Reproducible Experimentation with beyond-5G Blueprints in SLICES-RI.

Damien Saucez
Inria
Sophia Antipolis, France
damien.saucez@inria.fr

Sebastian Gallenmüller
Technical University of Munich
Munich, Germany
gallenmu@net.in.tum.de

Nikos Makris
University of Thessaly
Volos, Greece
nimakris@uth.gr

Raymond Knopp
Eurecom
Sophia Antipolis, France
raymond.knopp@eurecom.fr

Serge Fdida
Sorbonne University
Paris, France
serge.fdida@sorbonne-universite.fr

***Abstract*—Experimental research in Post-5G involves complex interactions between software, hardware, and protocols. Therefore, it is crucial to develop solutions that allow researchers to conduct their experiments in a reproducible manner. To support this need, the EU SLICES Research Infrastructure (RI) provides a scientific instrument that encompasses all the needs for Post-5G experimental research. The facility is currently being built to enable experimentation with state-of-the-art resources in various fields. SLICES-RI is intent-driven and facilitates the entire lifecycle of thought experiments. This is achieved by enabling reproducible deployment of experiments over the infrastructure using blueprints and by systematically collecting and archiving all outputs through a clear and structured methodology for experimentation. For this demonstration, we focus on the Post-5G part of the facility and will showcase how the entire lifecycle of such an experiment is orchestrated using the tools and functionalities developed. We will showcase blueprints for deploying a cloud-native 5G core and a split 7.2 radio network using open-source software in a fully reproducible manner, with the results being automatically archived and published using the SLICES metadata model. The reproducibility, deployment options, experimenter control capabilities, and access to the collected results will be highlighted.**

***Index Terms*—5G, blueprint, reproducibility, SLICES-RI**

I. Introduction

Experimental research integrates software, hardware, and technical expertise, requiring significant time and resources. SLICES-RI, the first community-driven scientific instrument in Digital Sciences, aims to support researchers and engineers to provide evidence in real-world settings [1]. It offers experimentation services across a wide range of Digital Infrastructure technologies, including programmable radio, Edge and Cloud computing, and GPU/DPU-assisted AI model validation.

As a community-driven initiative, SLICES-RI translates user needs into deployable blueprints, which are essential to ensure experimental reproducibility. These blueprints form the basis for replicating and extending community work, while providing a method for bootstrapping advanced experiments for novel users. This demonstration focuses on the part of the SLICES-RI that supports experimentation with Post-5G resources, facilitated by a corresponding blueprint built with cutting-edge hardware and software. The *Post-5G blueprint* provides replicable tools and methodologies for advanced 5G research, allowing users to concentrate on their core objectives (e.g., developing trajectory prediction models) while leveraging SLICES-RI facilities.

The demonstration will showcase how complex cloud-native 5G networks can be deployed in SLICES-RI, integrating disaggregation at different levels (Control/User plane disaggregation at the RAN, data-plane RAN disaggregation through different split options) and cloud-native deployment of several functions (core network & RAN functions). In parallel to scriptable file-based tools, a Web-based solution is also provided to configure and deploy the blueprint, as well as monitor the entire process. The entire experiment – from definition to results publication – is orchestrated with the pos framework [2].

II. Post-5G blueprint experimental research

The SLICES-RI *Post-5G Blueprint* provides the community with a set of replicable software tools, hardware, and methodology for conducting experimental research with cutting-edge environments.

The demonstration will showcase an advanced scenario covered by the SLICES-RI post-5G blueprint [3], as illustrated by Fig. 1, using the accompanying tools to support experiments. The general workflow that the blueprint follows is summarized as the following:

1) Initially, the experimenters define their experiment, including the key parameters that need to be observed, the granularity of measurements that need to be collected,

The research leading to these results was supported by the EU HE program under grant agreement No 101079774 for the SLICES-PP project. This work was supported by the ANR under the France 2030 program, grant "NF-Plateforme XG: ANR-22-PEFT-00011"

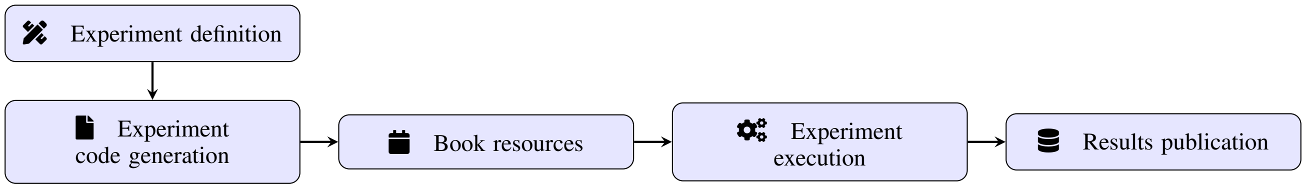

Fig. 1. Experimentation workflow with the post-5G blueprint in SLICES-RI

and the equipment (location and type) that shall be used for their experiment.

2) During the second step, the SLICES-RI tools and backend software package the configurations and tools into scriptable tools and commands, and are uploaded to the SLICES centralHub server.
3) In the third step, the experimenters need to book the resources that shall be used for their experiment. The resources are either entire sites, or parts of testbeds, included in their experiment. Resource reservations are using a calendar-based tool, and can be scheduled for any time in the future that the resources are available.
4) When the resources that the experimenters request are available and their reservation begins, the experiment is executed over the infrastructure. The experiment is orchestrated through the *pos* controller, used to facilitate reproducibility of results across different nodes/sites.
5) Upon the experiment completion, the results and key monitored parameters, as defined during the initial experiment definition, are collected and uploaded to the SLICES-RI data management infrastructure. As SLICES is compliant with the open access guidelines, the data are published online and accessible with a unique identifier. Metadata models are used to describe the data, accounting for the compliance of the published research data with the FAIR principles.

In the scenario that will be demonstrated, an OpenAirInterface 5G core [4] is deployed in a Kubernetes cluster hosted by SLICES-RI. The core network is functionally disaggregated, with each function being implemented within a dedicated pod. The 5G RAN, also hosted at a SLICES-RI site, follows the 3GPP split 7.2 specifications [5] and is connected to the core via a long-distance link. The Radio Unit (RU) is realized through dedicated hardware, interconnected with the respective RAN software functions (CU & DU), realizing the hardware in-the-loop principle. As for the RU operation, tight synchronization with the DU is required. SLICES-RI infrastructure supports GNSS acquired signal propagation through the Precision Time Protocol (PTP) that is vital for the configuration of the RU. Moreover, the DU needs to be deployed over hardware with dedicated features (e.g. multi-core setup, no CPU frequency scaling, AVX512 instruction set, etc.). All the above functionalities are handled by the different SLICES-RI tools and services, that are in place to guarantee that the experiment will be executed as expected, and over the hardware that is needed.

To streamline the creation and execution of experiments with the post-5G blueprint, SLICES-RI provides a user-friendly dashboard (see. Fig. 2) through which certain parameters of the experiment can be tuned. Examples of such parameters include the level of split, the selection of where the deployment will take place, the configuration of slicing for the infrastructure, the use of dedicated hardware, applications that shall be run during the experiment and others. This dashboard also provides a webshell that grants direct access to the SLICES infrastructure, allowing experimenters to use all the resources (tools, software, and hardware) by just interacting with the web service, without the need to install anything on the local user machine. The dashboard features an LLM-based chatbot assistant to guide through defining the experiment's 5G core and RAN settings, ensuring that the infrastructure meets each experimenter's specific requirements. SLICES-RI covers the entire spectrum of users: beginners using the chatbox, standard users use a graphical interface to prepare their setup, and experts access resources with no limitations of any sort.

Using a calendar-based resource reservation system, users can book the necessary hardware resources, such as servers, networking devices, or radio units. Upon the configuration of the infrastructure, the parameters are uploaded to a server and can be used to configure the hardware within a valid reservation. Upon the experiment definition, the data is passed to the backend service that is in charge of packing together all the necessary scripts and upload them to the nodes involved in this experiment instance. All the interactions with the web dashboard, and the backend service use token-based authentication with the SLICES Open ID Connect (OIDC) authority. For the orchestration of the actual experiment, the pos framework is used. Pos is in charge of loading the appropriate image on the involved nodes during the reservation, and orchestrates the execution of all the scripts and tools that the user has defined for this specific experiment.

Upon the completion of an experiment, all the data and outputs of all the pods and system components are captured and uploaded to the SLICES Data Management Infrastructure (DMI). The collected data are annotated with the respective metadata complying with the SLICES-RI metadata model and published and made accessible as open access, complying with the FAIR principles. Experimenters can use the collected

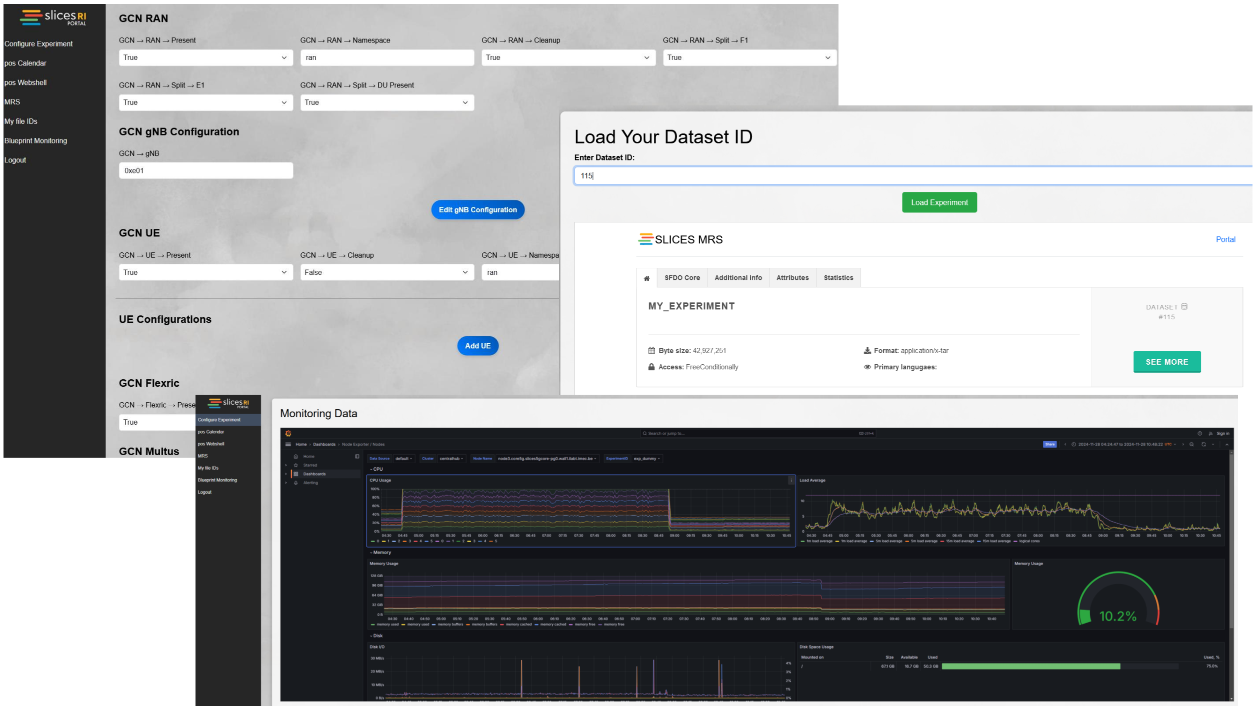

Fig. 2. Configuration dashboard for the Post-5G blueprint, and access to the Metadata Registry System (MRS) and the monitoring data.

data to determine their findings, and use the experiment definition as a guideline that can be reproduced by other groups/researchers.

As there are several parameters that can affect an experiment when running on real hardware, live monitoring of key values is provided during the experiment execution. This serves as an early evaluation of the experiment status, that can be used by experimenters to inaugurately conclude on the experiment success. Key metrics are collected from the respective cloud-native instances of the deployment, as well as the nodes that hosts them. Examples of the collected metrics include resource utilization per each computing node, traffic exchange per each pod, and log outputs from each service running at each pod, and others. The data are collected from all the different sites that support experimentation with the post-5G blueprint, by using well established tools such as Prometheus and Grafana Loki for timeseries and log storage respectively. Their setup and architecture is defined in a manner that allows their scaling, by deploying local monitors on each cluster that collectively publish periodically the results to a central monitor. The collected data are accessed and visualized in real-time through dashboards integrated into the web dashboard service, allowing users to filter through the data that are interested in (e.g. node on which their workload is running, log outputs of specific pods, and others).

III. Demo Setup

The demonstration will be executed remotely on the SLICES infrastructure, using all the aforementioned services, and demonstrating the entire lifecycle of experiments to the conference attendees. Different configurations of the post-5G blueprint will be showcased, demonstrating the deployment of different levels of split, different sites, different measurement applications, and others. Each experiment will be uploaded to the SLICES DMI and annotated according to the SLICES metadata model, the parameters of which will be highlighted to the attendees. More details on the SLICES-RI post-5G blueprint, as well as example scripts, and guidelines on how each experiment is conducted, are available on the official SLICES-RI website https://doc.slices-ri.eu.

References

[1] S. Fdida *et al.*, "Slices, a scientific instrument for the networking community," *Computer Communications*, vol. 193, pp. 189–203, 2022.

[2] S. Gallenmüller *et al.*, "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, p. 259–266, ACM, 2021.

[3] D. Saucez *et al.*, "Blueprint-based reproducible research with the slices research infrastructure," in *IEEE INFOCOM 2024 - IEEE Conference on Computer Communications Workshops*, pp. 01–02, 2024.

[4] N. Nikaein *et al.*, "OpenAirInterface: A Flexible Platform for 5G Research," *SIGCOMM Comput. Commun. Rev.*, vol. 44, p. 33–38, oct 2014.

[5] V. Q. Rodriguez and others1, "Cloud-ran functional split for an efficient fronthaul network," in *2020 International Wireless Communications and Mobile Computing (IWCMC)*, pp. 245–250, 2020.