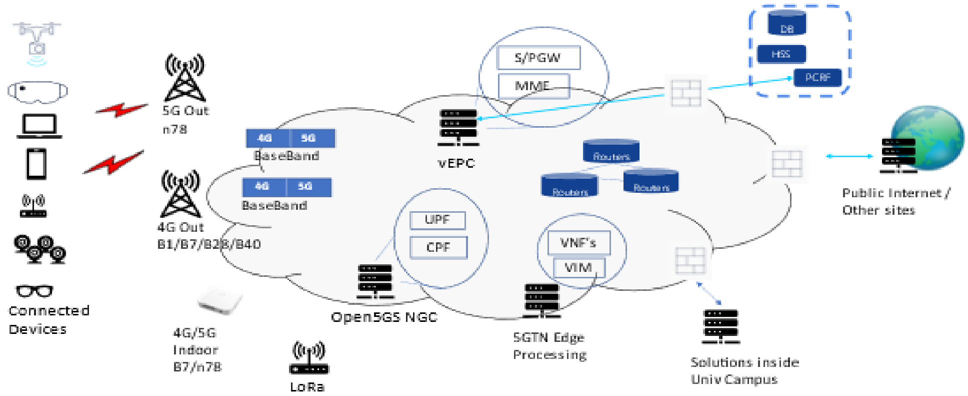
Annual Operating Costs: 250k€

Node Description

7.5.1. Technologies/Node offering

The 5G Test Network(5GTN) is a full-scale micro-operator. It is a national Finnish joint effort of University of Oulu, Technical Research Center of Finland (VTT) and fifteen different industry partners. It is a complete 5G test system and worlds first open 5G test network. Currently 5GTN is an essential part of the 6G Flagship Program (University of Oulu, Finland).

5GTN is designed and implemented to be scalable and to support various research and industry needs and experimentations. It has radio coverage in several locations in Finland: Oulu, Tampere, Ii, Sodankylä and Ylivieska. In Oulu there is radio coverage in the Oulu city center, University Hospital, VTT, Technology Park, University of Oulu and University of Applied Sciences campuses and also industry RD premises in Rusko.



5GTN main features:

- Uses both non-stand alone and stand-alone architecture allowing dual connectivity where compatible devices can utilize both LTE and New Radio access
  - Support for both 4G and 5G connections through 4G and 5G Base Stations
- Own SIM cards
- Core network implemented in cloud environment
- Possibility to utilize four different EPC's:
  - EPC (CMM17)
  - OpenEPC
  - Cumucore EPC
  - Open5GS
- Bluetooth based tracking system with 200 nodes
- LoRa network
- WiFi and IoT networks
- 400+ IoT sensor platfor operational at the campus
- Energy consumption / production measurement environment
- Both centralized and distributed computing servers and GPUs
  - Edge servers available
  - Multi-access Edge Computing (MEC)
- Frequencies in use:
  - 700MHz (B28) BW=10MHz
  - 2100MHz (B1) BW=10MHz
  - 2300MHz (B40) BW=20MHz
  - 2600MHz (B7) BW=20MHz
  - 2600MHz (B7) BW=10MHz

    - 3.5GHz (n78) BW 60MHz
    - 26GHz (n258) BW 825MHz
- Base Stations and antennas:
    - Three 5G Macro cells (n78)
    - Indoor 5G radios (n78)
    - One 5G mmW cell (n258)
    - Macro cell (B28) with NB-IoT and Cat-M
    - Macro cell (B7), LTE-FDD
    - Macro cell (B42), LTE-TDD
    - 20+ Pico Base Stations (both B1 and B7) on air
    - 10+ Pico Base Stations available/in use for different tests

7.5.2. Locations deployed

5GT is located at following sites in Finland:

- Oulu
- Tampere
- Ii
- Sodankylä
- Ylivieska.

In Oulu there is radio coverage in:

- University of Oulu campus
- University of Applied Sciences campus
- Universityof Oulu Hospital
- VTT
- Technology Park
- Industry RD premises in Rusko

7.5.3. Services Offered by the testbed

As an open and scalable innovation platform 5GTN offers:

- Possibility to experiment with different 5G technologies
- Creating new business models and services – value chain in digital platforms
- Real life experience in future mobile network already now
- Accessible interfaces create test options from components to solution
- Eco-system co-operation
- Access to new business/research areas and markets

5GTN offers accessible interfaces and supports several vertical use cases like:

- Care, wellbeing, and fitness
- eHealth in hospitals and on wheels
- Conscious Factory empowered by 5G Media production and distribution

- Connected and self-driving car
- Intercontinental 5G connections

7.6. COSMOTE Node

Name: **LeonR&Do IoT testbed**

Website: -

Annual Operating Costs: >10k€

Node Description

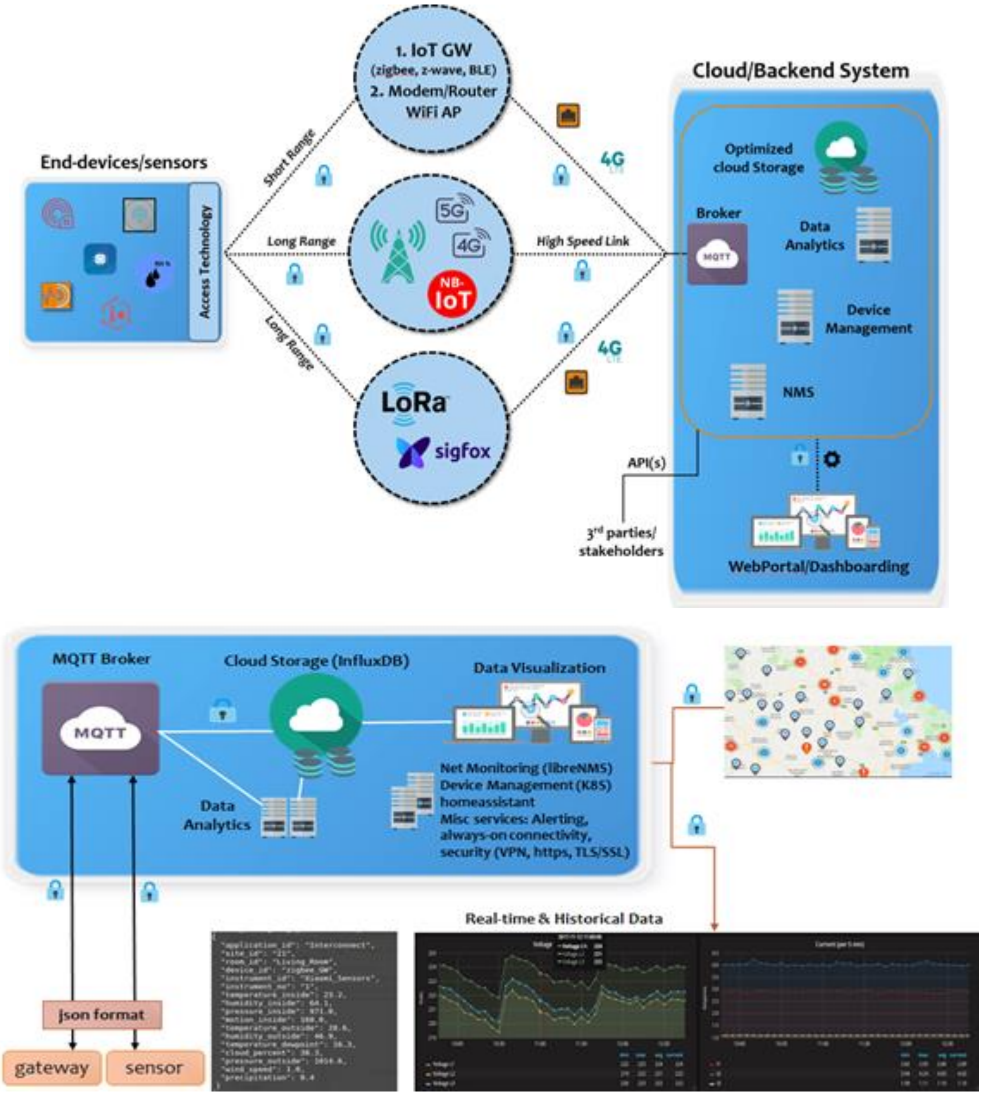
7.6.1. Technologies/Node offering

The LeonR&Do IoT testbed constitutes an integral part of COSMOTE's LeonR&Do testbed, which is composed of: (a) an e2e 5G NSA testbed (with MEC/edge capabilities), (b) an e2e 5G SA testbed (c) Red Hat Openstack-based Cloud ICT infrastructure and (d) an e2e IoT testbed/platform. The "LeonR&Do" IoT testbed, in particular, constitutes an e2e, open, flexible, scalable, vendor and technology/protocol agnostic solution -developed internally from scratch-, which, based on open-source tools, may support a wide range of IoT use cases. As shown in Figure 1, it is composed of:

- a (wide range of) commercial and custom end-devices/sensors independently of the access technology they utilize (WiFi, 2G/3G/4G/5G, NB-IoT, LoRa-WAN, Sigfox, ethernet, etc.).
- the "LeonR&Do" IoT gateway supporting secure remote access, facility automation, energy management/control, 100s' technologies/protocols, etc.
- a (common) backend cloud infrastructure enabling gateway/device management, automated data storage, data processing, (real-time and historical) data visualization, cloud-based Graphical User Interface, remote access from anywhere/anytime, alerting (via push notifications), security and command exchange.

Since the "LeonR&Do" IoT testbed is based on an open architecture and open-source tools, it may: (a) simplify and accelerate the development of new services and capabilities, (b) simplify the integration of the testbed with 3rd party integrators (by offering various APIs for real-time and offline, historical data acquisition), while providing them with the ability to use specific/preferred tools for deep dive data analysis and (c) provide the appropriate WebGUIs/dashboards to its end-users/stakeholders. Last but not least, it offers an open, json-based API between the IoT sensor and the backend, to achieve full sensor/technology compatibility.

The novelty of the "LeonR&Do" platform lies in its capability of supporting any IoT use case by integrating any custom/commercial sensor/device, while offering secure access, enriched insight for both real-time and historical measurements, GUI customization, rules definition, automations or even AI capabilities (e.g., object detection). Its long-term utilization since 2014 in various R&D EU-funded innovative projects (e.g., INTERCONNECT, 5G-COMPLETE, LIFE-SAFE CROSSING, aerOS) and internal to COSMOTE projects (such as energy monitoring/management, physical security), has resulted in the development of a stable and complete IoT platform, that is constantly being evolved (i.e., expansions/upgrades, field trials towards higher TRL) with beyond state-of-the-art capabilities.



"LeonR&Do" IoT Architectural Overview

An indicative list of sensors that have already been integrated in our platform is the following:

- Power/Energy meters (active and reactive power, energy, voltage, current, frequency, power factor)
- Energy: energy consumption in KWh
- Smart plugs/switches/relays/light-switches: change the current state of a relay. It can be also used to obtain the current state of the relay.
- Activity/motion/presence sensors: indicates presence in a room
- Door/Window sensors: current state of door/window [open/closed]
- Temperature [oC], Relative Humidity [%] and Pressure [hPa] sensors
- Luminance [lux]: illuminance level
- GPS sensors: location related info [co-ordinates]
- Smoke/fire sensors: smoke/fire detection
- Flood sensors: water leakage detection
- Gas sensors: gas leakage detection
- Push buttons

- Air-quality sensors: incl. CO2, CO, CH4, NH3, NH4, NO2, O3, alcohol, tolueno, acetone, particulate matter [PM1, PM2.5, PM10], TVOC, etc.

Misc end-devices: air-purifiers, de-humidifiers, doorbells, IP cameras, sirens, routers/modems, smartphones' sensors, thermostats, air-condition units, TVs, BT speakers, projectors, smart bulbs, assistants (google home, alexa), etc.

7.6.2. Locations deployed

The backend/cloud segment of the LeonR&Do IoT testbed has been deployed at OTE ACADEMY premises (Marousi, Athens, Greece), while a large number of IoT sensors (>250) have been deployed in various locations (incl. houses and telco sites in Athens and Thessaloniki greater areas), providing a diverse range of environments for testing and experimentation. Note that the testbed has been designed so as to support/aggregate sensors located anywhere in the world directly (if there are WiFi, 2G/3G/4G/5G, NB-IoT, LoRA enabled) or via our IoT gateway if they are based on zwave or zigbee technologies.

7.6.3. Services Offered by the testbed

The IoT use cases that are currently supported are: (1) energy monitoring/management, (2) home comfort, (3) security and (4) smart cities (air-quality/pollution monitoring).

The "LeonR&Do" IoT testbed offers 3 APIs to 3rd parties for data acquisition:

1. By subscribing to one or more MQTT topics where the measurements from the sensors are being published. This can be done using e.g., a Python script (see below) enabling real-time processing or utilizing e.g., the Telegraf tool so that the measurements to be (automatically) inserted in a timeseries database for post processing purposes. In the context of the AEOLUS normal operation, the MQTT-based API will be utilized, since it offers real-time information provisioning to the AI/ML platform for data analytics purposes.
2. By directly querying the InfluxDB using a curl command supporting HTTP response codes, HTTP authentication and basic authentication. The responses are returned in JSON format.
3. By extracting the relevant measurements directly from the Grafana visualization tool using the "Export CSV" option. The results are stored in a .csv file.

Regarding the end-users, the following services are being offered:

- A near real-time and historical data visualization environment (Grafana) where the user may visualize/compare sensor measurements at any time interval, depict min/max/average values, depict the data using various graph types (bar, XY scatter, gauge, heatmap), create alerts and send push notification / e-mail messages, etc.
- A cloud-based graphical environment (WebGUI/dashboard) realized via the home-assistant open-source home automation software (https://www.home-assistant.io/).

The main features/capabilities that are being offered to the end-users (via a cloud-based graphical environment) are listed below -non exhaustive list:

- Secure login using username and password over https connection
- Add/integrate new sensors/devices (>2200 ready to use integrations are available)
- Add, remove or re-configure IoT sensors/devices
- Monitor the state of the devices (unavailable, on, off, open, closed, etc.)
- Devices actuation for e.g., smart plugs, light switches, HVACs, TVs, air-purifiers, humidifiers
- Create groups of devices that can be treated as a single "entity" (e.g., living room lights, yard lights, all lights)

- Create advanced automations based on complex rules/events such as, when a presence sensor is activated when the alarm is on, the living room lights are turned on sequentially, an announcement is triggered via a Google Home Assistant device, the siren is activated, snapshots from the cameras are captured and sent to the user as enriched push notification messages.
- Real-time alerting via enriched push (and actionable) notifications for any user defined event, sensor status, etc.
- Voice commands, location-based presence for family members, smartphone sensors' integration (Android, iOS), etc.
- Countless layout customizations, including multiple tabs, interactive floorplans, various devices depiction options (e.g., on a per room or type basis), sensor measurements visualization (latest value, gauge, graph or via interactive floorplans), etc.

Both the above graphical environments are accessible from anywhere, anytime and via any device e.g., PC/laptop, smartphone or even smartwatch.

7.7. CNR Node

Name: **CNR-IIT Lab**

Website: -

Annual Operating Costs: 50k€

Node Description

7.7.1. Technologies/Node offering

The focus of the current CNR-IIT Lab testbed is to enable experiments in the research domains of edge computing, edge intelligence and decentralised AI. The main component of the CNR-IIT Lab testbed is a latest-generation local cluster for HPC that includes:

- 3 bi-processor nodes (Intel Xeon Platinum) with 104 cores, 512GB RAM, and an NVIDIA Tesla T4 16GB GPU;
- 1 bi-processor node (Intel Xeon) with 40 cores, 128GB RAM, and an NVIDIA TITAN Xp GPU;
- 1 64-core quad-processor (AMD Opteron Processor 6282).
- Management routers and bare-metal switches

In addition to the above hardware, the CNR-IIT Lab infrastructure also includes (20) IoT devices, such as sensors and gateway devices, that are used to support experiments on WSNs for Industrial Internet applications, and decentralised AI on resource-constrained networked devices. Finally, the CNR-IIT Lab testbed also offers the use of a limited number of mobile devices, such as smartphones, tablets, wearables, to support experiments involving fog-computing technologies.

7.7.2. Locations deployed

CNR-IIT Lab testbed is deployed at CNR's premises in Pisa.

7.7.3. Services Offered by the testbed

Currently, the CNR-IIT Lab tested does not implement a management framework that allows users to set up the testbed environment according to Testbed-as-a-Service paradigm. We use libvirt tools for static allocation of virtualized resources, built as guest VMs. Furthermore, offline registration procedures are used to authorize researchers to use the resources of the testbed. Currently, external researchers can use the testbed only within the framework of a regional Digital Innovation Hub (Artes 4.0).

7.8. iMEC Node

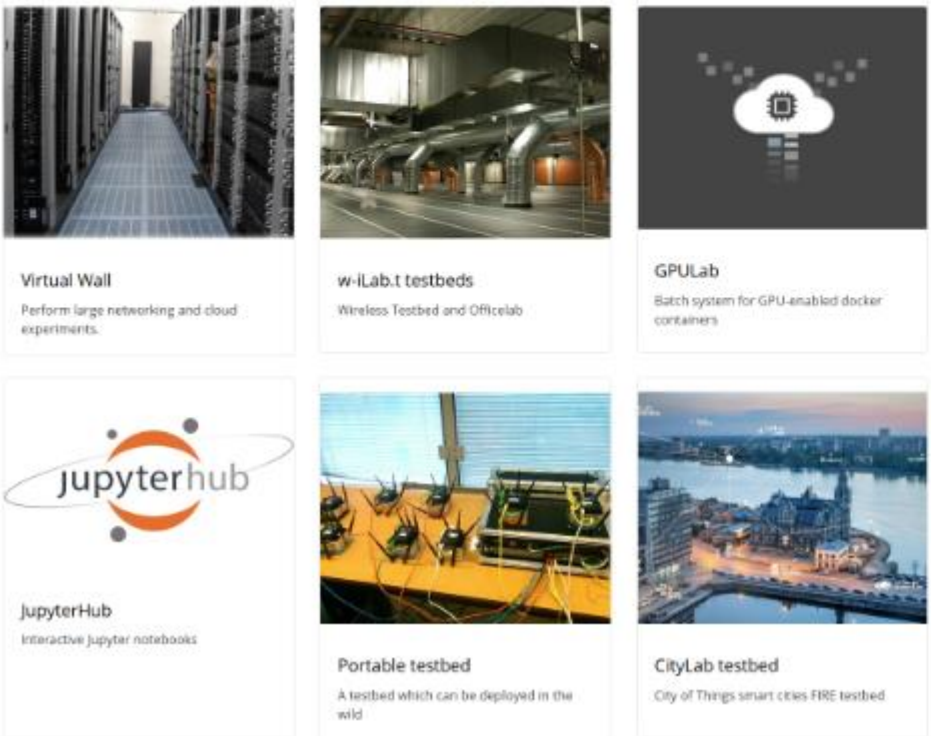
Name: **imec iLab.t Belgium**

Website: https://idlab.technology/infrastructure/ and https://doc.ilabt.imec.be/ilabt/

Annual Operating Costs: 400k€ (no hardware investments)

Node Description

7.8.1. Technologies/Node offering



imec testbed portfolio available through Slices-SC

- Virtual wall (Gent): to perform wired networking, cloud, distributed software, service backends and scalability experiments. 550+ installed servers.
- w-iLab.t (Gent): pseudo shielded environment for wireless and IoT research with over 150 wireless nodes (fixed and mobile), including software defined radios
- Officelab (Gent): a real office environment for wireless and IoT research with over 110 embedded PCs spread over the building.

- GPULab (Gent and Antwerpen): testbed with 125+ GPUs with over 570.000+ cuda cores and 1.8TB+ GPU RAM for AI research and everything which needs GPUs. Available through interactive jupyter notebooks and scheduled jobs.
- CityLab (Antwerpen): testbed for wireless networking experimentation in the unlicensed spectrum in the city of Antwerp. 50 nodes are spread over an area of 1 square km.

All testbeds are available through the SLICES portal and tools. The testbeds are open to externals. All testbeds are perfectly accessible through remote access, which is also the main usage of the testbeds. For w-iLabt.t, Officelab and Citylab experimenters can come also physically and bring their own device (BYOD).

7.8.2. Locations deployed

Gent and Antwerp in Belgium, see above for details.

7.8.3.Services Offered by the testbed

All testbeds can be remotely used with a single account. The GPULab testbed is accessed by a web interface or by using a Jupyter notebook (and offers also a command line interface), while the other testbeds support the GENI/Fed4FIRE AM APIs and can be used with the jFed tool (https://jfed.ilabt.imec.be).

The wireless testbeds and GPULab offer advance reservation, while the others can be used instantly.

The documentation website describes the available hardware and tutorials how to use them.

If needed, consulting services by imec can also be offered for a fee.

7.9. SZTAKI Node

Name: **ELHK Cloud**

Website: https://science-cloud.hu/en

Annual Operating Costs: Not determined

Node Description

7.9.1. Technologies/Node offering

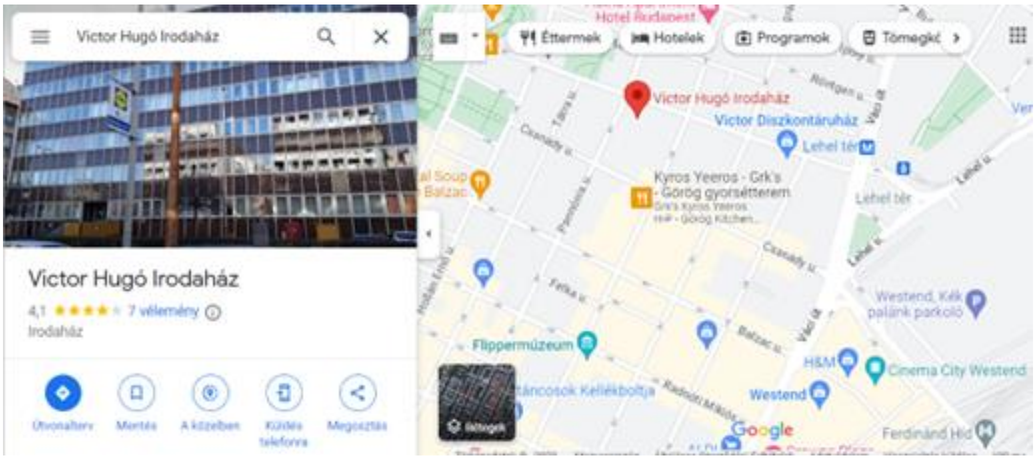
ELKH Cloud is an e-infrastructure framework that allows users to create an e-infrastructure tailored to their specific needs in a cloud environment. ELKH Cloud is based on a project-oriented approach meaning that users do not typically utilize the cloud as individual researchers but as members of a project. Launching of a project can be initiated by the project manager by filling out a request form describing the purpose, duration, and resource requirements of the project. If the project is accepted, it receives the required resource capacity in the form of a quota. Within this quota, the project is then free to create an e-infrastructure that is best suited to its objectives (e.g., Spark cluster, Kubernetes cluster, deep learning supporting environment, etc.). The project manager may allow individual researchers to join at any time. Project members share the e-infrastructure that was created within the project. The different projects are completely isolated from each other and cannot access each other’s data.

ELKH Cloud was built on the infrastructure of MTA Cloud created in 2016 and underwent significant development starting from the third quarter of 2020. The table below shows the actual resource capacity.

Type of resource	ELKH Cloud capacity
number of vCPU	5.904
memory (RAM, TB)	28
HDD (TB)	1,248
SSD (TB)	338
internal bandwidth (Gbit/s)	100
number of GPU cards	68
GPU memory (RAM, GB)	2.400
GPU double (TFLOPS)	584
GPU single (TFLOPS)	1.174
GPU FP 16 tensor (TFLOPS)	13.736

7.9.2. Locations deployed

The server machines of the ELKH Cloud are physically located in the east-north part of Budapest, Hungary at the former site of SZTAKI. The address of the site is 1132 Budapest XIII. Victor Hugo u. 18-22.



The ELKH Cloud operation team is working at a different location. The operation team is located in the west-south part of Budapest, Hungary at the Lagymanyosi site of SZTAKI. The address of the Lagymanyosi site is 1111 Budapest, Lágymányosi u. 11. More details can be found at https://www.sztaki.hu/en/contact-us

The main webpage of the ELKH cloud is at https://science-cloud.hu/en

The technical support of the ELKH cloud can be reached at https://science-cloud.hu/en/contact

7.9.3. Services Offered by the testbed

As an IaaS Cloud ELKH Cloud allows researchers to create different types and sizes of e-infrastructures that are dynamically adjustable according to the current needs of their ongoing projects. With the help of the reference architectures, these infrastructures may range from a simple desktop computer (e.g., MS Windows, Linux) to high performance computing clusters (e.g., SLURM cluster).

ELKH Cloud also provides a large storage capacity for the temporary storage of scientific data while the applications running on the associated e-infrastructure are processing said data. The secure storage of data is ensured by OpenStack cloud middleware.

Creating the desired e-infrastructure in a cloud environment is usually a complex task requiring expertise, so ELKH Cloud provides reference architectures for the most commonly used, typical e-infrastructures to help users build their desired infrastructures in minimal time. Reference architectures are premade, carefully tested, ready-to-deploy infrastructures that can be used to automatically deploy the desired infrastructure after some customization and adjustment of properties.

Reference architectures are available in the following categories:

- General solutions for architectural, access control, orchestration, continuous integration and delivery.
- Clustering of various services based on industry standard solutions, such as Kubernetes, Docker-Swarm, CQueue as well as several tailor-made solutions like our own Occopus cloud orchestrator, gUSE grid user portal or Flowbster data workflow management.
- BigData oriented services, such as Jupiter, Apache Hadoop, Apache Spark, RStudio, DataAvenue.
- Applications for machine learning, like Tensorflow, Keras and Horovod.

The actual list of available reference architectures can be found at https://science-cloud.hu/en/reference-architectures.

ELKH Cloud offers direct assistance to users wanting to build non-typical e-infrastructures and then aims to create reference architectures for all e-infrastructures created this way while also providing a repository for them for easy access and storage. This allows all ELKH Cloud users to utilize these unique reference architectures as well.

7.10. INRIA Node

Name: R2Lab - Reproducible Research Lab

Website: https://fit-r2lab.inria.fr/

Annual Operating Costs: Not determined

Node Description

7.10.1. Technologies/Node offering

R2lab is an open tested located in an anechoic chamber for reproducible research in wireless WiFi and 4G/5G/NG networks. R2lab is part of the FIT federation, an open large-scale testing infrastructure for systems and applications on wireless and sensor communications.

Located at INRIA Sophia-Antipolis, R2lab proposes thirty-seven customisable commercial off-the-shelf wireless devices, together with USRP nodes and commercial LTE phones, fit to create rich experimental setups. The testbed also features advanced software like leverage OpenAirterface (OAI) and GnuRadio, as well as efficient software tools, to support easy experimentation. These tools allow to book the whole testbed, to remotely control the wireless devices, to easily deploy various scenarios and to collect results.

The R2lab platform sits in an insulated anechoic chamber of ≈ $90m^2$. It hosts thirty-seven nodes scattered on a fixed grid; about one third of these nodes feature a USRP board of various kinds. In addition, commercial phones are available for connecting to a simulated 4G network.

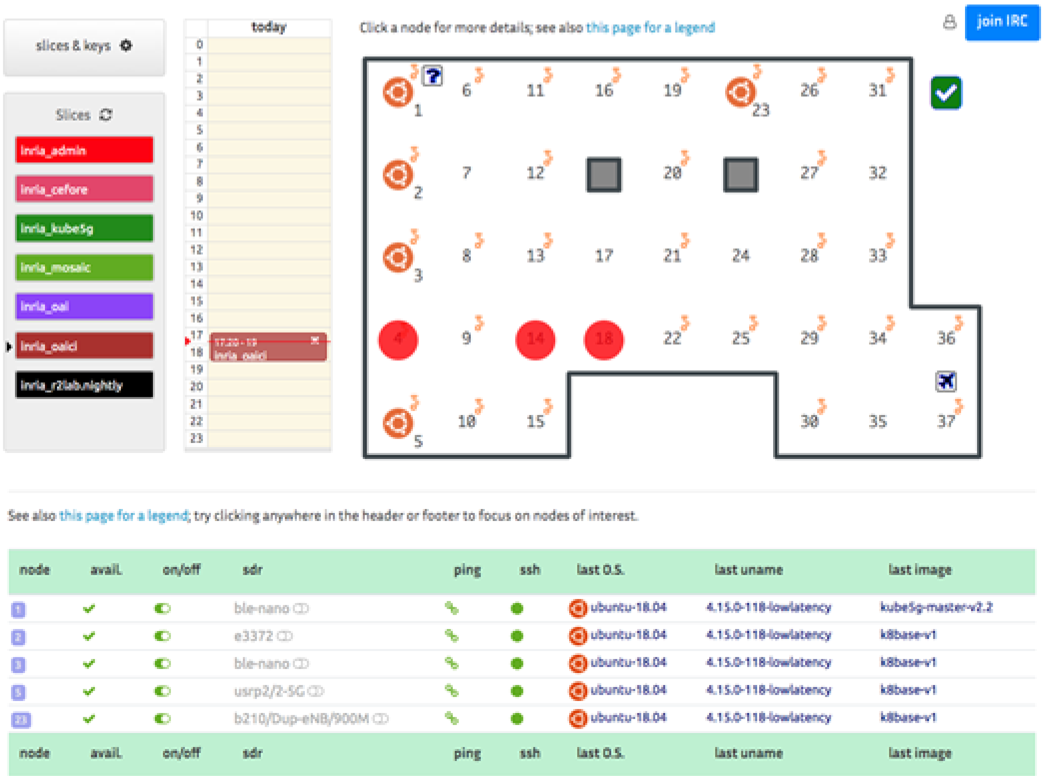
7.10.2. Locations deployed

All R2lab nodes are based on Nitos X50. More than two dozen of R2lab nodes are equipped with USRP devices from ETTUS to run SDR-based experiments such as spectrum analyzer or 4G/5G OpenAirInterface scenarios. All these devices can be remotely-controlled through the ust/uon/uoff utilities. Currently, our deployment features the following types of USRP devices: USRP B210, USRP N210, USRP2, and USRP1.

R2lab also features other hardware node such as Lime SDR devices, Duplexers Commercial Huawei LTE Sticks, Commercial Bluetooth 4.2/5.0 Low Energy (BLE) devices and Commercial 4G Phones.

7.10.3. Services Offered by the testbed

The testbed is reservable as a whole in a very user-friendly manner (see UI hereafter). Once the testbed is booked, registered users can ssh into the gateway (faraday.inria.fr), and from there control all the resources in the testbed. Users have full control, and can run their OS of choice with any experimental software they need for achieving their goals.



Experiments can then be orchestrated with standard tools. For convenience, we also provide software tools as python libraries (see more details and tutorials here), that allow to quickly script efficient experiment deployment capabilities, complete from nodes provisioning to data collection. Check out our YouTube videos for further information.

Access to R2lab is open 24/7. R2lab is used by more than 150 users, half of them from France and the other half from all over the world (Australia, Belgium, Brazil, Canada, Chile, Spain Finland, Germany, India, Indonesia, Italy, Japan, Luxembourg, Netherlands Norway, Tunisia, Turkey, UK, US, Vietnam, etc.) to evaluate a wide range of wireless networking scenarios in realistic and reproducible environment. For more details see R2lab home page.

7.11. IoT Lab Node

Name: IoT Lab

Website: https://www.iotlab.eu/

Annual Operating Costs: Not determined

Node Description

7.11.1. Technologies/Node offering

IoT Lab combines into an online common platform crowdsourcing and crowdsensing tools together with several testbeds on the Internet of Things (IoT). The primary objective of IoT Lab is to offer a

Testbed as a Service research infrastructure to ease multidisciplinary research and experiments with more end-user interactions in the context of the Internet of Things.

The available resources provided by the IoT Lab testbed are composed by CoAP sensors and actuators, HTTP gateways accessing CoAP nodes, and sensors installed into the smartphones through a mobile application to be installed on Android and iOS phones. To be more precise in terms of used technologies, CoAP is in fact an application-layer protocol and the underlying communication protocols are IEEE 802.15.4 and 6LoWPAN.

Different types of CoAP resources are provided in the different IoT Lab testbeds:

- Temperature
- humidity: relative humidity [%]
- co: level of carbon monoxide
- co2: level of carbon dioxide
- luminance: illuminance [lx]
- motion: indicates the presence
- location: position of the IoT device
- energy: consumption of energy [W]
- electricity: all the attributes linked to the electricity like the voltage [V], the current [A], etc.
- blind and blinds: change the position of a blind. It can be also used to retrieve the current status of a blind.
- valve: change the position of a valve. It can be used to get the current position of the valve.
- switch and relay: change the current state of a relay. It can be also used to obtain the current state of the relay.
- alert: enable or disable a red flashing lamp

Furthermore, the http gateways permit to access CoAP nodes through HTTP connections. They are using CoAP and HTTP protocols, of course.

For the communication between the IoT Lab testbed and the different smartphones using the mobile application, a notification service is used and allows a quick exchange of data between the testbed and a smartphone without taking care of the location of the smartphone or its IP address. Five kinds of sensors, and so five sorts of measurements, are available inside the smartphones:

- location: position given by the GPS or similar positioning systems like GLONASS or Galileo
- accelerometer: measures the acceleration
- magnetometer: measures the magnetic field
- gyroscope: measures the orientation of the smartphone
- light: illuminance in lux

Some limitations to get the measurements provided by the sensors installed into the smartphones can occur for privacy reasons. Indeed, each owner of a smartphone can restrict at any time the access to the data generated by his smartphone.

7.11.2. Locations deployed

IoT Lab is composed by different IoT testbeds located in Europe. These testbeds are federated inside IoT Lab using SFA Wrap. The main IoT Lab server is running in Geneva and includes the different required databases. The users of the IoT Lab platform, researchers or the crowd, reach the online services offered by the IoT Lab server through the website (https://www.iotlab.eu/) and the dedicated mobile application.

Basically, there are four testbeds in IoT Lab and all are located in Europe:

- CTI testbed located in Patras, Greece
- UNIGE testbed located in the University of Geneva, Switzerland
- UNIS testbed located in the University of Surrey, United Kingdom
- IoT Lab testbed located in Geneva, Switzerland

Wireless sensors and sensors installed into the smartphones are also integrated into the IoT Lab online platform. The wireless sensors are members of a virtual portable testbed. The sensors of the smartphones are considered as mobile resources with the point of view of the IoT Lab testbeds federation.

The four major IoT testbeds are federated using SFA Wrap and each testbed is running a piece of the SFA Wrap software. A centralized instance of SFA Wrap collects the data provided by the instance of SFA Wrap running locally on each IoT testbed. This allows to detect the resources available in each testbed and to update regularly the list of resources.

The centralization and the cloudification of the IoT Lab platform are done in Geneva. The IoT Lab research infrastructure was integrated into the Fed4FIRE testbeds federation, through the implementation and the use of the GENI Aggregate Manager (AM) API version 3 in the IoT Lab platform, notably for the advertisement of resources and for the allocation of the resources in the experiments.

7.11.3. Services Offered by the testbed

First of all, the IoT Lab is provided as a Testbed as a Service through an online access at https://www.iotlab.eu/ and each interested researcher can ask for an access to the IoT Lab Testbed as a Service through an online registration form. A registered researcher can discover the different resources available through the IoT Lab platform, reserves the needed resources corresponding to the measurements done by the heterogeneous IoT devices and to create experiments using the reserved IoT devices. Then, the researcher can execute the experiments and retrieve the results of the experiments. Furthermore, a LimeSurvey server is available to collect the feedback of the end-users participating to a given experiment.

7.12. TUM Node

Name: SLICES Virtual pos Testbed

Website: https://testtestbed.net.in.tum.de

Annual Operating Costs: *not determined*

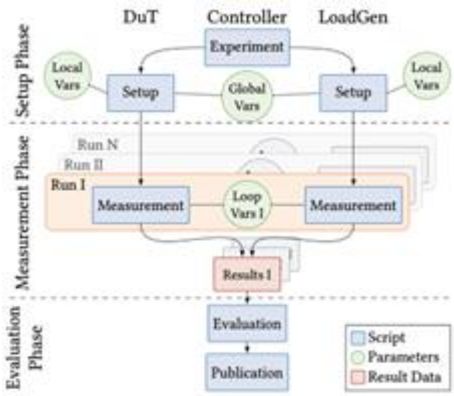
Node Description

7.12.1. Technologies/Node offering

The SLICES Virtual pos Testbed is a fully virtualized testbed that is controlled by a management system with an integrated experiment controller called plain orchestrating service or short pos.

The main feature of the experiment controller is the creation of reproducible experiment workflows. Reproducibility is achieved through a structured experiment workflow, that offers enough flexibility for experiment designers to realize experiments involving different domains such as compute, network or storage. By adhering to the workflow's structure, experiments are created in an inherently reproducible way, leading to a property that we call reproducibility by design.

The workflow relies on a fully automated workflow that involves the setup of the experiment, the actual creation and collection of the measurement data, and the evaluation. All of these steps need to be automated via scripts. Our testbed provides only live images for the experiment nodes. On the one hand, live images require the recreation of the configuration after a reboot. On the other hand, a reboot also ensures a well-defined state for each experiment node when starting a new experiment. Live images and automation ensure that experiments become **repeatable**. This means that an experimenter can recreate its experiments using the identical testbed. **Reproducibility** is achieved if other researchers can also recreate the original experiment, which can be achieved by providing access to the original testbed.



TUM pos experiment workflow

The pos experiment workflow is a well-structured and organized approach to conduct experiments for performance measurements and system evaluation. The workflow consists of three main phases: setup, measurement, and evaluation. Each phase uses different scripts that are stored in separate files, making the experiment easier to understand and follow.

The setup phase involves the use of setup scripts, which are used to prepare the testbed for the experiment. The measurement phase involves the actual execution of the experiment, where the performance of the system is measured and recorded. The task description is an important part of this phase as it outlines the objectives of the experiment and the parameters to be used. The collected data is stored in a format that can be easily processed and analyzed in the evaluation phase.

The evaluation phase involves the use of evaluation and publication scripts, which are used to analyze the results of the experiment and present the findings. The results are stored in a git repository, which serves as a repository of all the experiment artifacts, including the files used in the setup, measurement, and evaluation phases.

The SLICES Virtual testbed is part of the European Open Science Cloud (EOSC), a European initiative to provide resources for scientific use (https://marketplace.eosc-portal.eu/services/slices-virtual-pos-testbed). EOSC provides a portal that lists different resource providers that offer relevant services to their respective scientific communities.

7.12.2. Locations deployed

The Virtual pos Testbed is currently hosted on the premises of the Chair of Network Architectures and Services at the Technical University of Munich in Garching near Munich in Germany. This is currently the only location of the testbed.

7.12.3. Services Offered by the testbed

TUM testbeds follow an Infrastructure-as-a-Service approach providing access to bare-metal or virtual hardware. This means that experimenters have full, low-level control over the available resources.

The testbed controller provides several Linux images that can be used for experiments. Currently, Debian and Ubuntu Linux with different kernel versions are provided. However, TUM also provides a tool for users to generate their own images using their preferred Linux distribution.

A typical approach for testbeds, is the provision of container or network connectivity without the possibility to apply an experimenter-defined configuration. In the pos workflow, experimenters have a low-level access to the hardware, e.g., servers and switches, to deploy their own configuration of the container management or network. This allows the investigation of performance between network nodes or containers that may be impossible on other testbeds that do not offer this kind of low-level accessibility.

7.13. IMDEA Node

Name: 5TONIC

Website: www.5tonic.org

Annual Operating Costs: 257k€ (not include the contributions in equipment and efforts provided by the 5TONIC members)

Node Description

7.13.1. Technologies/Node offering

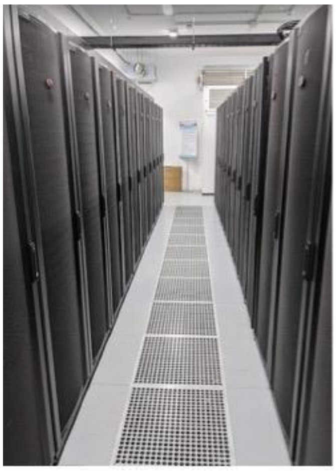
5TONIC is an open laboratory for the experimentation of new mobile technologies and the development of use cases that make use of them for different applications. It was founded in 2015 by IMDEA Networks Institute and Telefónica I+D, and currently its other members are University Carlos III Madrid, Ericsson, CommScope, InterDigital and Capgemini Engineering.

The objective of 5TONIC is to create an open global environment where members from industry and academia can cooperate on specific research and innovation projects related to 5G and 6G technologies with their combined insight allowing them to boost technology and business innovation ventures. The laboratory promotes joint project development and entrepreneurial ventures, discussion fora, events and conference sites in an international environment. The laboratory was awarded Digital Innovation Hub status by the European Commission.

In order to support its activities, 5TONIC has deployed a complete, end-to-end 5G network, that includes:

- RAN operating at low, mid and high (mmwave) 5G frequency bands, with both indoor and outdoor coverage solutions. Infrastructure deployed support massive MIMO and other advanced radio functionalities.

- 4G and 5G core networks, providing 5G NSA and SA services.



- Processing platforms, including edge processing platforms, as Gapgemini's Ensconce MEC platform.
- Experimentation areas, prepared to host the activities of industrial collaborators

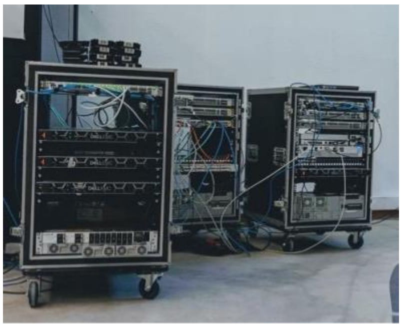
7.13.2. Locations deployed

The node is deployed at the premises of IMDEA Networks Institute in Leganés, Madrid. The official address is:

IMDEA Networks Institute

Avda. del Mar Mediterráneo 22

28918 Leganés (Madrid) – SPAIN



As indicated below, the lab is looking at its expansion in the University Carlos III Madrid polytechnic campus, also located in Leganés.

Among 5TONIC offerings is the possibility of moving 5G network and processing infrastructure to other locations, deploying portable units developed for these purposes. In this sense, 5TONIC has deployed a complete 5G network infrastructure for supporting use cases at IFEMA Madrid Convention Centre, Innovalia premises at Bilbao and Ford car factory in Almusafes, Valencia.

7.13.3. Services Offered by the testbed

Basically, the lab provides different levels of support

1. 5TONIC provides technical support for the implementation use cases that have been approved by the Steering Board. For these purposes, 5TONIC can provide an end-to-end network infrastructure, as well as processing platforms, devices, testing equipment, etc. To support these activities, it is usually the case that a collaboration agreement is signed between 5TONIC and the other parties involved, regulating aspects like intellectual property, ownership of data, diffusion of results, etc.
2. 5TONIC can also host the infrastructure of tests associated with European and national projects undertaken by its members and their partners.
3. Finally, 5TONIC also provides support for new companies to test new technological solutions and applications based on 5G and beyond 5G technologies.

So far, the lab has not defined a catalogue of a set of services that can be offered for researchers nor the conditions to get access to them, but it is working in this direction in the context of SLICES project.

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