HORIZON 2020

ICT - Information and Communication Technologies

Deliverable D3.3
Second Report on Joint Technology Demonstrations and Data Analysis

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Executive summary

This deliverable reports on all preparation efforts carried out by EMPOWER to foster joint EU-US technology demonstrations in the second year and provides evidence of mutualization of platform components and systems and in particular those link ICT-17 and USA initiatives including PAWR facilities, Magma Foundation Projects. Examples of integration of ICT-17 activities with Linux Foundation projects (OPNFV, ONAP and O-RAN) are also provided. An overview of current efforts in EMPOWER towards establishing a reference architecture for federating and operating long-term wireless research facilities is outlined.

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1. Introduction

One of EMPOWER's main objectives is to stimulate mutualisation of platform components and software and to demonstrate the joint developments and proof-of-concept activities at high-profile venues such as the Mobile World Congress and Linux Foundation events. As a follow-up to D3.2 [1], the purpose of this deliverable is thus to report on the progress of these activities and others established since M12 of EMPOWER, including preparation of joint demonstration activities, actual demonstrations and later data analysis efforts resulting from joint proof-of-concept demonstrations. In addition, we provide concrete examples of mutualisation of tools through these efforts along with evolutions in architectures to facilitate future joint experimentation and demonstration.

Specifically, EMPOWER now has ongoing engagements with several entities in the USA, in particular the PAWR facilities and associated testbeds as well as Linux foundation MAGMA and OPNFV-VCO3 projects. These collaborations aim firstly to reduce fragmentation by producing common software toolsets and coordinating joint development efforts. A key step in this direction was taken in 2020 to provide a single core network solution for the mobility-management entity (MME) between OpenAirInterface (OAI) and MAGMA. A similar endeavour is now underway with teams from OAI in Europe and US colleagues from PAWR through the OpenAirX-Labs initiative which targets acceleration development of 5G RAN and Core Network components through community-based development.

We also aim to harmonize software deployment methodologies in order to join forces on testbed computing resource management. This objective aims at providing common blueprints which can be used to deploy containerized versions of radio-access, core network software, mobile-edge computing functions and mobile service frameworks, including but not limited to OAI, Mosaic5G and Magma. These targets both Kubernetes-based and bare-metal computing clusters.

Finally, we focused on aggregating testing procedures across multiple platforms. Testing is a key component for ensuring software-integrity, in particular for community-based development, when new features are added to a software package. Because of differences in infrastructure at different sites (different computing platforms and radio equipment) testing of common software packages should firstly be automated by a continuous-integration (CI) and continuous-delivery (CD) system and secondly adapted to the specific needs of the experimental sites. These needs are expressed in terms of features, deployment environments (static, highly-mobile, over-the-air or with test and measurement equipment) and require a high-level of coordination between the various parties. EURECOM, R2Lab and OpenAirX Labs are working closely on defining and implementing a multi-site testing architecture for the OAI, Mosaic5g and MAGMA software packages using the various academic sites at its disposal. The framework will also make use of other similar software components such as srsLTE, Amarisoft and commercial testing hardware and software. Certain portions of the framework are expected to be extended to the 5G-EVE Site at Orange Labs in 2021. A similar effort is being implemented with the Magma Foundation and the Open Core Network (OCN) project. Testing of the MAGMA MME currently occurs jointly at EURECOM 5G-EVE and Magma Foundation infrastructures and this will be extended to include 5G core network components from OAI and OCN.

1.1 Overview of this document

At this stage of EMPOWER (M28) we report in Section 2 on the continued steps that are being used to stimulate joint demonstration between ICT-17 project facilities (5G-EVE [2], 5G-VINNI [3] and 5GENESIS [4]) and the US National Science Foundation (NSF) Platform for Advanced Wireless Research Program (PAWR) facilities (COSMOS [5], POWDER-RENEW [6], and since M12 AERPAW [7], Colosseum [8]). These activities all involve joint development work between the EU and USA researchers to enable future joint demonstrations and experimentation. Progress on the millimeterwave hardware provided by InterDigital for integration into both

PAWR and ICT-17 / EU facilities as described in D3.2 [1] is reported upon. A new activity initiated with both AERPAW and COLOSSEUM pertaining to testing OAI for highly-mobile channels using real-time channel emulation equipment provided by AERPAW. USA and EU researchers began collaborating on this effort at the end of 2020 and this work will continue in 2021-22 to provide higher stability of OAI for the aerial platforms at AERPAW.

In Section 3 we summarize the work carried out to coordinate the use of ICT-17 5G-EVE in Linux Foundation projects. The first is the case of making the 5G-EVE site in Sophia Antipolis available for use in the OPNFV VCO 3.0 project [9] [10]. The second example initiates the collaboration between 5G-EVE and POWDER teams aiming to contribute to the O-RAN Alliance [12] reference implementation, an effort also managed by the Linux Foundation and O-RAN. The implementation will make use of OpenAirInterface and will be available for testing at PAWR sites and 5G-EVE.

Section 4 is concerned with the efforts to devise the reference architecture allowing for improved interoperability at all levels and to ensure viability of large-scale experimentation platforms over several years. The architecture is tailored to benefit from and evolve with open-source software components and deployment methodologies.

2. Joint Demonstration Activities between ICT-17 and PAWR

2.1 NETCONF-YANG protocol extensions for OpenAirInterface (OAI) RAN and Core Network Components (ICT-17 5G-EVE and COSMOS [1])

This activity was described in D3.2 and ongoing with minimal progress in 2020. It will be revisited in 2021 now that an ONAP-compatible framework is completely integrated on the 5G-EVE infrastructure in Sophia Antipolis and Paris. NETCONF-YANG is commonly used in conjunction with ONAP-based network deployment.

2.2 Continuous Deployment of OpenAirInterface RAN and Core Network Components at POWDER-RENEW [2]

This activity was described in D3.2 and has progressed towards the end of 2020 and early 2021. Automatic testing is now being deployed at POWDER in Utah based on successful integration on the French R2LAB testing environment. The evolution will be carried out in conjunction with the framework being put in place with the AERPAW and COLOSSEUM sites described in Section 2.3. This will allow for joint experimentation based on OAI to be performed on the POWDER infrastructure and, moreover, testing and qualitative improvement of OAI RAN and Core Network software for the POWDER environment. Several meetings between POWDER and EURECOM were organized to understand the difficulties of using OAI on POWDER and in particular improving the user-experience on the POWDER radio hardware. The main focus in 2021 is to integrate automated testing procedures for 5G NR SA (standalone operation) and to benefit from the repeatable mobility scenarios offered by the POWDER infrastructure.

2.3 New OAI Testing Facilities at AERPAW and COLOSSEUM

As mentioned in the introduction, we regard testing as a fundamental component for ensuring software-integrity, in particular for community-based development used on a heterogeneous set of experimental sites comprising significant differences in infrastructure and deployment topologies. Testing of common software packages needs to be automated by a continuous-integration (CI) and continuous-delivery (CD) system and secondly tailored to the specific needs of the different experimental sites.

Work was launched early in 2020 with COLOSSEUM [3] and in early 2021 at AERPAW [4]. The COLOSSEUM group at Northeastern University's Institute for the Wireless Internet of Things has one full-time employee now dedicated to contributing to OAI software development and testing on PAWR sites, including contributing to the evolution of the testing framework of multiple communities. She is a fully integrated team-member today working with EURECOM staff and other members of the OAI community in Europe. She manages links with other USA projects, in particular AERPAW. As described in D3.1, COLOSSEUM is a large-scale lab network comprising one hundred high-end USRPs connected in a matrix along with a large number of high-end Intel-architecture servers.

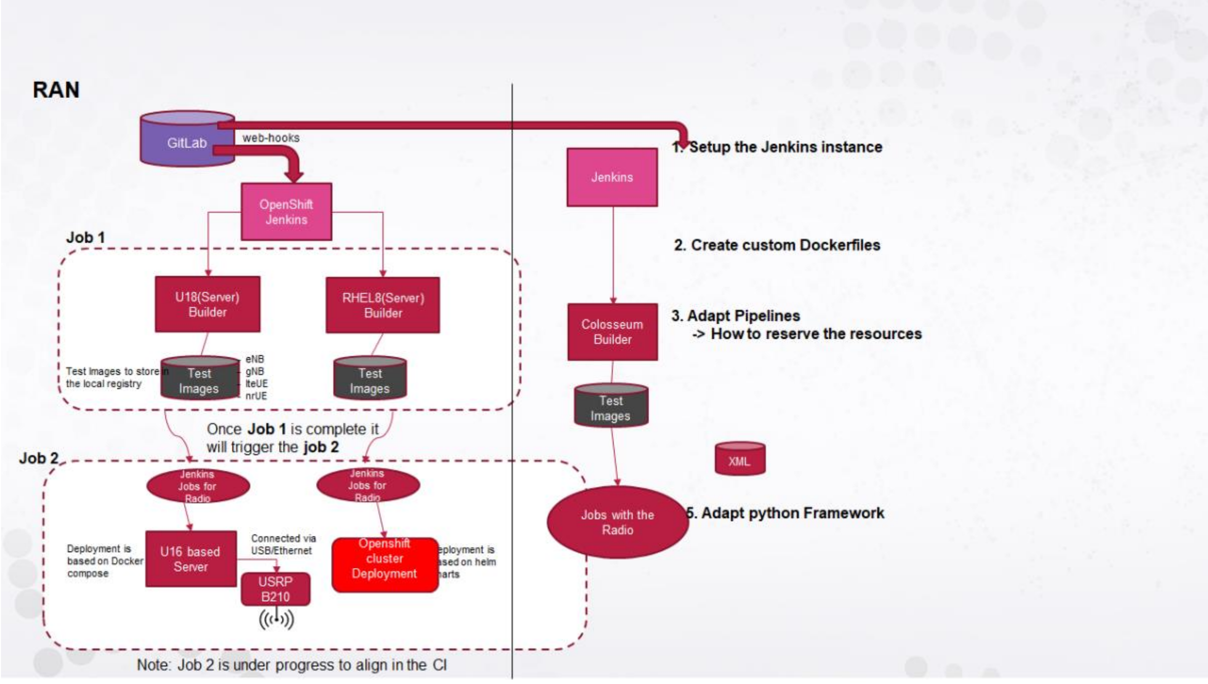

Figure 1: COLOSSEUM extension to OAI automatic testing framework

The work which is now part of the OpenAirX-Labs initiative [5] at Northeastern aims at extending the current EURECOM testing framework to launch jobs on COLOSSEUM (and POWDER) when community merge requests are provided to the main OAI repositories. OpenAirX-Labs was recently launched by Northeastern University and other partners (North Carolina, Texas A&M, Rutgers, Mississippi, EURECOM). The main purpose of this initiative is to promote and help coordinate the development of OAI 5G software packages, 5G radio-access network and core network, for academic use-cases in the USA. OpenAirX-Labs works in conjunction with the main development teams in Europe coordinated by the OAI Software Alliance.

Hooks for the OAI Jenkins based CI/CD framework are being added for COLOSSEUM as shown in Figure 1. COLOSSEUM will provide a significant increase of computing resources to the main testing site at EURECOM to handle the merge requests to the OAI codebases which are increasing very quickly, in particular for the 5G components. This will reduce the amount of time for testing community merge requests and encourage more developers from the USA to contribute to the codebases. The framework was also validated on POWDER and will be integrated and harmonized with the ongoing work described in D3.2 and Section 2.2, in particular for vehicular mobility scenarios. The method is based on automated generation of containers of the OAI packages using an Ansible front-end.

AERPAW has provided remote access to a Keysight real-time MIMO channel emulator, high-end servers and 4G/5G radio platforms for EURECOM and COLOSSEUM team members to improve the functionality of OAI for aerial platforms. EURECOM is currently working with Northeastern and North Carolina State University on building the test-platform and deploying both OAI RAN and Core functions for testing with the channel emulator. This will be a very beneficial activity for both sides. EURECOM does not have access to such equipment in its 5G-EVE facility in Sophia Antipolis and the resulting collaboration will help improve the quality of the radio software immensely.

Figure 2: Remote PROPSIM Setup at University of North Carolina

2.4 Integration of InterDigital MHU mmWave radio-units in 5G-EVE (Sophia Antipolis), POWDER and COSMOS facilities

This activity was described in D3.2 [6]. In 2020-2021, new Version 1 units were shipped to EURECOM to be used at the 5G-EVE site in Sophia Antipolis. Version 3 units with enhancements will be supplied to 5G-EVE and INRIA R2LAB in Q2 2021 with enhanced functionality based on measurements with the V1 units. Interoperability testing with commercial mmwave UEs has been done and the OAI FR2 (millimetrewave) functionality is nearing maturity to be replicated in partner labs in the USA. The V3 units will also be shipped to POWDER and COSMOS facilities to replicate the experiments being performed in France.

3. Joint Demonstration Activities between ICT-17 and Linux Foundation Projects

3.1 Integration of 5G-EVE French Node and OPNFV VCO 3.0 Project

This activity was initially reported in D3.2 [6] and has continued in 2020-21. Its objective aims to provide common blueprints which can be used to deploy containerized versions of radio-access and core network software, including but not limited to OAI, Mosaic5G and Magma. To this end, EURECOM has been working since 2019 with RedHat and other partners in the context of the Linux Foundation OPNFV VCO (Virtual Central Office) project on providing multi-site testing of such deployment frameworks targeting Kubernetes / OpenShift clusters. The 5G-EVE site at EURECOM was the first to make use of this framework and similar sites in USA and Canada are using the VCO3 blueprints for deployment of telecom functions. The technologies are continually being extended to include support for orchestration and automation frameworks such as ONAP. In 2021, replication of architecture and network functions at North American sites took place at Kaloom (Canada/USA/EU) and other sites management by RedHat. This included replication of OAI core network components on similar infrastructure to 5G-EVE Sophia Antipolis at Kaloom's lab in Montreal. Kaloom has also provided their 5G User-Plane-Function (UPF) control software for P4 switches to 5G-EVE Sophia Antipolis site at EURECOM for deployment in early 2021. This will highlight 5G user-plane acceleration functions and provide demonstrations with Kaloom software in Q2 2021 in the context of 5G-EVE dissemination and Linux Foundation webinars. This will focus on the integration of industry-grade UPF equipment with the fully container-based 5G deployment framework of 5G-EVE Sophia Antipolis. Demonstrations for EU Industry partners (e.g. Orange) as well as in the context of Linux Foundation events are planned for Q3 2021.

Redhat (USA) has continued to support 5G-EVE Sophia Antipolis with its OpenShift Container Platform in order to continue joint proof-of-concept demonstration and integration with other 5G-EVE resources. In particular, the integration of ONAP-ready interfaces based on Helm charts [7] which was validated with the ONAP infrastructure in Paris provided by Orange Labs. Public documentation has been made available in [8]. The main dissemination objective is to show a joint demo with 5G-EVE and the Linux Networking Foundation before the end of the 5G-EVE project (Q2) 2021.

In a simpler vein, OAI also now provides fully open-source containerized deployment frameworks using docker-compose for both Ubuntu and RedHat based deployments of Docker or Podman containers. These are being used in conjunction PAWR for deployment on Colosseum, AERPAW and POWDER and R2LAB in France. OpenAirX-Labs now assists in maintaining the Docker-compose based deployment framework on the sites it manages in the USA. The simplified Docker deployment framework is documented in [9] [10] [11].

A few other initiatives related to replicating the VCO 3.0 infrastructure at EURECOM have been launched. Firstly, some discussions between EURECOM, Northeastern University and RedHat on replication of the VCO3 architecture on a similar OpenShift infrastructure being deployed at Northeastern in 2021 can be reported. This is an independent platform from the COLOSSEUM equipment.

3.1.1 Future Sophia Antipolis Node

Tight integration in terms of infrastructure enhancement and mutualisation of personnel and equipment between 5G-EVE Sophia Antipolis and evolution of INRIA R2LAB (see EMPOWER D3.1 [12]) under way for future EU projects. This will pave the way for the creation of a Sophia Antipolis Node using the OPNFV VCO3 blueprint coupled with the testing and experimentation methodologies of OAI and INRIA R2LAB and strong interconnections via RENATER/GEANT with similar sites in Europe.

3.2 Implementation of O-RAN interfaces (E2, O1) in OpenAirInterface (5G-EVE and PAWR POWDER-RENEW)

This activity was initially reported in D3.2 [6] and has continued in 2020-21. The initial integration work has been completed by POWDER teams and the resulting code is partly public [13] pending release of certain specifications by O-RAN Alliance. It will be integrated into the main OAI codebase. The development will be integrated with the publicly available O-RAN Near Real-Time RIC on 5G-EVE Facility in Sophia Antipolis for community testing and on the POWDER Facility. Interoperability testing in the context of the Affordable5G ICT-42 project [14] is expected in Q4 2021.

A call for collaboration in the OAI community was given to stimulate development of the O-RAN O1 interface in OpenAirInterface during the OAI online workshop co-organized with PAWR [15]. O1 is the interface between the Service Management and Orchestration Framework and Infrastructure Management Framework supporting O-RAN virtual network functions. This is similar to interfaces developed for OpenShift (K8S) in the context of the VCO3 project (see Section 3.1). This community effort will make use of infrastructure interconnections with ONAP clusters (e.g. Orange 5G-EVE ONAP cluster in Europe) and future O-RAN Testing and Innovation Centers. The basis will be the ONAP work carried out for the OPNFV VCO3 framework (Section 3.1) in the context of 5G-EVE. It is hoped that through the provisioning of E2 and O1 that joint use of 5G-EVE Sophia Antipolis and Paris will lead to use of 5G-EVE in O-RAN plugfests starting in Q4 2021.

3.3 Full Integration of OpenAirInterface MME with Magma Foundation MME

The MME is the key signaling entity in a 3GPP network allowing communication with commercial handsets and other user-equipment terminals. The MAGMA MME was forked from OAI in 2018 and both were developed mostly independently. MAGMA developments were focused on production-ready deployment commercial applications in rural markets and OAI developed new features, e.g. 3GPP Release-15 signaling for 5G non-standalone operation. In 2020, after an agreement on relicensing the MME, OAI and MAGMA joined forces on producing a common design used for both communities and distributed by the Magma Foundation which is now administered by the Linux Foundation and has Arm, Deutsche Telekom, Facebook, FreedomFi, Qualcomm, the Institute of Wireless Internet of Things at Northeastern University, the OpenAirInterface Software Alliance, and the Open Infrastructure Foundation (ex OpenStack) as founding members. Testing for the MME component is done jointly by EURECOM/OAI and Magma Foundation partners both on EURECOM's 5G-EVE site and Magma Foundation resources at Facebook and FreedomFi.

4. Joint Demonstration Activities in 2020

In this section we report on two explicit online demonstrations that occurred in 2020 highlighting a few of the activities reported earlier in this document.

4.1 OpenAirInterface5g 5G non-standalone demonstration at WINTECH 2020 (online)

This demonstration was the first occurrence of the OpenAirInterface 5G non-standalone implementation in a live demonstration setting. It took place online at the WINTECH 2020 workshop in conjunction with ACM MobiHoc. The demonstration showed the current implementation status of the OpenAirInterface (OAI) 5G non-standalone (NSA) system operating with a common-of-the-shelf (COTS) phone in the sub-6 GHz band. The radio access network (RAN) comprises an OAI eNB and a gNB, both running on general purpose x86 servers and USRP N310 software defined radios. Further we use the OAI evolved packet core (EPC) comprising home subscriber server (HSS), mobility management entity (MME), serving and packet data network gateway (S-PGW), which are all deployed in Docker containers. The demo highlighted the initial connection and user registration on the 4G cell, the secondary cell addition, the initial connection on the 5G cell and some initial traffic on the 5G cell.

4.2 Joint OpenAirInterface-Magma Foundation demonstration at Magma Developers Conference (online)

This was the first full demonstration of OAI RAN with the Magma MME for 5G non-standalone (NSA) operation since the OAI and Magma MME codebases were remerged. The event was held in February 2021 and is traditionally aimed at an extremely technical audience and focuses on innovations within the Magma community. The demonstration showed the current 5G OAI implementation running in a lab setting with simple USRP devices coupled with a fully-containerized core network components running on a bare-metal machine and including the Magma MME with OAI's 3GPP Release-15 extensions for 5G support. The presentation and demonstration are available online [16].

5. Joint Demonstration Activities in 2021

5.1 ONF Aether deployment at SU lab

This activity has just started and discussions are planned with ONF team related to deployments of Aether node(s) in lip6 which is the computer science laboratory of Sorbonne University. The Aether deployment at SU lab will act as seed for the development of SLICES (https://slices-ri.eu/).

6. Reference Architecture for Future Experimental Facilities

EMPOWER aims at the creation of a common space among the participating research infrastructures to construct and operate an effective and timely unified research Digital Sciences that will lead at a global scale research activity. Currently, the research facilities that are being operated across Europe and the US offer their standalone resources independently with no common substrate. Notwithstanding the efforts taken to enable federation among those facilities in the past, efficient organization and management of the individual resources and services to achieve high standards of performance hindered the potential to offer a fully unified research infrastructure that could integrate heterogeneous technologies, hardware, tools and equipment of the experimental facilities globally and offer them as a suite of services to multi-disciplinary research communities. Leveraging the legacy of the previous research projects where research activities towards unifying the research infrastructures were established, EMPOWER supports the definition of a future reference architecture that utilizes existing tools and facilities to build on top their set of services and bring new functionalities on the experimental based research, based on the most recent standardization activities and interface specifications for Network Functions Virtualization (NFV). Those new functionalities harmonically combine physical and virtual resources across European borders and expose them with the aid of specific APIs to the research communities.

Some of the highlights around which EMPOWER and EU Research Facilities will evolve in the initial years are summarized in the components below. These are envisioned as the key technologies that will rule the Digital Infrastructure experimentation landscape during the first decade of operation. The integrated facility is organised in hardware components, software components and sites deployments. The latter are selected based upon the existing platforms and the experience of the sites' local communities.

1) **Hardware architecture**
   a) *Multiple radio*: for supporting different types of wireless connectivity in licensed/unlicensed spectrum, with existing 5G/4G technologies or their evolution (6G and THz network operation)
   b) *Antennas*: for supporting a wide range of frequency spectrum, as well as beyond existing state-of-the-art applications for Massive MIMO.
   c) *User's equipment*: for supporting experimentation with the latest generation of wireless networks (e.g. 5G-NR and beyond). Bring-your-own-device (BYOD) cases where experimenters provide their own User Equipment in the facilities will be also supported. Forthcoming networking paradigms should also be supported, involving user equipment, such as edge computing, infrastructure-controlled proximity services and the like.
   d) *Special purpose processors* (GPU, FPGA, AI-dedicated processors): For facilitating the calculations of computationally intensive tasks. ASIC processors targeting especially Artificial Intelligence/Neural Networks will also be offered. Hardware offloading equipment, programmable in "universal" languages like P4, could be also considered in this category, with the aim of experimenting various methodologies for the reduction of energy consumption and boosting computational efficiency (e.g., for security-related functionalities and network functions).
   e) *NVRAM memory and in-memory devices*: for complementing the infrastructure and applications running over them with high-speed memory access.

f) *Traffic generation and monitoring equipment*: to allow distributed testing of network functionalities under various kinds of traffic loads and the accurate measurement of KPIs (including energy consumption ones).
g) High speed optical links: for connecting the infrastructure sites located at different places.

2) Software Architecture

a) *Experiment orchestration components:* for deploying experiments in an easy manner and benefiting from resource virtualization (supporting more users, energy savings).
b) *Experiment Support components:* for monitoring the status of the entire distributed infrastructure and managing the experiment and relevant data (e.g. visualization, etc.).
c) *Open APIs:* for enabling the extension of the basic architecture with new sites.
d) *Common development framework:* to manage computing, storage, network and IoT resources
e) *Security architecture and software*: to effectively manage network security in Cyber Physical and highly virtualized/softwarized networking environments and to support testing of security solutions against various attacks (e.g., implementing cyber-ranges).
f) Single web portal assigned to experimenter, which will allocate/reserve test resources, plan test scenario, execute at a requested time slot, save and share test results back to experimenter

3) Cloud, edge and compute support infrastructure

a) This is in order to support functions such as signal processing, controls and related computational, high performance and data intensive computations;
b) In addition, it provides the programmability framework for the experimenter, APIs, resource access, reservation and slicing and data storage.
c) The management part of the users, slices and experiments.

In the subsection below, we detail some of the advancements for the software-based architecture.

6.1 Future Software architecture

In order to keep up with the most recent trends in experimentation and resource orchestration, complying with the fully softwarized and cloud-native network operation, the respective frameworks shall be developed for ensuring seamless and easy access to the experimental resources. The different site facilities can be integrated in a single facility, adopting common tools for managing and orchestrating experiments over the infrastructure, as well as providing a single access and credentials to users. The reference architecture with respect to the tools used for its management, is described in Figure 3.

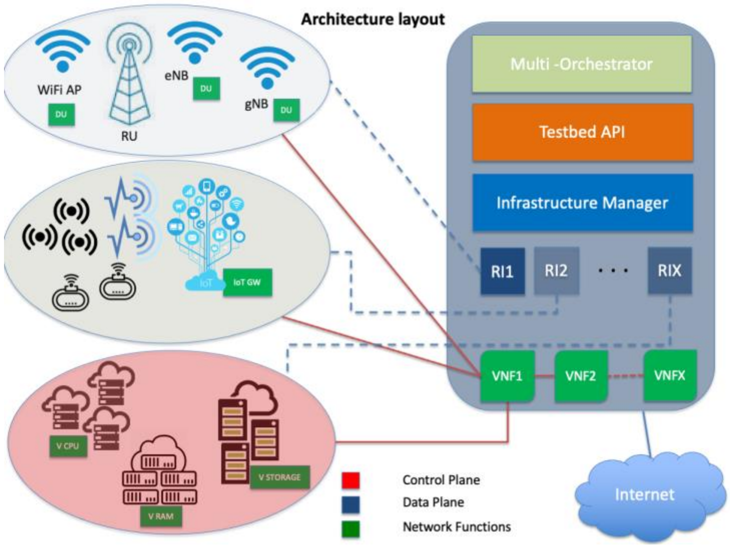

Figure 3 : EMPOWER Reference Architecture

Towards achieving this integration, the sites shall adopt network virtualization for their resources (for example, compatible with the ETSI Management and Orchestration (MANO) architecture[1] or the Kubernetes/Openshift paradigm) for managing and deploying new services over the physical equipment. Each testbed island can be considered as a single domain for experimentation, while the overall orchestration of experiments is performed through a centralized infrastructure. Site and node selection frameworks shall be developed, towards ensuring the optimal use of resources among the sites.

Moreover, and towards ensuring the smooth operation of the infrastructure, tools for facilitating access shall be developed and deployed. Open-source software shall be employed, based on the paradigms of existing testbed access schemes, user authentication and authorization. This software will be appropriately tailored with new modules for managing constant upgrades in the offered equipment.

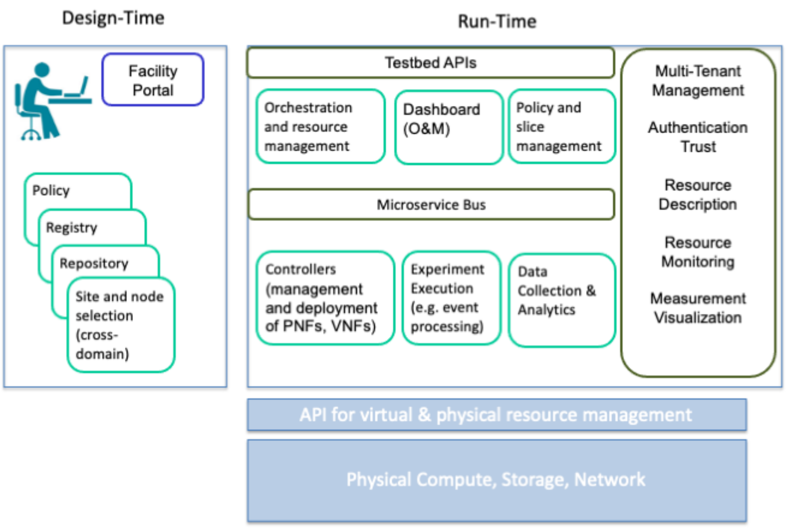

Figure 4: Software architecture and tools for experiment design and run-time

[1] Mijumbi, R., Serrat, J., Gorricho, J. L., Bouten, N., De Turck, F., & Boutaba, R. (2016). Network function virtualization: State-of-the-art and research challenges. IEEE Communications Surveys & Tutorials, 18(1), 236-262.

In terms of integration of the various components, the software tools shall encompass single-sign in procedures, with access certificates issued by a single authority. The resource discovery, reservation, and allocation shall comply with pre-defined access policies and be interchanged with the respective facility authorities through a standardized process. For this purpose, the SFA[2] protocol has been extensively used in past and present solutions and could inspire the candidate solutions together with new complementary or alternative solutions that will be considered as well.

Moreover, and towards realizing the full potential of the recent technology trends for network virtualization, facilities shall employ state-of-the-art resource management architectures, such as for example the Management and Orchestration (MANO) architecture for managing and deploying new services over the physical equipment. Through MANO, services and network elements are packed as Virtual Network Functions (VNFs) which can be instantiated over physical equipment; the same physical equipment can be used to execute different VNFs, whereas multiple VNFs can be instantiated over the same piece of hardware, thus allowing the equipment to be virtualized and shared among different operators (multi-tenancy). As the network infrastructure relies greatly on software, even for the RAN realization, the efficient and simple management and orchestration of these VNFs becomes of paramount importance.

Based on the automation tools complying with the MANO architecture (e.g. OpenSourceMANO[3], ONAP[4], or Kubernetes[5]), new experimenters can access a testbed/integrated specific store of experiments, in order to easily and readily deploy services over the infrastructure. This can be achieved with these frameworks by using pre-compiled versions of services, and by supporting different methods for virtualization of resources (e.g. Virtual Machines, docker containers, Linux Containers). For example, public docker repositories provide different images that can be used to deploy commonly used services (e.g. databases, web services, applications and application servers) through a friendly interface. One of the main capabilities of such a facility is its potential usage for supporting remote learning, enabling virtual labs based on advanced technologies that are barely available on site and therefore, contribute to education and developing skills in a very competitive environment. Moreover, the entire architecture can be augmented with the appropriate tools for experiment monitoring, experiment data and results visualization and cross-correlation analysis and inference with previous experiments executed over the infrastructure.

The low-level architecture for each site is shown in Figure 5. Each node can be connected over the Geant network, and/or through the Internet. Computational infrastructure shall be distributed, located at the central site of each node, supplemented with individual edge/core sites depending on the experimental equipment that they provide. Connections to the core datacentre for enabling acceleration of computational elements will be provided for all the nodes. Depending on the experiment type that is expected to be deployed, and the types of resources that will be used, the experiment will take advantage of either resource virtualization or metal-access to the resources. In the latter case, the appropriate APIs in the equipment will be developed in order to allow non-detrimental configuration that could stop the operation of the hardware (e.g. configuring an off-the-shelf AP to use more power than allowed in the area). In terms of wireless equipment, state-of-the-art equipment will be deployed, accompanied by the respective licenses for accessing spectrum in specific areas complying with local regulations.

[2] Peterson, L. (2010). Slice-based federation architecture. *http://groups.geni.net/geni/wiki/SliceFedArch*

[3] Komarek, A., Pavlik, J., Mercl, L., & Sobeslav, V. (2017). VNF Orchestration and Modeling with ETSI MANO Compliant Frameworks. In Internet of Things, Smart Spaces, and Next Generation Networks and Systems (pp. 121-131). Springer, Cham.

[4] Open Networking Automation Platform (ONAP), [Online] https://www.onap.org/

[5] Kubernetes, an open-source container-orchestration system, [Online] https://kubernetes.io

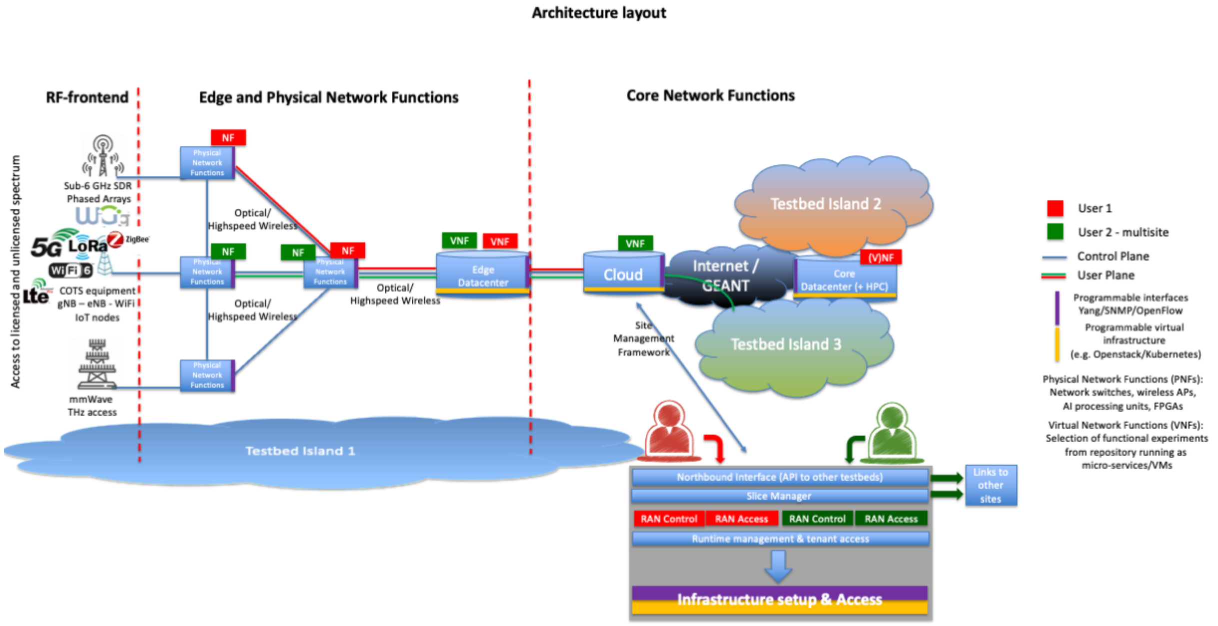

Figure 5: Low-level software architecture and tools

The overall architecture has been designed in order to allow experimentation with emerging and beyond-the-state-of-the-art algorithms, protocols and practices. Several scenarios can be enabled that can currently be deployed only by large industrial players. For example, deploying a continent wide 5G-network can currently only be achieved by mobile network operators. The figure below illustrates such an experiment, that considers the deployment of the core network in central Europe, managing base stations in south Europe, and being able to migrate their functionality either to other datacentres or at the edge site.

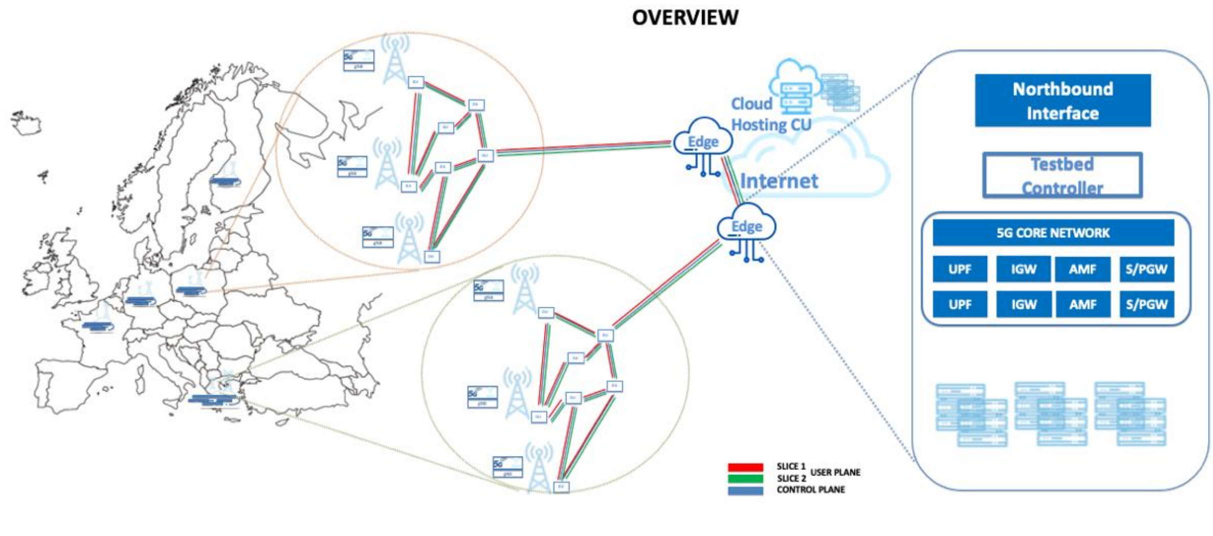

Figure 6: A use case that considers deployment of a 5G network spanning the entire continent

6.2 Design considerations for Future testbed infrastructure

The testbed architecture will follow MANO framework to manage the experimental resources (compute, memory, space, IOT devices, network, slices), lifecycle of the VNFs and network services. MANO includes the following components: the NFV orchestrator (NFVO), the VNF manager (VNFM), and the virtual infrastructure manager (VIM).

Open source software solutions shall be used for virtual infrastructure manager (e.g. Openstack), while Open Source Mano (OSM) to be used as VNF manager. VNF onboarding techniques shall be provided to the users to onboard their VNF's in testbed infrastructure.

Variety of use cases will be experimented including 5G/6G, AR/VR, IoT, SDN/NFV, V2X, AI/ML, edge networking. Requirements of some use cases are high-computing, some use case requires low-latency, some IoT use cases require high-coverage and density capabilities, while some use cases require combination of these requirements such as V2X and AR/VR. The architecture of future testbed should be designed considering all such requirements.

For low-latency use cases, 5G CN and RAN components are motivated to run as CNF's (instead of VMs) supported by Kubernetes directly on bare-metal. Open source projects are moving towards cloud-native design, but till then mix of VM's and CNF's could be adopted. For coverage and density use cases, network components can be configured as VNF's or CNF's, provided that these components can be scaled easily. Edge computing will have requirements for low-latency, cost-efficient infrastructure, secure with AI/ML capabilities.

For SDN/NFV and Cloud use cases, high performance VMs, containers and network functions are needed.

Openstack deployed to manage the hardware resources (CPU, RAM, disk) and VMs can be created hosting network elements required for experiments. For non-real-time requirements, containers can be deployed on VMs. For real-time requirements, containers can be deployed by Kubernetes hosted barre-metal servers.

a) ORAN support

The future testbed architecture should simulate an ORAN system and for a long run (beyond 5G or 6G). One option is to deploy ONF's Aether, it is a 5G connected edge cloud platform build with open source components. It provides mobile connectivity and edge cloud services for distributed enterprise networks as a cloud managed offering. As mentioned in ONF Aether deployment at SU lab, Aether nodes will be deployed in one or two sites and based on the experience the architecture can be enriched with ORAN support as well.

b) Portal design

The testbed architecture can have one UI portal to users (researchers) which can provide two different services:

1. Allows users to access services or design multi-domain services. This will allocate/reserve test resources, plan test scenario, execute at a requested time slot, save and share test results back to experimenter
2. Allows users to self-manage NFV artifacts and onboard them to a target MANO/NFV Orchestrator

NFV artifacts reside into a VNF/NSD catalog and are onboarded to a target MANO/NFV Orchestrator. Couple of trainings and demo can be organised in the form of documents, links and videos that can be beneficial to the researchers to use the Service portal, design experimental services and onboard NFV artifacts. The feasibility of the portal architecture will be further explored and the document will be updated accordingly.

6.3 Computational and service infrastructure

Last but not least, this is a key component for controlling and monitoring the resources, controlling the experiments, providing reproducibility and verifiability of the experimentation.

a) This is in order to support functions such as signal processing, controls and related high performance computational and data intensive operations;
b) In addition, it provides the programmability framework for the experimenter, APIs, resource access, reservation and slicing, data storage.
c) It will also deal with the data and reproducibility services, as described in the section below.

A significant component of the service infrastructure is related to the management part of the users, slices and experiments. A NOC (Network operation Center) shall aggregate and display all the information that will enable an automation of the experiment life-cycles as well as provide the full status of users, slices and resource consumption. The NOC functions will provide a support to the operation as well as the steering of the facility. It will be associated and under the control of a single governance.

The ***reference architecture provides the guidelines for the various components and their articulation*** and shall be constantly updated in order to provide a solid outcome about the solutions to be deployed in the long term during the construction as well as operation of the entire facility.

7. Conclusion

This report summarized all preparatory efforts carried out by EMPOWER to foster joint EU-US technology demonstrations in the second year and provided evidence of mutualisation of platform components and systems and in particular those aiming to link ICT-17 facilities and USA initiatives including PAWR facilities and Magma Foundation Projects. Some new concrete examples of collaboration with PAWR were detailed aiming to increase automatic test coverage of software components used in experimental wireless testbeds jointly using ICT-17 facilities and some of the PAWR nodes. The latter is a critical component to maximize usability of EU software components on both EU and USA platforms and to integrate USA development teams in EU-dominated software projects. Examples of integration of ICT-17 activities with Linux Foundation projects (OPNFV, ONAP and O-RAN) are also provided. Links to documentation for researchers to assist in the deployment of software components using containers both on bare-metal servers and Kubernetes clusters were documented. A few online demonstrations that occurred in 2020-21 were reported upon and corresponding links to online material were included. An overview of current efforts in EMPOWER towards establishing a reference architecture for federating and operating long-term trans-Atlantic wireless research facilities was outlined and can serve as a basis for future EU research infrastructure initiatives.

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