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D4.2 Final report and assessment of training activities

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

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Executive Summary

The objective of this document is to report the final round of training activities conducted by the consortium partners for training external users of the SLICES research infrastructure. This deliverable serves several purposes: firstly, to describe the SLICES framework for training activities, which includes the preparation of training materials, organization of summer schools, hackathons, training sessions, and a research mobility program. Secondly, this document reports on all the training activities carried out during the course of SLICES-SC. As a main conclusion from organizing these training activities during this second period, the consortium has decided to construct a common framework for all training activities, forming a new open educational ecosystem known as the SLICES Academy.

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1. Introduction

The objective of this deliverable is to report the training activities and material conducted by SLICES. The deliverable is targeting SLICES-SC consortium members and external communities related to SLICES. This encompass both novice and expert users from multiple disciplines, including R&D staff in industry and academia, all targeting to use the SLICES research infrastructure. The document reports on the activities of the consortium partners regarding training activities and outlines plans for future joint training activities designed to foster the participation of external users in SLICES.

The document initially describes the motivation for the creation of the SLICES Academy and different steps towards its creation. It furthermore provides future steps to be carried out in the context of SLICES-PP. The deliverable describes the work done to create new and adapted existing content within SLICES Academy. In addition, it reports on the different training activities such as SLICES summer schools, hands-on activities, workshops on SLICES-RI related subjects in major EU and international venues, their audiences and feedback from the community. SLICES organised several hands-on and hackathon activities related to stimulating software development activities in the community to enrich SLICES-RI facilities and toolsets used for experimentation in networking and information systems and they are reported in this deliverable. Finally, SLICES use of mobility funds to foster interactions within the SLICES-RI community and to attract new partners in EU and links worldwide and these activities are presented.

2. The SLICES Academy

2.1. SLICES Academy Purpose

There is an increasing concern that most recently published research findings are false, which leads to a potential risk of limited confidence in novel scientific research.[1] This concern strongly motivates the need to educate a new research community that will propose more grounded theoretical concepts, which have already been evaluated in practical deployments using experimentation platforms. One of the primary objectives of SLICES is to provide the research community with access to the SLICES-RI distributed facility, which will serve as a scientific instrument to support their research endeavors. The SLICES-RI operates as an accessible platform for the global research community, available 24/7, and allowing for remote access. Such an infrastructure expands the research capacities of the scientific community, allowing for experimentation with costly and scarce resources that can be integrated in modular settings. The problem is that this infrastructure is used through tools and methods that are currently not standardized. As follows, the research community faces a significant challenge in acquiring the necessary knowledge and skills to get acquainted with SLICES-RI and begin utilizing it. This gap is going to be filled with the assistance of SLICES Academy[2].

It is crucial to establish and maintain an active dialogue between the participating organizations and other stakeholders (researchers, industry, technology providers, research institutions, and public authorities) through a modern, multi-functional communication and training platform, which also serves as a knowledge broker for the end users. The compilation of needs for skills and competencies, along with the identification of the optimum training delivery channels, provides the building blocks in terms of information and analysis for the development of the SLICES Academy. This academy responds to user needs and identifies the best channels to deliver know-how and facilitate knowledge transfer to various target audiences. SLICES Academy offers an ideal environment for novice researchers to explore the potential of the SLICES-RI. By taking courses at the academy, students broaden their knowledge and enhance their skills in utilizing SLICES-RI. The courses have two main objectives: teaching students how to utilize SLICES-RI and expanding their knowledge by allowing them to experiment with new environments that integrate different technologies and resources.

To this end, we have constructed a platform for online courses. The main service of the SLICES Academy is this platform, supported by Moodle software (https://moocs-academy.slices-ri.eu/). All partners of SLICES can access this platform and publish their online courses, which cover a range of topics including 5G and 6G technologies, AI/ML, IoT, SDN, Cloud/Edge computing, Hypercomputing, and more. Additionally, we offer a range of webinars and training events, specifically emphasizing SLICES-RI and its application. Many of these recordings have been generated through documenting our involvement at major events and conferences, as well as the tutorials we have conducted regarding SLICES. Moreover, SLICES Academy provides a direct link to the Networking Channel, which is a twice-a-month online activity to maintain and build a research and education community by organizing a series of lectures. Finally, we also provide a code repository for all software developments of SLICES. Figure 1 presents the homepage of SLICES Academy and Figure 2 presents the online coursing platform.

[1] Ioannidis JP. Why most published research findings are false. PLoS Med. 2005 Aug;2(8):e124.

[2] SLICES Academy website, https://www.slices-ri.eu/slices-academy/ [Last accessed 26 August 2024]

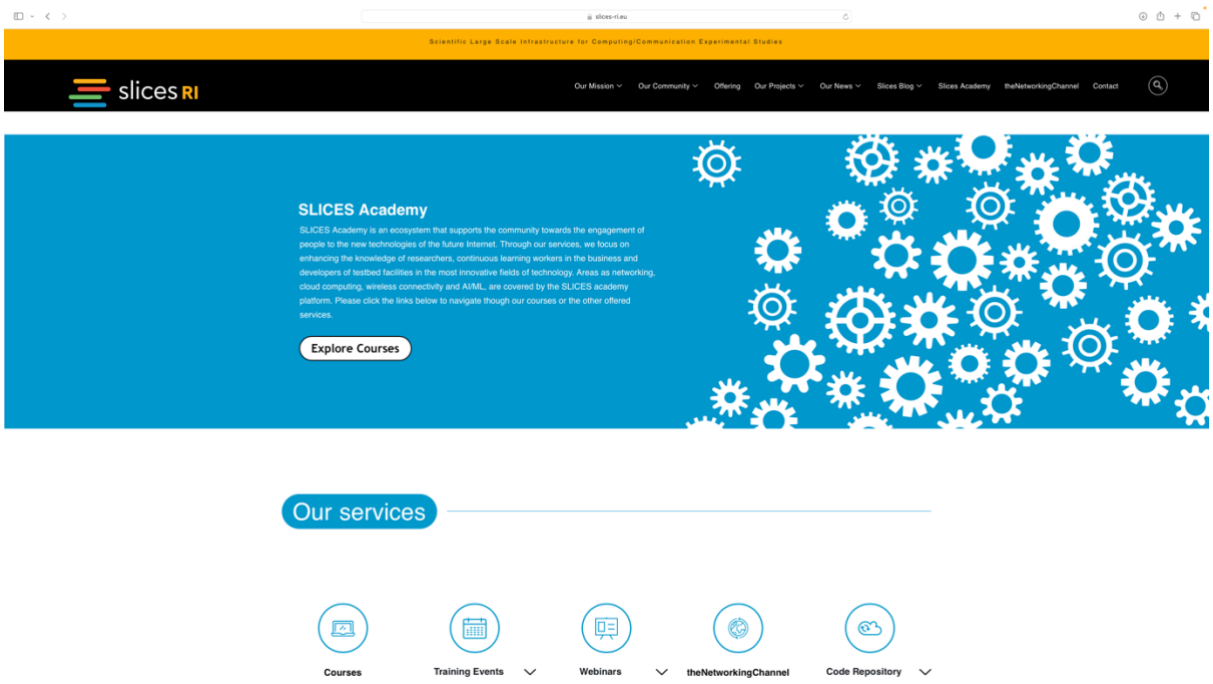


Figure 1. The SLICES Academy homepage

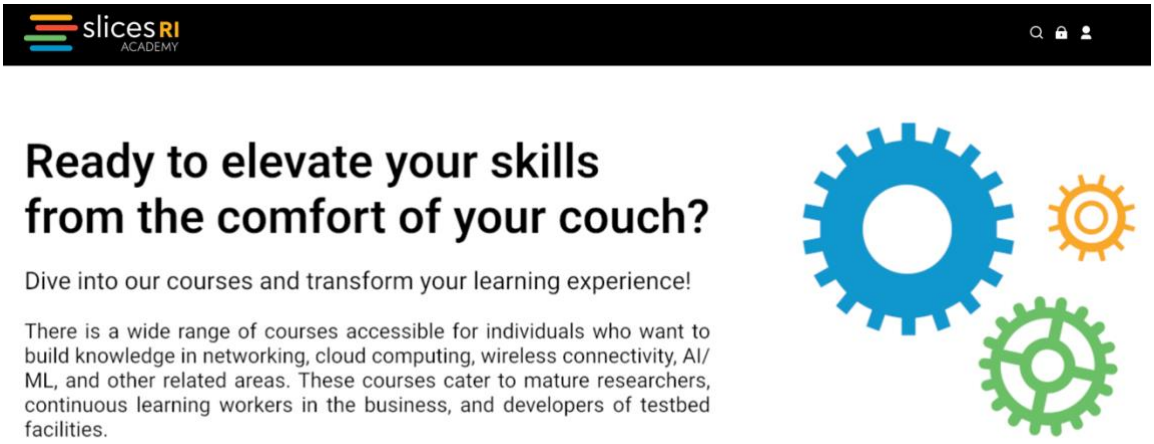


Figure 2. The homepage of the SLICES Academy platform for online coursing.

2.2. SLICES Academy Users

In SLICES Academy, we have defined three target groups of students and potential users of the SLICES-RI: the testbed developers, the experimental researchers and the industrial engineers. Potentially, in the future, these three target groups may be extended with the public authorities, but for now, we believe that these users can be treated as inX4dustrial engineers. As it is depicted in Figure 3, there is a choice in SLICES Academy platform for online coursing, where the students select one of the three roles below, to see a filtered set of the available courses for this role. The three roles are:

- The **testbed developers**, which are interested in deploying a testbed like the ones provided by SLICES. They are offered a range of courses that teach them how to reproduce one or more

of the SLICES testbeds in their own facilities. These courses also provide the methodology for extending the replicated testbeds to support a wider range of experimentation tools.

- The **experimental researchers**, which want to use a SLICES testbed for their research. They can enroll in various courses that instruct them on how to effectively utilize the SLICES testbeds for their experiments involving protocols, software tools, and hardware resources. These courses allow researchers to become acquainted with SLICES and its facilities, introducing them to the SLICES community.
- The **industrial engineers**, which want to be familiar with the SLICES supported technologies. They can choose from a range of courses that teach them how to efficiently use the SLICES testbeds to become familiar with new protocols, software tools, hardware resources, and research methodologies.

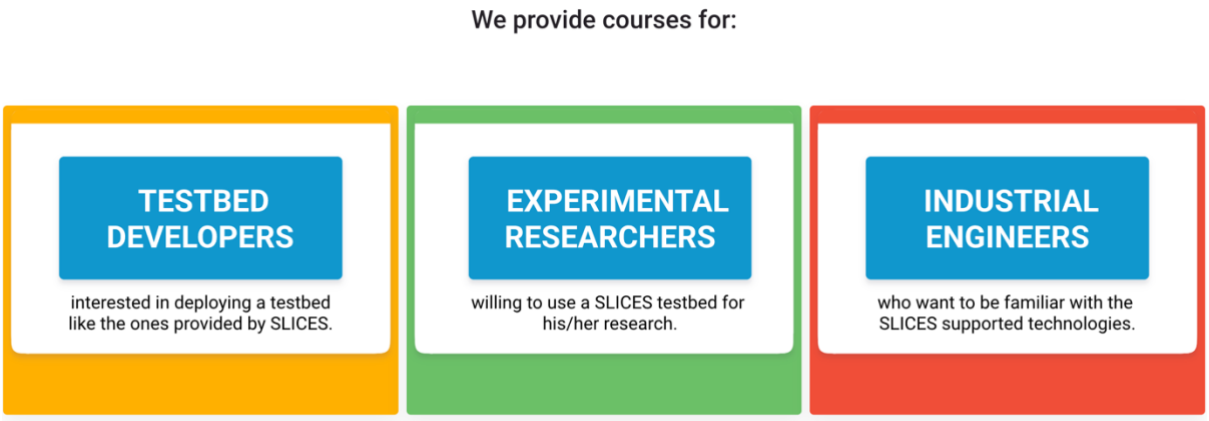


Figure 3. The three different SLICES Academy student roles.

At this point, we should mention that a course for a specific topic may be available through a different version for each role (which is preferable), or it may have the same version for more than one role. Moreover, as future plan, apart from the public authorities, we aim to support one more student role that is the academic professors who want to explore SLICES-RI in order to build new online courses in SLICES Academy.

2.3. SLICES Academy Course Categories

The SLICES Academy students, apart from declaring their role, they are also prompted to mention which areas of expertise they wish to expand or begin developing their knowledge in. More specifically, they are prompted to select one of the 5 following knowledge areas:

- **Fixed networking**, which includes optical networking, SDN/P4, TSN, Data-plane acceleration, Quantum networks, etc.
- **Edge/cloud**, which includes virtualization, containerization, DevOps, Orchestration, Cloud security, etc.
- **Wireless**, which includes OpenRAN, SDR, Fronthaul, near RT-RIC/xAPPs, NTN, B5G/6G RAN, cloud-native RAN/Core, wireless networking drivers, IoT, mmWave, Smart Antenna Tech, Positioning, URLLC, mobility, etc.
- **Computing**, which includes HPC, Quantum, GPU/FPGA, etc.
- **Data & AI/ML**, which includes Data analysis, Federated learning for networking, AI/ML for RIC, etc.

The following Figure 4 depicts these areas.

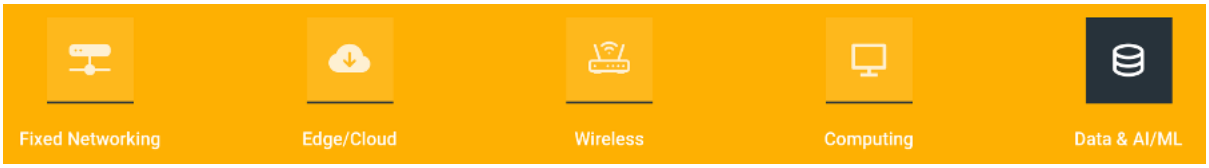


Figure 4. The research areas that students are prompted to select if they are interested in.

Then they are facilitated by the platform by having access to the available courses that correspond to their role and the selected knowledge area, as it is depicted in Figure 5, for an Experimental Researcher who is interested in Fixed Networking courses.

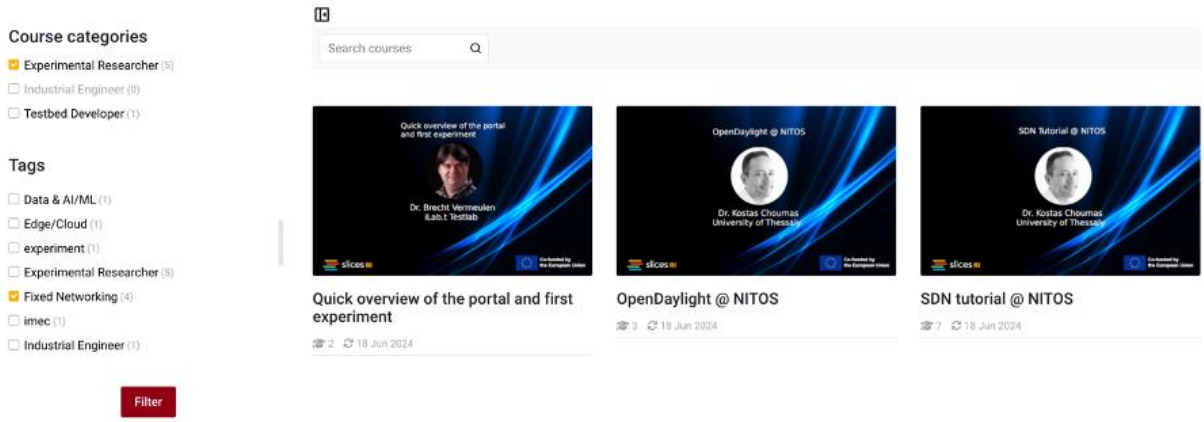


Figure 5. Typical presentation of the available courses for an Experimental Researcher who is interested in Fixed Networking.

The categorization of the available courses in these five research areas has been done after a series of internal workshops between the partners of SLICES, who aimed to explore the commonalities between the courses, to support the most interesting research topics and to align with the requirements of the external users of SLICES-RI. It is also worth to mention that a course may be assigned to more than one category, since for example the usage of AI/ML for RICs is correlated with both Wireless and Data & AI/ML topics.

Currently, the SLICES Academy platform provides a rich variety of courses, as illustrated in Figure 6. Our future steps include further expanding the variety of available courses and extending the list of offered research areas as needed. The technical implementation of the entire platform is modular and easily extensible, allowing for the flexible addition of categories whenever necessary.

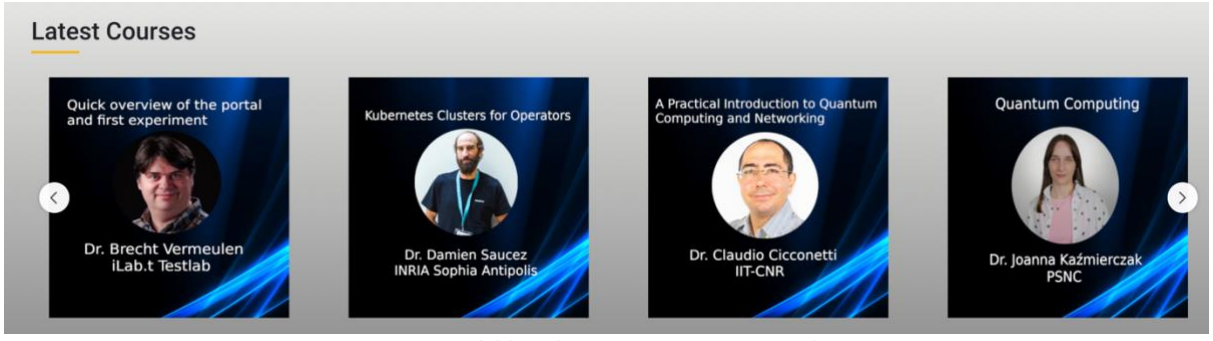


Figure 6. Available online courses in SLICES Academy.

2.4. SLICES Academy Course structure

After multiple discussions and workshops between the members of the SLICES consortium, we concluded that the best practice for building the courses of the SLICES Academy is to organize the content of each course into modules, which can be shared between courses. This approach is particularly effective for courses that have different versions of the same topic, where each version corresponds to a different student role. Although these courses are different versions, it is expected that there will be multiple common parts between them, making it helpful to organize these parts into sharable modules. Moreover, even for courses on different topics, there is often common information in their structure, which is more easily managed as a semi-independent sharable module. For example, the course for OpenRAN has 3 different versions for the three roles, as it is depicted in Figure 7.

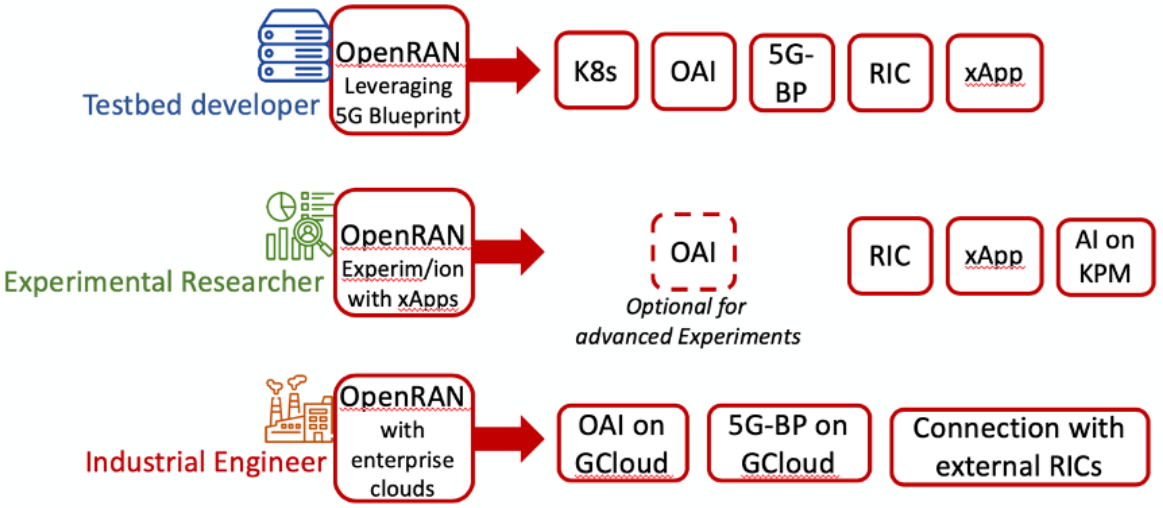


Figure 7. The three different versions of SLICES Academy course for OpenRAN.

As illustrated, the module organising the information about RIC is shared between the two versions for testbed developers and experimental researchers. There are also optional modules for students who want to deepen their knowledge on a topic, such as the module explaining OpenAirInterface (OAI) in the version of OpenRAN designed for experimental researchers.

3. New and adapted training material

The objective of this section is to describe the methodology and work done during the generation of training material, whether new or adapted from previous resources. During the first period of the project, reported in the first deliverable D4.1, we started by identifying the training needs for education and upskilling the future generation of scientists, engineers, and data professionals who will be implementing and using the SLICES research infrastructure.

At European level it is important to highlight the international context, where the European Commission adopted 2023 as the European Year of Skills[3] with the objective of boosting innovation,

[3] European Year of Skills 2023. https://year-of-skills.europa.eu/index_en [Last accessed 26 August 2024]

competitiveness, participation and talent providing a fresh impetus to lifelong learning, and empowering people and companies to contribute to the green and digital transitions. SLICES is contributing to this joint European effort of training and education in the scientific field of **Advanced Research and Experimentation on Digital Sciences** with the creation of the SLICES Academy, a lifelong framework for capacity building aimed at developing the skills of the future scientists and engineers who will build and use the SLICES research infrastructure

SLICES Academy was established within the framework of SLICES-SC with the vision of evolving into a flagship site for education on the skills demanded by the digital revolution of SLICES and promoted by ESFRI. ESFRI incentivizes and supports the role of RIs in **education, training and mobility of students, researchers, technicians and engineers**, as well as in **promoting science and scientific careers to young people** through stronger, structured collaboration between **RIs, Universities and Industry.**

During the process of defining and creating material for SLICES Academy, we are adopting the following methodology and principles:

- **Promotion of open access through** high-quality training events, courses, summer schools.
- **Identify the training gaps for the key relevant skills on the SLICES scientific domain** that cover technologies like: AI/ML for networking, deployment and orchestration of programmable networks, computing at the cloud/edge, 6G networks, quantum computing and communications.
- **Fostering the cooperation between Academia and Industry** for matching the full potential for the European workforce and the opportunities on the job market.
- **Attracting people from third countries with the skills needed by the EU**, including by strengthening learning opportunities and mobility and facilitating the recognition of qualifications.

Some examples of the initial contributions available as open access on the SLICES Academy portal are: TheNetworkingChannel, the SLICES Summer Schools, and SLICES Training Events and Courses. With this initial seed available in the portal, we recognize the need to work on the articulation of the new curricula aimed at enhancing researchers' competences and skills. There is a clear necessity for developing the new skills and competences that the SLICES scientific ecosystem will demand. With this objective in mind, the SLICES Academy serves not only as a simple repository of material, but also as an observatory for the continuous monitoring of the skills required for the deployment and use of the SLICES research infrastructure throughout its lifecycle.

This section includes and summarizes the live discussion within the SLICES consortium to define the current key skills needs with particular emphasis on the identifying the gaps to be filled with the new skills currently not present in our ecosystem. These gaps and the definition of new skills will serve as the foundation for creating the corresponding training and education materials within the SLICES Academy. The structure to articulate the discussion on the skills follows the classification of the technical fields as follow:

- Testbed and Tools for Experimentation: Blueprint framework, Reproducibility frameworks, national testbeds.
- Fixed Networking: Ethernet, SDN/P4 switching, TSN, Data-plane acceleration, Cloud-native Networking, Telco security, Quantum networks.
- Edge/Cloud: virtualization, containerization, devops, ci/cd, orchestration, far-edge resource orchestration, Cloud Security.
- Wireless Networking: OpenRAN, SDR, fronthaul, near RT-RIC/xAPPs, NTN, B5G/6G RAN, cloud-native RAN/Core, wireless networking drivers, IoT devices and energy-efficient

protocols, Applications and Services, Optical Wireless, mmWave/THz, Smart Antenna Tech, Positioning, URLLC, mobility, Wireless network security

- Compute: HPC, Quantum, Accelerators (GPU/FPGA), new programming languages.
- AI/ML: Data analysis, Federated learning for networking, AI/ML for RIC.

The following sections summarize some of the discussion and conclusions on skills and needs for training material on a subset of the previous technical dimensions.

3.1. Testbed and tools for experimentation

In the last couple of years, there has been enormous growth in the technology domain including wireless, IoT, Cloud/Edge, AI/ML, HPC etc. For instance, in the field of wireless technology, end users are witnessing 5G deployments in several countries alongside ongoing research and development activities focused on several key aspects of 5G technology. In parallel, research on 6G has been initiated by many projects, organizations, academia, and standardization forums, driven by the limitations of 5G technology. In this research path, state-of-the-art testbeds[4] are essential for providing advanced evaluations of scenarios with accurate results. State-of-the-art deployments of testbeds ensure that resources are commonly managed through unified access and unified tools, regardless of their location, while onboarding user experiments is an automated and harmonized process across different sites. These tools require a common resource description framework, a trusted architecture and a standardized control plane and API[5]. On top of that, tools that ensure the reproducibility of the experiments, as well as their replicability across different locations are mandatory. Such functionality, and skills to build such tools are of particular importance to SLICES as:

- SLICES develops, operates and integrates seemingly disaggregated experimental islands into a single, large-scale pan-European facility. Existing experimental islands need to be interconnected efficiently, with common APIs, and common tools to operate as a single facility.
- For the harmonization of the different tools across the distributed SLICES islands the concept of blueprints is being employed. Different blueprints, depending on the services and features that each testbed provides ensure the unification of APIs per each service provided through SLICES.
- Large scale experiments on facilities such as SLICES are a breakthrough towards the feasibility of the proposed solutions. Nevertheless, reproducibility of an experiment to other sites and from different groups ensure that the solution can achieve a higher technology readiness level and can be exploited for further innovations in the field. SLICES is organizing a framework for reproducibility of experiments, allowing automatic archiving and analytics of data collected from the experimental instances, ready to be fed into different platforms for further analysis/development.

Reproducibility: The SLICES/pos framework[6] describes an operational framework to manage research infrastructures and perform scientific experiments according to a well-defined experiment workflow.

[4] Serge Fdida, et al. "SLICES, a scientific instrument for the networking community." *Computer Communications* 193 (2022): 189-203.

[5] M. Polese, et al. "Understanding O-RAN: Architecture, Interfaces, Algorithms, Security, and Research Challenges," in *IEEE Communications Surveys & Tutorials*, vol. 25, no. 2, pp. 1376-1411, Secondquarter 2023, doi: 10.1109/COMST.2023.3239220.

[6] Sebastian Gallenmüller, Dominik Scholz, Henning Stubbe, Georg Carle, "The pos Framework: A Methodology and Toolchain for Reproducible Network Experiments," in The 17th International Conference on emerging Networking EXperiments and Technologies (CoNEXT '21), Munich, Germany (Virtual Event), Dec. 2021.

The workflow relies on a fully automated experiment execution and ensures that testbed resources are reset to a well-defined state after every experiment. These properties ensure that experiments can be executed in a repeatable manner. Experimenters are not required spend additional effort on making their experiments repeatable, adhering to the templates provided by the SLICES/pos controller ensures the reproducibility of their experiments—a property that we call *reproducibility by design*.

Portable Experiments: Another property of the pos experiment workflow is its portability. This leads to experiments that can be executed on other testbeds. A study[7] showed that the SLICES/pos controller can be adapted to run on different testbeds (a native pos testbed, and US-based testbeds CloudLab & Chameleon). The same experiment scripts could be executed on all investigated testbeds, minimizing the effort for experiments. Testbed-specific extensions were implemented in the SLICES/pos controller software used to execute the experiments.

In this context, the following inputs are considered for the training sessions within SLICES Academy:

- Methodology for the creation of repeatable & reproducible experiments.
- Creation of (blueprint-based) experiments using the SLICES/pos experiment workflow.
- Post-5G Blueprint deployment as a first step.
- Multi-cluster management through centralized Rancher instances with the post-5G blueprint.

3.2. Fixed networking

Ethernet was initially created as a network technology for local area computer networks (LANs). Its key property's reliability, simplicity, high performance, and low price ensured its success in that area over competing technologies such as Token Ring. The success of Ethernet did not stop there, over time Ethernet was used in other areas such as industrial networks, data centers or wide area networks (WANs).

Time-Sensitive Networking (TSN): The label Time-Sensitive Networking sums up a set of additions to the Ethernet standard introducing features that were not initially present in Ethernet, such as methods to precisely schedule messages and shape network traffic, or to increase the reliability of networks by introducing path reservation schemes and (de-)duplication of messages. These technologies are relevant for networks in industrial or medical settings that require highly reliable traffic with real-time guarantees. To effectively use TSN, experimenters need access to dedicated TSN hardware and software stacks. Testbeds can help provide these resources and fostering research in the domain of real-time networks.

Sofre-Defined Networks (SDN) are a technology that brings programmability to the network. The latest incarnation of SDN technologies uses domain specific programming languages, such as P4.[8], tailored to specific needs of network protocol development. These languages should be versatile and be used on different target architectures such as off-the-shelf hardware, programmable network interface cards (SmartNICs, also called IPUs or DPUs), FPGA-based network cards or dedicated application specific integrated circuits (ASICs) that can execute such programs natively. The SLICES 5G blueprint can utilize P4-based switches to offload specific tasks to the network equipment which helps improve the performance of networks.

[7] Henning Stubbe, Sebastian Gallenmüller, Georg Carle, "The pos Experiment Controller: Reproducible & Portable Network Experiments," in 2024 19th Wireless On-Demand Network Systems and Services Conference (WONS), 2024, pp. 1–8.

[8] Bosshart, Pat, et al. "P4: Programming protocol-independent packet processors." ACM SIGCOMM Computer Communication Review 44.3 (2014): 87-95.

High-Performance Packet Processing Software: One of the most widely used API for networks are the BSD sockets that date back to 1980s. Modern operating systems still offer this API offering a stable and well-known network API for applications. However, bandwidths have significantly increased since their inception from 10 Mbit/s to up to 400 Gbit/s for a single network port. To fully utilize the increased bandwidth including modern hardware features such as multi-core CPUs or multi-queue network cards specialized frameworks were created. One of these frameworks is DPDK, which offers approximatively 10-fold performance compared to traditional network APIs[9]. Therefore, frameworks like DPDK create the foundation for modern network applications that need to keep up with the bandwidths offered by the hardware.

3.3. Wireless Networking

5G RAN has evolved from 4G with significant improvements in capabilities and functionalities. With the usage of a wider range of carrier frequencies that includes part of millimeter Wave (mmWave) frequency spectrum, and flexible frame structure with variable number of symbols per subframe, 5G NR can utilize up to 400MHz of bandwidth per carrier. Several platforms exist that implement the 5G stack fully in software. By making use of Software Defined Radios (SDR), such platforms 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 OpenAirInterface 5G platform (OAI), and 2) the srsRAN platform. 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[10]) along with Virtualized RAN architecture. 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. Building on top of the different disaggregation options, and especially delving into the CP/UP separation (CUPS), Open RAN (O-RAN) architecture defines open and standardized interfaces among the different elements of the disaggregated RAN. Using such standardized interfaces, interoperability of functions between different vendors is enabled, while programmability of the RAN through dedicated interfaces is enabled[11]. 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).

Such skills are of particular importance to SLICES as:

- SLICES-RI is at the forefront of research on wireless networks, with testbeds integrating the latest trends and programmable APIs in wireless networking. Several SLICES sites operate real-world 5G networks, and experimental prototypes for beyond 5G and 6G networking.

[9] Sebastian Gallenmüller, Paul Emmerich, Florian Wohlfart, Daniel Raumer, Georg Carle, “Comparison of Frameworks for High-Performance Packet IO,” in ACM/IEEE Symposium on Architectures for Networking and Communications Systems (ANCS 2015), Oakland, CA, USA, May 2015.

[10] L. M. P. Larsen, et al. "A Survey of the Functional Splits Proposed for 5G Mobile Crosshaul Networks," in IEEE Communications Surveys & Tutorials, vol. 21, no. 1, pp. 146-172, Firstquarter 2019, doi: 10.1109/COMST.2018.2868805

[11] A. Garcia-Saavedra and X. Costa-Pérez, "O-RAN: Disrupting the Virtualized RAN Ecosystem," in *IEEE Communications Standards Magazine*, vol. 5, no. 4, pp. 96-103, December 2021, doi: 10.1109/MCOMSTD.101.2000014.

- SLICES-RI relies on Open-Source platforms for its operation. Through such platforms, further innovation is empowered, allowing new solutions and protocols to emerge, tested under the closest settings possible to real-world operation.
- SLICES-RI is providing the respective interfaces for new solutions to integrate with the platform, by integrating O-RAN on the telecommunication stack. Users can plug-in their solution as an xApp to already instantiated base stations, and further develop their idea/algorithm.

In this context, the following inputs are considered for the training sessions within SLICES Academy:

- SLICES helps to bring state-of-the-art technologies into the hand of researchers (e.g., powerful Ethernet & P4-programmable hardware).
- Networked applications such as the 5G blueprint demonstrate the setup and usage of these technologies reducing the effort for researchers and allowing them to focus on their actual research interests.

3.4. Examples of development of new training material within SLICES Academy

One of the primary goals of SLICES-SC is to develop new and updated training materials that will be made available to the SLICES research community in order to familiarize them with the corresponding facilities. This material is specifically designed for the SLICES community, as it refers to the testbed facilities and technologies provided by SLICES, with regards to the unique roles of each user. For instance, a testbed developer user acquires a comprehensive understanding of the SLICES testbeds and their tools, whereas an experimental researcher concentrates on the technologies that are available and how to conduct experiments with them. There is also one more target group of users, the industrial engineers, who focus on using commercial tools and need this training material to exercise themselves in SLICES platform before applying these tools to their industrial facilities.

The result of the aforementioned efforts is the SLICES Academy, which is a web platform based on the Moodle software. The offered training material is categorized into numerous courses in the framework of SLICES Academy, while each course may refer to various technologies and one of the three user roles. Except from the courses, the SLICES Academy offers a great variety of training events and webinars. In the following list, we present an indicative list of the courses that are currently available in the SLICES Academy.

Experimentation Platform - 5G Test Network, offered by Olli Liinamaa from University of Oulu

Figure 8. Experimentation Platform – 5G Test Network

In this edition of 6G Talks Olli Liinamaa explains what 5G Test Network all is about. Discover the significance of 5G Test Network in the realm of 6G technology and its pivotal role in vertical experiments. Dive deep into the innovative approaches and breakthroughs that are shaping the future of wireless communication.

Quantum Computing, offered by Joanna Kaźmierczak from PSNC

Figure 9. Quantum Computing

Quantum computing focuses on creating and operating quantum computers to solve complex problems more efficiently than classical computers. Quantum communications involve transmitting quantum states over distances, leading to advancements in quantum networking, which aims to establish programming interfaces and protocols for quantum infrastructures. This tutorial aims to raise awareness in the research community about quantum computing and networking by introducing the latest technologies, providing hands-on examples, and outlining promising research challenges.

SLICES Blueprint, offered by Damien Saucez from Inria

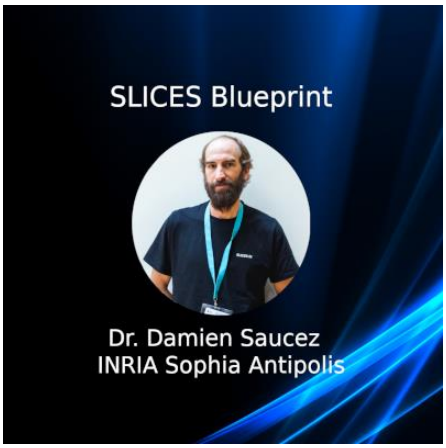


Figure 10. SLICES Blueprint

SLICES-RI is defined as a scientific instrument to support the discovery process related to the future, emerging digital infrastructures. It is a joint investment between the EU and the member states, on the ESFRI roadmap since 2021. SLICES avoids fragmentation and achieves critical mass by bringing together research communities related to networking protocols, radio technologies, data collection, parallel and distributed computing and in particular cloud and edge-based computing architectures and services. The SLICES blueprint is aimed at sharing the same vision and solutions among the

partners as well as proposing a plan for the design and deployment of SLICES-RI. In this blueprint we propose to define the infrastructure baseline augmented with a reference implementation, which aims at keeping a focus on the goals of the project yet identifying technological challenges and breakthrough at the early stage of the process. The blueprint shall be deployed by the SLICES-RI partners and will provide the baseline service that will be exposed to the experimenters when SLICES will move into the operation phase (continuous integration and deployment strategy that will start mid 2024). This blueprint is meant to continuously evolve in order to onboard lessons learned and recommendations from the community, both academia and industry.

Data Analytics for Networks, offered by Andrea Passarella from IIT-CNR

Figure 11. Data Analytics for Networks

The course starts with general modules introducing the basic machine learning tools relevant for the techniques covered in the rest of the modules. It covers specifically clustering, classification, training and overfitting, linear regression, fitting. Then, it provides a drill-down on data analytics techniques to model and understand the macroscopic properties of large-scale networks, providing thus a “data analytics toolbox”. Specifically, it first defines the graph abstraction. Then it provides the tools for degree analysis and its interpretation. It then deals with clustering analysis and path length distributions. It covers assortative and centrality measures. Finally, it covers community detection tools. In the last part of the course, the use of the toolbox is exemplified in detail in the case of the analysis of robustness of networks to attacks. Specifically, this module deals with the definition of different types of attacks, the metrics to assess their efficacy, and techniques to improve the structural strength of the networks.

Machine Learning in 6G Wireless Communication Networks, offered by Samad Ali from Uni. of Oulu

Figure 12. Machine Learning in 6G Wireless Communication Networks

This 6G Research Visions Webinar Series took place on Wednesday 14th October 2020, highlighting the key results of the expert group that prepared the White Paper on Machine Learning in 6G Wireless Communication Networks. In this white paper, the group provided an overview of the role of machine learning in 6G, applications of machine learning in physical layer, MAC layer, and application layer, and implementation and standardization aspects. Talks by Expert Group representatives: Prof. Walid Saad, Virginia Tech, Prof. Nandana Rajatheva, University of Oulu and Daniel Steinbach, InterDigital. The webinar was moderated by Dr. Samad Ali from University of Oulu who led the Expert Group.

Introduction to Federated Learning, offered by Lorenzo Valerio from IIT-CNR

Figure 13. Introduction to Federated Learning

The explosion of the number of IoT and Edge devices is boosting the generation of massive amounts of data at the Edge of the Internet. In parallel, the knowledge extraction process from these data for training AI models is facing a paradigm shift, from centralized solutions run in remote Cloud facilities to more decentralized and lightweight ones executed at the Edge of the Internet. Performing collaborative training in an Edge environment poses several challenges, all connected to the extreme heterogeneity of the context, i.e., data patterns might be represented unevenly across devices, devices have limited resources that might prevent or limit their contribution to the process, the locality experienced by each device in training the local AI model might affect the overall process. Federated Learning is a decentralized training framework that implements a Cloud-to-Edge paradigm shift for decentralized collaborative training, addressing the abovementioned challenges. The course

will introduce the Federated Learning framework, exploring the most recent advancements proposed to address some of the challenges connected to the constraints posed by the Edge environment.

A Practical Introduction to Quantum Computing and Networking, offered by Claudio Cicconetti from IIT-CNR

Figure 14. A Practical Introduction to Quantum Computing and Networking

Quantum computing addresses the construction and operation of quantum computers to solve more efficiently instances of specific problems that are difficult to tackle with classical computers. Quantum communications cover the transmission of quantum states across distances. Recent advances in this context have led to the novel research area of quantum networking, which covers the programming interfaces and protocols for the practical operation of quantum communication and computing infrastructures. The tutorial has the objective of raising awareness in the research community about quantum computing and networking by introducing the latest technologies developed in each, providing hands-on examples of how to use them for simple use cases, and finally sketching the more promising open research challenges.

SLICES Data Management Infrastructure for Reproducible Experimental Research, offered by Yuri Demchenko from University of Amsterdam

Figure 15. SLICES Data Management Infrastructure for Reproducible Experimental Research

This tutorial provides a practical introduction to important aspects of data management to ensure experimental research reproducibility. The tutorial information about ongoing research efforts in the SLICES project related to the design of the Data Management Infrastructure (DMI) to support

experimental research on digital technologies. The tutorial introduces the research lifecycle and related data management aspects. Experimental research reproducibility requires the documentation of all data from all components involved in the experiment setup and execution including the whole continuum of access network, IoT, edge, cloud, and data processing workflow. The tutorial discusses the practical aspects of data management and explains the requirements for DMI to enable research reproducibility of complex and large-scale experimentation. The tutorial describes what data can be collected and processed in SLICES and explains approaches and solutions used for experimental research reproducibility, primarily based on the plain orchestration service and supported by metadata collection tools. The proposed multi-layer DMI includes: data (storage) access, data processing, data ingest, experiment management, and virtual research environment. The tutorial also provides recommendations for the selection of existing standards and tools for data and metadata management, in particular those developed by EOSC and supported by the RDA community to ensure wide compatibility and integration.

Target audience: Researchers dealing with experimental studies and planning to address data management issues to ensure proper experimental data collection, processing and storing for research reproducibility.

Open Science and Research Data Management: Core principles and best practices for effective data management, offered by Yuri Demchenko from University of Amsterdam

Figure 16. Open Science and Research Data Management: Core principles and best practices for effective data management

This tutorial provides information about general principles of Open Science, Open Access and Open Data initiatives. The tutorial will refer to different related initiatives in Europe and worldwide. The details on the widely accepted in the research community FAIR data principles will be provided with a discussion of the technical details. The tutorial will explain metadata properties and their role in adopting FAIR data principles for research data sharing. Popular open data publishing services will be referred Tutorial will discuss the best practices in organisation/project research data management and provide recommendations on managing personal data collections. The tutorial will discuss the structure, main elements and an example of the Data Management Plan that is required by majority of funding bodies in Europe. The tutorial intends to facilitate researchers in introducing best practices in consistent research data management and implementing FAIR data principles in their practice.
Target audience: Researchers and practitioners dealing with collecting, processing and storing research data, data stewards, data analytics teams.

Experiment Reproducibility, offered by Sebastian Gallenmüller from TUM.

Figure 17. Experiment Reproducibility

The course briefly introduces the definition of reproducibility and the significant challenges of reproducible research. To solve these challenges, we present a framework that integrates a testbed orchestrator to manage testbed resources and an experiment controller to manage the execution of the experiments. The experiments follow a well-defined experiment workflow. If researchers adhere to the template of this workflow, the framework ensures the reproducibility of the created experiments. This framework is called the plain orchestrating service (pos). The pos framework will be an integral part of the future SLICES research infrastructure to allow the creation of reproducible experiments at the start of the operational phase.

Quick overview of the portal and first experiment, offered by Brecht Vermeulen from IMEC

Figure 18. Quick overview of the portal and first experiment

This quick overview shows hands-on how an experimenter can create an account and use the SLICES SC research infrastructure. With this account, all SLICES-SC research infrastructure can be accessed in an easy way. We also point the experimenters to the documentation website and how they can ask for support.

Target audience: all researchers and students wanting to use the SLICES-SC research infrastructure.

Running OpenWiFi on the w-iLab.t testbed, offered by Brecht Vermeulen from IMEC

Figure 19. Running OpenWiFi on the w-iLab.t testbed

This tutorial explains how to use software defined radios (SDR) on the w-iLab.t testbed of the Slices-SC research infrastructure. These radios are fully programmable and make it possible to implement new protocols/functionality/… on real hardware for experimentation. Specifically in this tutorial we show how a full WiFi stack can be run on the SDRs of the w-iLab.t testbed. This opens possibilities for deep experimenting with WiFi or researching on new features.

Target audience: experimenters who want to use wireless technologies/software defined radios on SLICES-SC.

Distributed post-5G Network Architecture: hands-on within the EU SLICES-RI Research Infrastructure, offered by Damien Saucez from INRIA

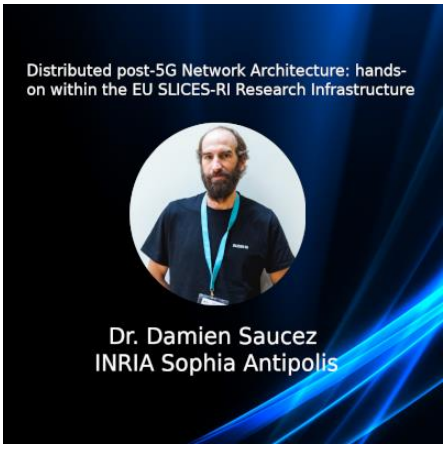


Figure 20. Distributed post-5G Network Architecture

5G has introduced the concept of modularization in its design. With this ubiquitous modular architecture, 5G allows telco and IT worlds to meet and thus outstanding innovations follow with the so-called post-5G propositions. Despite that, deploying a full-fledged 5G remains a matter of specialists who must choose the right combination of software, hardware, and locations of the infrastructure. The objective of the SLICES blueprint is to provide the community with a set of replicable software and hardware of 5G architectures. In fact, the blueprint is designed in a modular way such that one can either deploy it fully or only partially. For example, people only interested in 5G can only deploy the core and use a simulated RAN, while people interested only in the RAN can just deploy a RAN, assuming they have access to a core (e.g., via the SLICES central node or another

partner). Advanced users may even deploy a core and connect it with multiple RANs. In this hands-on, we consider the case with a similar radio network as presented below where the 5G core and RAN are deployed in separate clusters that are remotely connected with VPN.

SDN tutorial @ NITOS, offered by Kostas Choumas from University of Thessaly

Figure 21. SDN Tutorial

This course employs the NITOS testbed for teaching SDN and for providing a deeper comprehension of network protocols using SDN. Topics covered: 1) How to access NITOS for the objectives of this course. 2) How to use Mininet in NITOS for deploying virtual SDN networks. 3) How to use Ryu for controlling SDN networks. 4) What is OpenFlow, the most popular SDN enabler. 5) An exercise at the end, using Ryu and OpenFlow.

Kubernetes clusters for Operators, offered by Damien Saucez from INRIA

Figure 22. Kubernetes clusters for Operators

Modern telecom networks are composed of dozens of functions distributed geographically. When 3GPP introduced 5G, it also introduced the notion of functional separation with standardized interfaces. This means that now it is potentially possible to have distinct implementations for each single function of the network (as opposed to monolithic implementations used up to 4G). Each function can be seen as an independent module that interacts with the others. To manage such distributed system, the common solutions is to containerize all functions and to deploy them in kubernetes clusters. Kubernetes is well known for data centers but when it comes to telecom

networks, some specific needs are required. In this course, we define the specific needs for telecom-oriented kubernetes clusters and show how to deploy them.

OpenDaylight tutorial @ NITOS, offered by Kostas Choumas from University of Thessaly

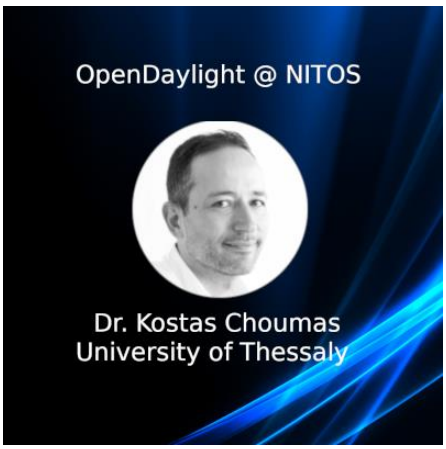


Figure 23. OpenDaylight tutorial @ NITOS

This course employs the NITOS testbed for providing a deeper comprehension of OpenDaylight. If you are not familiar with SDN and OpenFlow, you should first complete the course SDN Tutorial @ NITOS. Topics covered: 1) How to access NITOS for the objectives of this course. 2) How to use Mininet in NITOS for deploying virtual SDN networks. 3) How to use OpenDaylight for controlling SDN networks.

4. Report on explicit training activities carried out during SLICES-SC

SLICES-SC provides training opportunities and plays an important role in the education and upskilling of new generations of scientists, engineers and professionals. It is considered that human resources are a critical component of SLICES-RI. Training is essential to ensuring that best practices are shared across SLICES user communities. SLICES utilizes different training modules.

Different activities have undertaken during SLICES, such as the organisation of the SLICES Summer Schools, the organisation of theNetworkingChannel, the organisation of different workshops and events, the national Roadshow events.

Details on the events are given in Deliverable D6.4, however below we are listed the main training events:

4.1. SLICES Summer School: A series of three summer schools organised

July 19th – 21st, 2022: Open-RAN/Core/Edge Solutions for Cloud-Native Telco Experimental Platforms

This three-day school took a deep-dive into some of the available open-software and hardware solutions for building experimental telco networks that can be used by researchers to develop innovations leading to 6G network architectures in initiatives such as SLICES-RI, PAWR, Fabric and Horizon Europe SNS JU. A key objective of the school was to highlight cloud-native tools leading to fully converged cloud and telecommunication infrastructures. The Summer School covered initiatives including O-RAN, ONF Aether/SD-Fabric/SD-RAN, OpenAirInterface RAN and Core, Mosaic5G, Magma

and related cloud-native frameworks based on Kubernetes. In addition, for newcomers to the 3GPP ecosystem, it was provided a crash course on 3GPP networks and protocols.

Details can be found at: https://www.slices-ri.eu/events/slices-sc-summer-school

June 13th – 15th, 2023: Efficient wireless communication and computing experimental research in 6G-era

The three-day SLICES Summer School in Oulu, Finland introduced and familiarized its participants with the pan-European Scientific Large-Scale Infrastructure for Computing/Communication Experimental Studies Research Infrastructure (SLICES-RI), the unique experimental research capabilities it offers and foster the skills and knowledge for conducting experiment-based research. Aside from getting an overview of the various communication and computing SLICES-RI, the students got a unique opportunity to experiment with some of these infrastructures remotely from their own laptops. The participants got information about the best practices of experiment planning and data handling, and the novel, groundbreaking concepts paving the way beyond 5G towards the 6G communication and computing ecosystem. A key objective of the school was to introduce audience to the SLICES-RI and all possibilities it offers to the research community and third parties. Architectures and concepts have been shown to be used by researchers to develop new business concepts and innovations for beyond 5G and 6G networks, technologies, and solutions. The data management and GDPR compliancy of the research together with novel business concepts and ecosystems were in the focus of the school as well. Lecturers are from key players in the experimental wireless research community: University of Oulu, Sorbonne Université, University of Thessaly, UGENT, IMDEA and INRIA to name some of them.

Details can be found at: https://www.slices-ri.eu/events/slices-sc-2nd-summer-school/

July 7th – 13th, 2024 - Open and programmable 6G networks in the cloud/edge continuum: research challenges and experimentation tools in SLICES Research Infrastructures

The purpose of this Summer School was twofold. The first objective was to provide students with an up-to-date overview of the enabling technologies and fundamental research challenges of upcoming 6G systems and networks also considering the increasing synergies with the cloud-to-edge continuum. Tutorials presented the main technologies and tools for network and distributed systems programming, orchestration and virtualization. Lectures and keynotes focused on the theoretical and practical aspects of network sensing, distributed intelligence at the edge, the intersection between AI and networking, and the design of disaggregated programmable networks, providing a spotlight on key emerging research topics in the overall framework of 6G networks. The second objective was to introduce the students to the tools and methodologies offered by SLICES-RI, the only ESFRI research infrastructure for computer and networking research, for conducting experiment-based research in such cutting-edge research areas. The school provided dedicated hands-on training and sessions to permit the students to gain concrete experience through practical projects with SLICES tools. The keynote speeches were delivered by Larry Peterson from Princeton University, USA, titled: “Democratizing 5G: Open Source and More”, and by Abhimanyu Gosain from Northeastern University, USA, titled: “6G Standards development roadmap”. The tutorials delivered by Roberto Bruschi from University of Genoa/CNIT, Italy, titled “Fundamentals of virtualization technologies: and by Paolo Bellavista & Armir Bujari from University of Bologna, Italy, titled: “Fundamentals of orchestration for the cloud continuum”.

Details can be found at: https://netprog24.liparischool.it

SLICES will continue the organisation of the Summer Schools within the SLICES-PP project.

4.2. The NetworkingChannel

SLICES community building and awareness will also be expanded through the uptake of the support of the operation of theNetworkingChannel (https://networkingchannel.eu). The NetworkingChannel began during the COVID pandemic, when traditional forms of community gatherings were not possible, as a twice-a-month informal online activity "to maintain and build our networking research and education community." The NetworkingChannel is a series of events – organized as an online 'channel' – with events on topics of interest to the networking community, ranging from research to descriptions/discussions of commercial networked systems, to global societal considerations, to education and careers in networking. Lessons learnt from its four years of operation, shows that TheNetworkingChannel is working as a fantastic venue for the collaboration between EU and USA. In the last years, characterized by the explosion of virtual events, TheNetworkingChannel has succeed on attracting the networking community thanks to its top-quality talks and speakers. The top watched event has exceeded 2,500 post-event views on the YouTube channel. TheNetworkingChannel continues its operation with new events the SLICES umbrella together with the NSF PAWR Office, and in cooperation with ACMSigcomm, facilitating the community building, sustaining the international community that counts more than 6000 people and disseminating SLICES' results.

TheNetworkingChannel is organized as a regular event, taking place ***every other Wednesday, at 8am PST (11am EST, 5pm CET, 1am JST)***, where a diversity of events is organized for the community, live and pre-recorded. Topics are broad and open ranging from research to experimentation and education. The channel consists of webinars, panels, tutorials, virtual site visits, keynotes, and any other innovative forms of community interaction.

4.3. The SLICES events

The following events organised or presentations made by SLICES-SC for the awareness and the training of the community. Details of the events can be found in D6.3.

Event #1	
Title	SLICES 5GTONIC Node meeting with Industry and Government
Date / Location	March 16, 2022 / IMDEA Networks, Leganés, Madrid
Event #2	
Title	The 3rd KuVS Fachgespraech Network Softwarization
Date / Location	April 7/8, 2022 / online
Event #3	
Title	EuCNC & 6G workshop: Empowering Transatlantic Platforms for 5G Advanced and 6G Networks.
Date / Location	June 7, 2022 / Grenoble
Event # 4	
Title	EuCNC & 6G Summit, Exhibition via virtual platform
Date / Location	June 8 -11.6.2021 / Online, Porto Portugal
Event #5	
Title	IFIP Networking Conference 2022 workshop
Date / Location	June 13, 2022 / Catania, Italy
Event #6	
Title	SLICES France Roadshow event
Date / Location	June 28, 2022 / Paris (INRIA premises)
Event #7	
Title	3 Sessions in IoT Week 2022

Date / Location	Jun 23, 2022 / Dublin
Event # 8	
Event Name	IEEE International Symposium on Personal, Indoor and Mobile Radio Communications (PIMRC 2022)
Date / Location	12 – 15/9/2022, online
Event # 9	
Event Name	International conference on research infrastructures (ICRI 2022)
Date / Location	19 – 21 /10/2022, Brno, Czech Republic
Event # 10	
Event Name	Beyond 5G International Conference 2022
Date / Location	24 – 25/10/2022 - Tokyo, Japan
Event # 11	
Event Name	Future Internet: Lessons learned and way forward
Date / Location	27 – 28/10/2022 - Nice, France
Event # 12	
Title	GLOBECOM - IPA 16: FUTURE G RESEARCH PLATFORMS
Date / Location	5/12/2022 / Rio de Janeiro, Brazil
Event # 13	
Event Name	Seminar at RNP (the Brazilian National Education and Research Network)
Date / Location	6/12/2022 - Rio de Janeiro, Brazil
Event # 14	
Event Name	NetworldEurope General Assembly
Date / location	13/10/2022 – online
Event # 15	
Event Name	WONS'2023
Date / Location	31/1–1/2/2023 - Madonna di Campiglio, Italy
Event # 16	
Title	15th International Conference on COMmunication Systems & NETworkS / Comsnets TASIR workshop: Testbeds for Advanced Systems Implementation and Research
Date	8/1/2023 / Hybrid
Event # 17	
Event Name	26th Conference on Innovation in Clouds, Internet and Networks (ICIN'23)
Date / Location	8/3/2023, Paris
Event # 18	
Event Name	8th International Conference on Internet of Things, Big Data and Security (IoTBDS 2023)
Date / Location	21 – 23/4/2023 - Prague, Czech Republic, hybrid
Event # 19	
Title	Midscale Experimental Research Infrastructure Forum (MERIF) 2023
Date / Location	22-24/5/2023 - Boston, US
Event # 20	
Title	EuCNC & 6G Summit - Workshop 9: Empowering Transatlantic Platforms for 5G Advanced and 6G Network
Date / Location	6-9/6/2023 - Gothenburg
Event # 21	
Event Name	IEEE International Conference on High Performance Switching and Routing
Date / Location	5 – 7/6/2023 - Albuquerque, NM, USA
Event # 22	

Event Name	PSNC Days 2023 (International conference on projects, activities and initiatives of the Poznan Supercomputing and Networking Center with scientific, social and business partners)
Date / Location	14/9/2023, Poznan
Event # 23	
Title	SLICES Blueprint Workshop
Date / Location	18 – 19/9/2023 - Paris, France
Event # 24	
Title	Official presentation of the national Spanish SLICES node
Date / Location	3/10/2023 - Madrid, Spain
Event # 25	
Title	The 17th ACM Workshop on Wireless Network Testbeds, Experimental evaluation & Characterization (WiNTECH '23)
Date / Location	6/10/2023 - Madrid, Spain
Event # 26	
Event Name	Hyperconnectivity for European HPC Supercomputers – Feedback from HPC users and providers
Date / Location	22/11/2023 – Online
Event # 27	
Event Name	Academic Salon on High-Performance and Low Latency Networks and Systems
Date / Location	30/11 – 1/12/2023 - Munich, Germany
Event # 28	
Event Name	Workshop 5G/6G Inria
Date / Location	4 – 5/12/2023 - Lyon, France
Event # 29	
Title	2023 IEEE GLOBECOM Workshop - WS20-1: FUTUREG EXPERIMENTAL TEST PLATFORMS FOR ADVANCED SYSTEMS IMPLEMENTATION AND RESEARCH
Date / Location	4-8/12/2023 - Kuala Lumpur, Malaysia
Event # 30	
Event Name	AINTEC 2023 (18th Asian Internet Engineering Conference)
Date / Location	13/12/2023 - Hanoi, Vietnam
Event # 31	
Event Name	Wireless On-demand Network systems and Services Conference (WONS 2024)
Date / Location	29 – 31/1/2024 - Chamonix, France
Event # 32	
Title	Plenary meeting of SLICES-FR
Date / Location	7 – 8/2/2024 - Lille, France
Event # 33	
Title	ETSI OSM training SLICES
Date / Location	13-14/02/2024 - Leganés, Madrid, Spain
Event # 34	
Event Name	The annual scientific week common to the Electronics and Future Networks Priority Research Program and Equipment (PEPR)
Date / Location	18 – 22/3/2024 - Grenoble, France
Event # 35	
Event Name	6G Symposium
Date / Location	9 – 11/4/2024 - Levi, Finland

Event # 36	
Event Name	27th IEEE ISORC 2024: International Symposium on Object / Component / Service-Oriented Real-Time Distributed Computing
Date / Location	22 – 25/5/2024 - Carthage, Tunisia

Event # 37	
Event Name	INFOCOM 2024
Date / Location	22/5/2024 - Vancouver, Canada

Event # 38	
Title	EuCNC + 6G Summit
Date / location	3/6/2024 - Antwerp, Belgium

Event # 39	
Title	Thought experiments, data and reproducibility for networking and Future G research: SLICES Workshop 2024
Date / Location	3/6/2024 - Thessaloniki, Greece

Event # 40	
Event Name	Privacy Symposium 2024
Date / Location	10 – 14/6/2024 - Venice, Italy

Event # 41	
Event Name	TUM Sustainability Day
Date / Location	12/6/2024 - Munich, Germany

Event # 42	
Event Name	Annual symposium of Swiss European research infrastructure consortia community 2024
Date / Location	20/6/2024 - Bern, Switzerland

Event # 43	
Event Name	Centers of Competence / Industry Day 2024
Date / Location	21/6/2024 - Munich, Germany

Event # 44	
Event Name	Berlin 6G Conference 2024
Date / Location	2 – 4/7/2024 - Berlin, Germany

5. Hack-a-thons

This chapter provides an overview of activities related to stimulating software development in the community to enrich SLICES-RI facilities and toolsets used for experimentation in networking and information systems.

SLICES-RI relies on blueprints and their associated support (including documentation) to allow researchers to replicate and extend the work done by the community. To reach this objective, the blueprints provide a set of replicable tools, software, hardware, and methodologies to make sound experimental research with cutting-edge post-5G environments. Focus is being placed on reproducible outcomes of the deployments of blueprints. As such, researchers worldwide can focus on their core research (e.g., testing a new frequency allocation scheme) and leverage the rest of the infrastructure offered by the community. Several events took place in order to facilitate the further extension and experimentation capabilities offered by the SLICES-RI blueprints, as described below.

5.1. SLICES Hackathon organised during IFIP Networking 2024

One of the goals of the IFIP Networking 2024 hackathon that took place in Thessaloniki on June 3rd, 2024 was to bootstrap new software and features for the research community with the particular objective of integration with the SLICES portal. The selection of projects also took into consideration the potential of them to be implemented during the day. A list of suggested projects for the hackathon was provided during the initial launch and call for projects with indicative topics the following:

- Improving automation and CI/CD of SLICES-RI (e.g., Ansible, Terraform...)
- Advanced wireless networking experimentation
- Smart/intelligent infrastructure operation and management (e.g., Rancher, Kubernetes, Keycloack, OpenID)
- Design and validation of new Edge/Fog/Open RAN infrastructures
- Methodology for designing and operating a scientific instrument
- API backend and Frontend
- Integration of bare metal and physical custom resources into cloud environments (e.g., k8s CRD)

Five projects were submitted and selected to participate in the hackathon. During the event, an initial 20-minute slot was dedicated to introducing SLICES to the attendees. Following this introduction, we immediately dove into coding new features for the five projects, each designed to be implemented within a day. Specifically, we had:

Project 1: Integration of CEPH storage into the 5G blueprint by exposing CEPH volumes in the k8s clusters

As effectively using storage resources within SLICES is of paramount importance one of the projects was dedicated to this. In this context, the project took advantage of the CEPH[12] framework that can create clusters of storage resources and made use of Container Storage Interfaces (CSI) [13] in order to expose the storage components to clusters created by the post-5G blueprint of SLICES-RI (https://doc.slices-sc.eu/blueprint). During the hackathon, the following contributions were made: 1) Development of Ansible scripts to instantiate a new CEPH cluster, with storage provided by new nodes 2) accompanying Ansible scripts for attaching new nodes to the storage cluster, 3) extensions to the post5G blueprint of SLICES with the CEPH-CSI framework to use the CEPH storage as ephemeral/permanent storage devices within the clusters.

Project 2: Use of the SLICES portal as an authentication provider for the SLICES VPN service

The second project focused on extending the connectivity framework among the different SLICES nodes. Currently, interconnectivity among the different nodes (residing in different countries) is achieved by using VPN links. Such links require the authentication based on certificates/credentials issued by the VPN server. As the SLICES-SC portal allows for the authentication of experimenters to access the infrastructure in a similar manner, the project focused on creating the link between the OpenVPN server and the authentication backend of the portal towards allowing the link creation to be instantiated with the SLICES-SC portal credentials. The extensions were committed to the post-5G blueprint code of SLICES.

[12] Sage A. Weil, Scott A. Brandt, Ethan L. Miller, Darrell D. E. Long, and Carlos Maltzahn. 2006. Ceph: a scalable, high-performance distributed file system. In Proceedings of the 7th symposium on Operating systems design and implementation (OSDI '06). USENIX Association, USA, 307–320.

[13] CEPH-CSI: https://github.com/ceph/ceph-csi [Last accessed 26 August 2024]

Project 3: Addition of the RAN-split for bare metal resources in the blueprint reference implementation

The third project focused on creating new functionality on the telecommunications network setups provided by the post-5G blueprint. The student working on this project focused on providing the disaggregated network addressing both data plane and control plane disaggregation at the base station level (CU-CP/CU-UP/DU/RU disaggregated architecture). The code was developed as Ansible scripts, which can be used to deploy the blueprint on bare metal machines.

Project 4: Correction of a bug that appeared in POS resource booking calendar

All the services provided through SLICES must be correctly authenticated via the SLICES portal. Various protocols can be used for this purpose, such as the OpenID Connect (OIDC). The POS[14] system was restructured and new OIDC drivers were implemented in order to allow such authentication to take place. Nevertheless, restructuring uncovered some software bugs with respect to the calendar-based resource booking system that POS was using. One of the hackathon projects focused on resolving these issues, ensuring that POS functions correctly with all supported features when using the OIDC connectors.

Project 5: Addition of RBAC to the post-5G blueprint backend using casbin

As the post-5G blueprint is based on Kubernetes (K8s) for its deployment, different users need to take access to different parts of the deployments, in an isolated manner. In this context, Role Based Access Control (RBAC) provided by K8s is employed and configured in order to ensure the isolation of slices of the infrastructure. In order to achieve the seamless integration with the portal, casbin[15] was used, as the library used to connect the K8s RBAC models and the portal users, according to the privileges that they have/projects they have access to. The respective reference implementation of the project has been integrated to the Sophia (INRIA) SLICES-SC node.

[14] Sebastian Gallenmüller, Dominik Scholz, Henning Stubbe, and Georg Carle. 2021. The pos framework: a methodology and toolchain for reproducible network experiments. In Proceedings of the 17th International Conference on emerging Networking EXperiments and Technologies (CoNEXT '21). Association for Computing Machinery, New York, NY, USA, 259–266. https://doi.org/10.1145/3485983.3494841 [Last accessed 26 August 2024]

[15] Casbin authorization library: https://github.com/casbin [Last accessed 26 August 2024]

Figure 24. SLICES Hackathon

All five projects managed to deliver a first version of the proposed code that is expected to be integrated in the pre-op of SLICES. At the end of the day, attendees received congratulations from the coordinator of SLICES-SC.

5.2. SLICES BoF @ TNC 2024

Research has become more technological than ever, not for the sake of technology but because answering complex questions requires complex Interactions of software and hardware. Such that a single researcher or even a traditional team cannot have the skills to master their domain of science and at the same time setup and operate computational and validation tools. Interestingly, even though the field of application of the research instruments might be drastically different (if not orthogonal); all such instruments rely on complex hardware/computing systems that are interconnected and share some common needs and services. SLICES is an instrument dedicated to bridge this gap and provide the necessary infrastructure (hardware and software).

NRENs and GEANT provide plethora of services, from low-level high-speed links to Trust & Identity services or security. However, when it comes to put all the bricks together each instrument has to re-invent the wheel and we can see that often internal (sub-optimal) solutions are chosen.

This BoF was dedicated to starting the discussion on how GEANT and NRENs could help in providing a well unified set of services that are the core of research infrastructure, regardless of their domain of application. One could see it as a first thought on how to package all critical and common services of the infrastructure. Several discussions based on the tools that can be provided by GEANT and NRENs

to SLICES took place, such as for example using EduVPN[16] service for accessing SLICES resources etc. Another important point that has been discussed is how can we provide right levels of documentation to the potential users by means of academies and tutorials.

Figure 25. The SLICES BoF at TNC 2024

5.3. Post-5G BP pre-op Code Sprint 2024

As part of the continuous developments and integration in the SLICES post-5G blueprint components, a code sprint took place at Inria Sophia-Antipolis in order to integrate and further develop new functionalities with the post-5G blueprint to be run in pre-op. The code sprint was held in the week of 24-28 July, with participants from Inria, SU, TUM, UCLAN (Cyprus), and UTH. The components and new functionalities developed during the code sprint were the following:

- **Obj1:** restructure the implementation repository(ies) in order to include more explanatory documentation and clear up from obsolete implementations/files
- **Obj2:** integrate flexRIC[17] and Submariner in the implementation. FlexRIC support has been developed in order to provide near-RT control of the deployed gNBs. The implementation was integrated with the main contributions of the post-5G blueprint. Similarly, submariner[18]

[16] GEANT EduVPN: https://www.eduvpn.org/ [Last accessed 26 August 2024]

[17] FlexRIC O-RAN compliant controller for OpenAirInterface: https://gitlab.eurecom.fr/mosaic5g/flexric [Last accessed 26 August 2024]

[18] Submariner: direct networking between Pods and Services in different Kubernetes clusters, https://submariner.io/ [Last accessed 26 August 2024]

(www.submariner.io) has been used in order to enable secure and dynamic service exposure between Kubernetes clusters that implement the post-5G blueprint.

- **Obj3:** integrate the Metadata Registry System (MRS) in the implementation. As such the MRS system that collects and organizes metadata from experiments within SLICES has been integrated with the post-5G blueprint resources.
- **Obj4:** deploy an MRS in IMEC Vwall resources. As the resources will be used as a first central hub for accessing the SLICES-RI infrastructure, the MRS backend was installed in the Vwall resources.
- **Obj5**: deploy a submariner broker in vwall resources. In order for submariner to work correctly, a broker instance is required for advertising the available exposed services across the integrated clusters. The respective broker was installed and integrated with the rest of the post-5G resources.
- **Obj6:** restructure documentation to be LLM friendly. The project has developed an LLM model in order to make experimentation with the infrastructure user friendly. When using the LLM model, the experimenters engage into chatting with the chatbot[19], and get recommendations on the resources that they need to use, as well as code used for deploying their experiment. Nevertheless, the LLM model needs to be efficiently trained in order to produce the required outputs. During the meeting, the changes that need to be made to the documentation, as well as a new documentation style were discussed and agreed, in order to enhance the training process for the LLM model.
- **Obj7:** enable monitoring of resources and dashboard interfaces for the post-5G blueprint. A complete monitoring solution, with a centralized storage (located and to be integrated with the central hub) were developed. These contributions rely on the Prometheus[20] monitoring stack instantiated at each cluster and utilizing the remote write feature to a centrally located Prometheus instance. Similarly, the promtail[21] framework was integrated with the blueprint, allowing the scraping of logs from K8s pods from the different clusters, in the most non-intervening manner possible for the experimenter. The data gets labeled and pushed to a central Grafana Loki instance[22]. On top, a central Grafana visualization tool can be used to visualize metrics and logs scraped from the different post-5G clusters.
- **Obj8:** deploy the pos framework in the post-5G SLICES infrastructure. A pos server has been deployed in TUM. It will control all resources in SLICES. During the week, we attached bare metal servers from the Sophia Antipolis site to this pos server. This has required to setup secured VPN links and recabeling the IPMI of the infrastructure to provide proper isolation. In addition, to speed up experimentation deployments proxy caches have been installed to prevent using international links when it is not absolutely required.

During the meeting, details on the implementation of the central hub, the interconnections among sites, and overall topology and locations of where each service will be hosted were discussed.

5.4. Hand-on during SLICES Summer School 2024

During 7-12 July 2024, the Lipari School on Advanced Networking Systems was organized in cooperation with the pan-European Scientific Large-Scale Infrastructure for Computing/ Communication Experimental Studies Research Infrastructure (SLICES-RI)[23]. The primary goal of the

[19] D. Kefalas, S. Christakis, S. Fdida, N. Makris, I. Syrigos, V. Passas, and T. Korakis, "slAIces: an LLM Chatbot for Simplifying Experiments with the SLICES-RI," in *2024 IFIP Networking Conference (IFIP Networking)*, Thessaloniki, Greece, June 2, 2024

[20] J. Bastos and P. Araujo, *Hands-On Infrastructure Monitoring with Prometheus*. Packt Publishing, 2019.

[21] Promtail Framework: https://grafana.com/docs/loki/latest/send-data/promtail/ [Last accessed 26 August 2024]

[22] Grafana Loki Log aggregation system: https://grafana.com/oss/loki/ [Last accessed 26 August 2024]

[23] SLICES Summer School 2024 website, https://www.slices-ri.eu/events/slices-summer-school-2024/ [Last accessed 26 August 2024]

summer school was to provide the participants with an overview of the possible enabling technologies and fundamental research challenges of upcoming 6G systems and networks, as well as an introduction to the tools and methodologies offered by SLICES-RI for conducting experiment-based research in such cutting-edge research areas. The school was organized into three tracks (lectures/keynotes/hands-on). The hands-on sessions were broken down into two different parts, and the participants were shared among the two groups, depending on the infrastructure and type of project that they selected between the SLICES-RI and PAWR OpenRANGym. With respect to the SLICES-RI related projects, the session resembled a hackathon, with approx. 20 participants being initially introduced to the key concepts of SLICES around the post-5G blueprint and allowing them to select a project of their own that will help them validate their approaches. A repository[24] was setup to help them start their experiments in one of the following topics:

- setting up a split Radio Access Network in a multi-nodes kubernetes cluster
- modifying 5G Radio parameters and evaluating their performance
- setting up xAPPs to manage the radio network using a Radio Intelligent Controller (RIC)

By the end of the summer school, participants were invited to share their results with the summer school attendees, regarding their experimental findings, and provide feedback on the use of the platforms.

Figure 26. Hands-on at SLICES Summer School in Lipari

[24] SLICES Summer School 2024 repository, https://gitlab.inria.fr/slices-ri/blueprints/post-5g/summerschool_2024/ [Last accessed 26 August 2024]

Figure 27. Hands-on at SLICES Summer School in Lipari

SLICES-RI relies on blueprints and their associated support (including documentation) to allow researchers to replicate and extend the work done by the community. To reach this objective, the blueprints provide a set of replicable tools, software, hardware, and methodologies to make sound experimental research with cutting-edge 5G environments. Focus is being placed on reproducible outcomes of the deployments of blueprints. As such, researchers worldwide can focus on their core research (e.g., testing a new frequency allocation scheme) and leverage the rest of the infrastructure offered by the community. Several events took place in order to facilitate the further extension and experimentation capabilities offered by the SLICES-RI blueprints, as described below.

5.5. SLICES Hackathon (Sophia Antipolis)

EURECOM organized the OAI Near-RT RIC Spring of Code during the period Feb-June 2024 (https://openairinterface.org/spring-of-code/). The original time plan is shown in Figure 28.

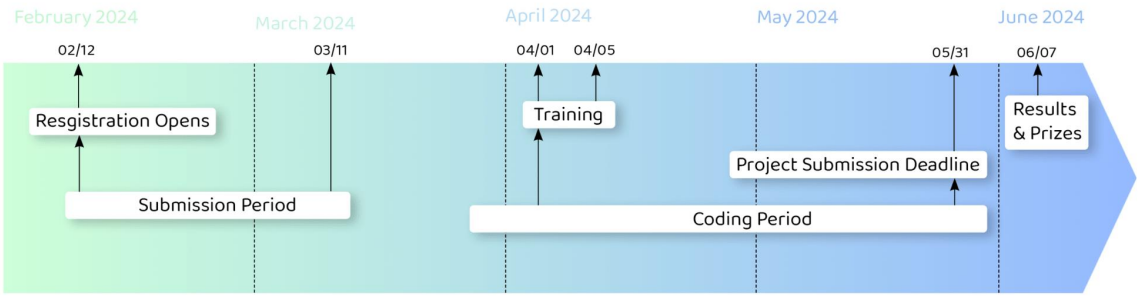


Figure 28. OAI Spring of Code 2024

The applicants were asked to propose subjects in the following categories topics.

Topic 1: Expansion of the Key Performance Measurement (KPM) Service Model

Description: In the current state of OAI RAN, some performance measurements from 3GPP TS 28.552 have been implemented through the existing xApp (xapp_kpm_moni) within the RIC stack. The aim is

to expand the KPM Service Model to capture additional data from L2 and L3 in OAI RAN. This expansion is intended to provide a more comprehensive view of network performance, aiding in better decision-making based on a wider set of measurements. The project also aims to log the messages reported by KPM SM into an SQLite database to permit further processing. Storing and additional management of this data would allow further data processing, for example, using ML/AI algorithms. This additional capability will enhance the project's capacity to analyze and derive meaningful insights from the collected data.

Topic 2: Mobility Control Implementation via RAN Control (RC) Service Model

Description: The primary aim of the RAN Control Service Model is to manage functionalities via E2 control procedures through xApps while maintaining a focus on optimizing radio resource management. This proposed scenario revolves around the exposure of RAN control of UE context-related information and procedures, specifically the UEs' RRC messages and PDU sessions. Additionally, the proposal involves experimentation with handover behavior through an xApp. The overall goal is to exercise mobility control by leveraging the RC SM, thereby contributing to enhancing network management capabilities, in a disaggregated RAN with F1/E1 splits.

Topic 3: Implementation of the Cell Configuration and Control (CCC) Service Model

Description: The CCC Service Model (SM) is designed to unveil node and cell level configuration information and initiate control and configuration of parameters at both levels. The proposal requires a comprehensive implementation of CCC ASN.1 encoding/decoding for node and cell-level configuration within the RIC framework. Moreover, the plan includes replicating the existing OAI O1 demo, with a specific focus on requesting DU node-level attributes and effecting modifications for bandwidth changes, in addition to executing base station soft-restart procedures.

Applicants submitted proposals in early March 2024 which were judged. The target scenarios concerned the development of both near real-time RAN intelligent Controller software using OAI's FlexRIC and the corresponding service models which will become part of the OAI radio-access network software packages. The selected proposals attended a training session by EURECOM/OAI staff in early April which took place at EURECOM. It was attended by representatives of the following institutions:

- I2CAT, Spain, 4 participants
- CTTC, Spain, 1 participant
- CNR, Italy, 1 participant
- Politecnico di Milano, Italy, 1 participant
- Sorbonne, France / University of Thessaly, Greece, 1 participant
- Fraunhofer IIS, Germany, 1 participant
- Fraunhofer HHI, Germany, 3 partcipants
- Gradiant, Spain, 2 participants
- Eindhoven University, 2 participants
- IT Aveiro, 1 participant

A few snapshots of the training session at beginning are shown in Figure 29. All EU participants received reimbursement for their trip and stay in Sophia Antipolis thanks to SLICES-SC funding.

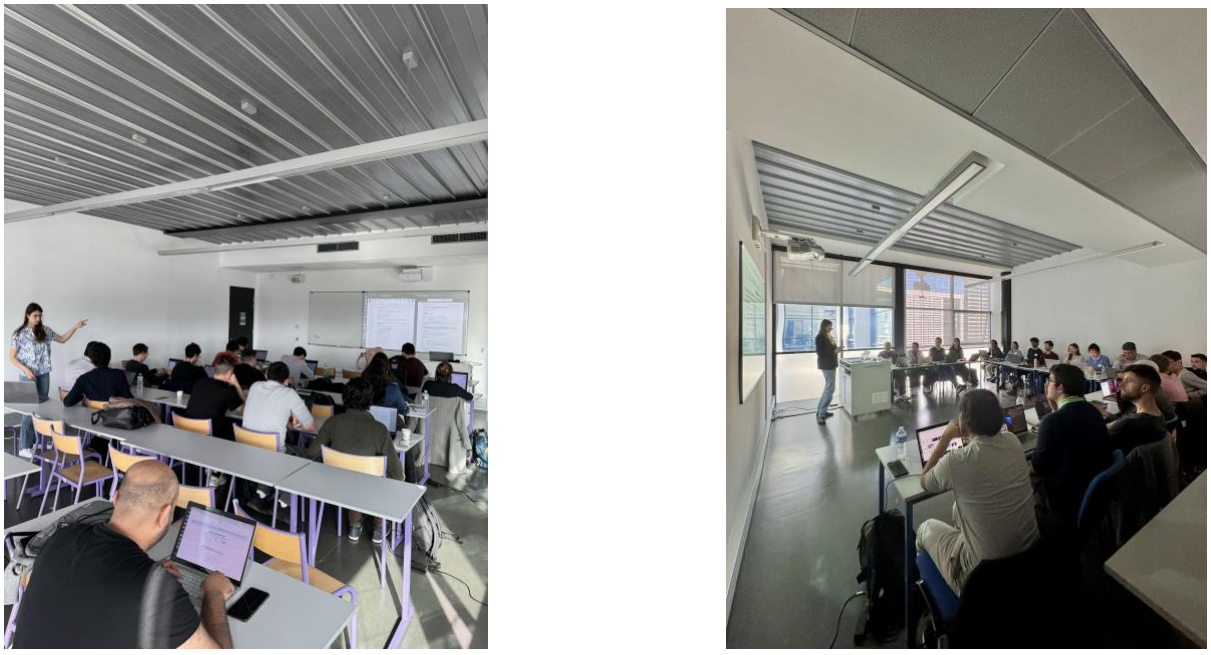


Figure 29. Snapshots from Spring of Code Training

After the training session the candidates worked remotely on their own infrastructures and using the EURECOM infrastructure (gitlab and ssh). Interactions with the training team occurred on the OpenAirInterface Slack channel. Originally, the work was planned until the end of May 2024, but this was extended by one month to allow the candidates to produce more complete contributions to the codebase. Monetary prizes were awarded to the top three contributors. 5,000€ for the first prize, 3,000€ for the second one and 2,000€ for the third one. This was provided using funds from the OAI Software Alliance which come from donations from its industry patrons. The code generated by the hackathon initiative will progressively be integrated into the main develop branch of OAI in the coming months.

6. SLICES Research Mobility

The ***SLICES Research Mobility Programme*** targets members of the consortium, as well as researchers not affiliated with any of the consortium partners, who want to use SLICES-SC facilities in other countries to conduct their experimentation. There are two mobility categories:

- ***Research Mobility for Knowledge Transfer***. This is a short mobility program (limited to one week, up to 3K€ reimbursement of travel costs and related subsistence) that is meant only for training (i.e., learning the infrastructure of a SLICES site and how to use it), and it reserved to the members of the consortium. The definition of a concrete exploitation and dissemination plan are essential parts of this mobility scheme.
- ***Research Mobility for Micro-project.*** This is a long mobility program (up to four weeks, typically split into two visits, up to 6KE reimbursement of travel costs and related subsistence) that is meant for carrying out a micro-project with a tangible scientific output for SLICES-SC (e.g., a dataset, a software package, a joint collaboration for a publication, or official technical report), and it is open to both members of the SLICES consortium and researchers not affiliated with any of the consortium partners. The main justification for organizing this mobility program into two stages is

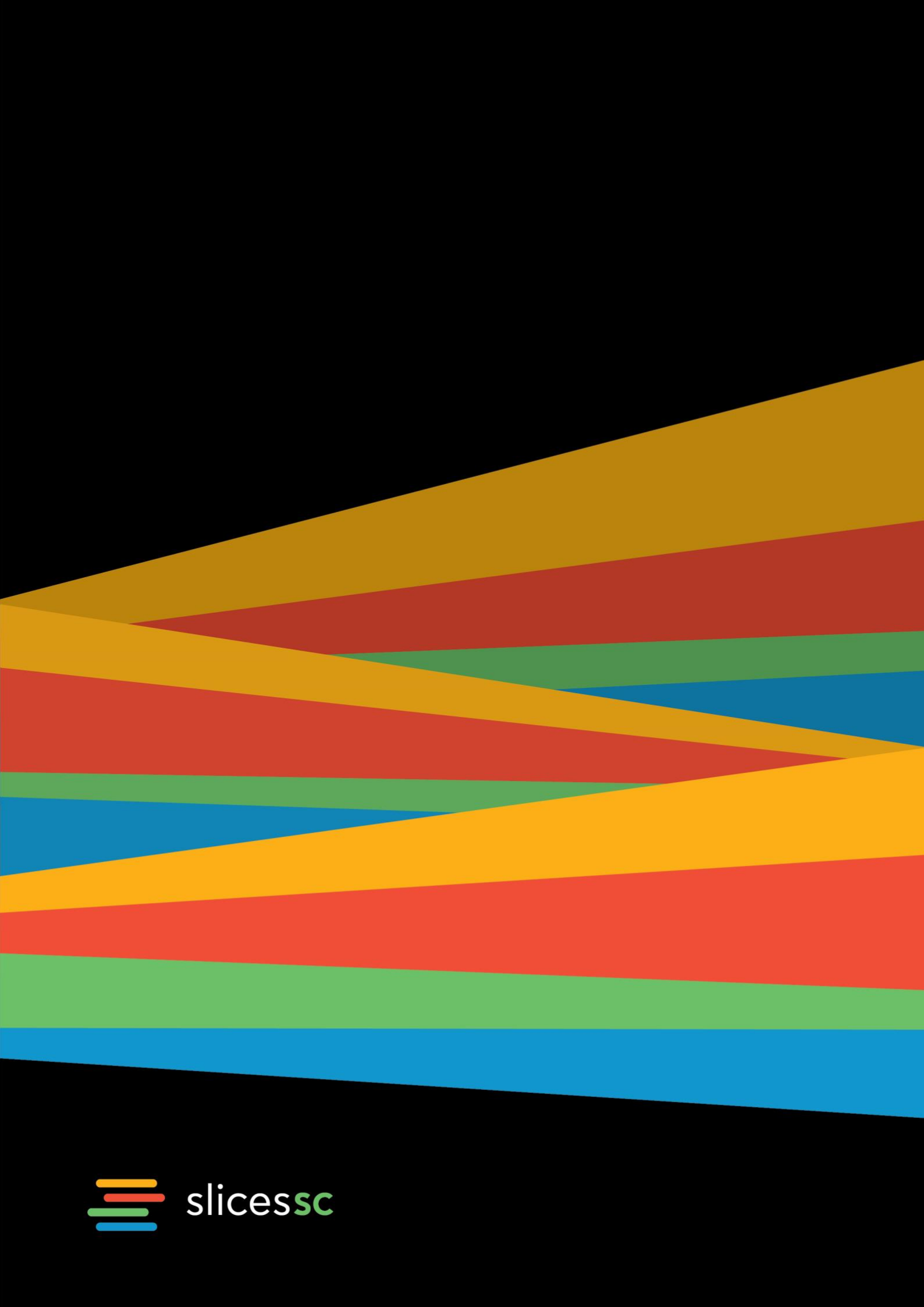
that the first stage might be needed to learn how to use the experimental facility while the second stage will be dedicated to use the RI to complete the planned experimentation.

It is important to point that the kick-off of the SLICES researcher mobility programme has been delayed due to the uncertainty about travel restrictions during the peak of the COVID pandemic. Furthermore, the SLICES researcher mobility programme is meant as complementary to Transnational Access activities, as the focus of the former is mainly on the training and the knowledge transfer. During this first period, we have mainly finalized the specification of the Call for Applications for both mobility schemes, which are now ready for being launched and announced inside and outside the SLICES community.

Conclusions

SLICES mission includes education and training as a component of utmost importance for the usage and broad utilization of the facility. It is well recognized that capacity building is instrumental for the research community but also for our society at large, in particular regarding digital literacy and more specifically infrastructure management and operation.

SLICES has organized different training activities during its implementation as described in the current document. It describes the process as well as the design of the training required for full participation and collaboration of stakeholders in the broader portfolio of SLICES services. As a main conclusion from organizing the different SLICES training activities during this second period, the consortium has decided to construct a common framework for all training activities, forming a new open educational ecosystem known as the SLICES Academy. It has been designed to be sustainable. In its current version, the SLICES Academy contains some initial Learning Courses, however, SLICES Academy will continue its operation under SLICES-PP project and will enhance the courses and extent its usage. As discussed, activities like the SLICES Summer Schools, the SLICES Hackathons, the researchers' mobility and theNetworkingChannel will also be continued after the end of the project.


slicessc