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Final Report on Joint Technology Demonstrations and Data Analysis

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Executive summary

This report summarizes all joint EU-US demonstration efforts carried out by EMPOWER's final year as well as new preparatory events to foster future joint EU-US technology demonstrations. We provide evidence of mutualization of platform components and systems and in particular those aiming to link ICT-17/19/42 facilities and USA initiatives including PAWR facilities and Magma Foundation Projects. Some new concrete examples of collaboration with PAWR are detailed and are 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 are also provided. Links to online and live demonstrations that occurred in 2021-22 are reported upon including links to corresponding online material. In particular, we note the 2022 demonstration at Mobile World Congress Barcelona which was an extremely high-profile event including contributions from both EURECOM and OpenAirX-Labs.

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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 D3.3 [1], the purpose of this deliverable is thus to report on the progress of these activities and others established since M28 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 facilitated engagements with several entities in the USA, in particular the PAWR facilities and associated testbeds, as well as Linux foundation MAGMA, OPNFV/Cloud-Native Networking Foundation projects, O-RAN and specific joint EU-PAWR integration activities (through OpenAirInterface and OpenairX-Labs described in D3.2 [1] with US industrial groups such as Xilinx and Nvidia) and finally with ONF. These collaboration aim firstly to reduce fragmentation by producing common software toolsets and coordinating joint development efforts.

We also aim to harmonize software deployment methodologies in order to join forces on testbed computing resource management. This objective ambitions at providing common blueprints that 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 target both Kubernetes-based and bare-metal computing clusters.

1.1 Overview of this document

At the end of EMPOWER (M42) we report in Section 2 on the continued steps that are being used to stimulate joint demonstration between EU facilities and the US National Science Foundation (NSF) Platform for Advanced Wireless Research Program (PAWR) facilities (POWDER-RENEW [2], AERPAW [3], and Colosseum [4]). These activities all involve joint development work between the EU and USA researchers to enable future joint demonstrations and experimentation.

In Section 3 we summarize the work carried out to coordinate the use of the EURECOM facility (derived from ICT-17 5G-EVE [5] and currently used in ICT-19 5G!DRONES [6], 5G-VICTORI [7], ICT-42 5G-RECORDS [8] and AFFORDABLE5G [4] in Linux Foundation projects. This is the consolidation of the site in Sophia Antipolis for use in future Linux Cloud-Native Networking Foundation (CNNF) projects and EU-based projects (e.g. SNS JU) and more general integration within the Linux Foundation.

2. Joint Demonstration Activities with PAWR

In this section we provide an overview of joint activities with OpenAirX-Labs partners to:

- share best practices in experimental 5G network deployment
- maximize reuse of existing software development efforts
- prepare joint experimentation activities
- Prepare joint demonstrations

2.1 Support for US demonstration activities with AERPAW and Colloseum

At the onset of the OpenAirX-Labs initiative in the USA the primary target was to empower the US teams in the Colloseum [2] site at Northeastern University and their colleagues at AERPAW [2] in North Carolina and Mississippi on replicating the 5G network deployment in Sophia Antipolis. The US colleagues are primarily interested in *full 5G standalone operation* including both infrastructure, core network and base station or gNodeB components and end-user terminals (or UE). For the terminal end both fully experimental software versions and commercial off-the-shelf (COTS) versions such as 5G IoT modules or smartphones. The experimental radios were all based on National Instruments USRPs (see D3.1 [2]), and particularly the X3x0 and N3x0 series devices (see D3.1 [2]). This entailed

- Creation of slack channels for information exchange between EU and USA engineers. These were carried out on the OAI Software Alliance Slack workspace (openairinterface.slack.com) where both dedicated channels for EMPOWER collaborations were created and more community-wide channels were used (e.g. 5g-end-to-end-testing - https://openairinterface.slack.com/archives/C01SDK6T8E4).
- Weekly zoom meetings were initiated which are still currently held on more direct interactions on the OAI 5G UE. In addition to EURECOM, OpenAirInterface Software Alliance and PAWR colleagues, these meetings were also attended by other institutions in the community involved in the development and testing of OAI (e.g., Fraunhofer IIS, Indian Institute of Science Bangalore, AllBeSmart Portugal, OpenCells France, EPISci Systems USA).
- Specific debugging sessions on PAWR hardware platform via remote access for EU Engineers was also occasionally required. Remote-access was provided for this purpose as described in D3.3 [1].

Two engineers were hired at Northeastern University for this activity and acted as a liaison with the OAI teams and others in the community. A former EURECOM research engineer later joined North Carolina State University to work on OpenAirX-Labs activities. Another current and one former EURECOM research engineers are expected to join the OpenAirX-labs team at Northeastern University later in 2022.

2.2 Support for Time-Division Duplex (TDD) deployment of OpenAirInterface at POWDER

POWDER was supported more directly on a particular configuration of OAI 4G on their outdoor network installation. The POWDER site was obliged to align its transmissions temporally with local incumbants sharing the same 2.6 GHz band in Utah, albeit on different frequency channels. The required TDD configuration 2 had not previously been tested in the Sophia Antipolis 5G-EVE site. This testing and additional modifications in the OAI codebase were carried out in support of the US partners and the changes were up streamed.

2.3 Tutorial using Colosseum site during OAI Fall workshop 2021

During the OAI fall workshop (Dec. 8-12, 2021) which was held online and co-organised with the PAWR office, a live tutorial was prepared in collaboration with the OAX-labs team at Northeastern university and included

- An overview of Colosseum for experimenting and testing with OpenAirInterface 5g RAN and Core
- A throughput demonstration for 5G standalone
- A multiple UE connection
- The continuous integration (CI) setup (as described in D3.3 [1])

- A demo of the CI framework running on Colosseum

The live tutorial can be viewed on YouTube here: https://www.youtube.com/watch?v=w0ZrIdeOD1M. The PDF version of the slides used in the tutorial are online here: https://openairinterface.org/wp-content/uploads/2021/12/Lab-4-OAI-SA-Mode-CI-OAXLabs.pdf.

2.4 Tutorial using POWDER site during OAI Fall workshop 2021

A similar tutorial to the one described in Section 2.3 was given at the same workshop with a different scenario using the POWDER platform in Utah. This tutorial provides a beginner's perspective of the usage of the OAI profiles on POWDER and showed how to deploy and test and end-to-end simulated 5G system including radio-access network and core network components. The tutorial can be viewed here: https://www.youtube.com/watch?v=ZrYQiCRjItU&t=2s and the pdf version of the slides used are here : https://openairinterface.org/wp-content/uploads/2021/12/RAN-LAB1-Presentation-1.pdf.

2.5 Joint presentation and Demonstration at National Instruments RF Round Table

National Instruments is the provider of high-end software-defined radios (USRP SDR, see [2]) for use in advanced wireless research. They work closely with the OAI Software Alliance and PAWR/OpenAir-X labs to optimize the functioning of their devices with OpenAirInterface software packages. To this end, they organized a seminar for next-generation SDR research entitled "What's Next in SDR Research" which was held online on Nov.3 2021 for EU and US research labs. NI asked EURECOM and OpenAir-X labs to present their current 5G radio-access offering in this seminar. The program can be found here:

https://events.ni.com/profile/form/index.cfm?PKformID=0x516554abcd

The seminar included an overview of using OAI on the ICT-17 site in Sophia Antipolis and the PAWR site at Colosseum, and more general information about other US sites. A live demonstration of 5G NR standalone operation using N310-series USRPs was provided to the audience.

2.6 Joint preparation of two MWC demonstrations in 2021-22

Through the partnership of AMD (Xilinx) in the OAI Software Alliance, a joint-activity with OAX-Labs was setup to integrate a Xilinx hardware accelerator card with the OAI 5G basestation implementation. The purpose was to show the benefits of hardware offload of critical baseband processing, in this case low-density parity-check code decoding using the Xilinx RFSoC on their T1 telco card. The first demonstration occurred Los Angeles October 26-28 at the Institute for the Wireless Internet of Things (W-IoT) Booth 1444.

The first video showed an end-to-end deployment of OpenAirInterface (OAI) 5G Standalone network over Colosseum is one of these demos. The demo uses OAI 5G soft gNodeB, OAI 5G soft UE, and Docker-based deployment of OAI 5G Core Network. The video shows the configuration and demo of OAI UE successfully registering with the OAI 5G CN, establishing a PDU session, and exchanging ping and dataplane traffic.

A second video showed a full stack demo of an OpenAirInterface cloud native 5G New Radio Standalone deployment on general purpose computing equipment and the Xilinx T1 accelerator card, which was used to offload the channel decoding. This architecture improves performance and energy efficiency in such deployments. The setup further uses a USRP N310 as a radio unit and a commercial UE from Quectel, allowing for an end-to-end demonstration of the offloading capabilities of the T1 card.

The second video shown at MWC Americas can be viewed here: https://openairinterface.org/news/osa-demos-at-the-mwc-americas/

The second demonstration was exhibited at the Mobile World Congress (MWC) in Barcelona from 28th Feb. to 3rd Mar. 2022 at the AMD, Inc. Booth 2M61 in Hall 2. This was an improved version of the one shown in Los Angeles although live. A filmed version of the onsite demonstration is available here: https://vimeo.com/691056290 (with password MWC_2022). A photograph of the demonstration is shown in Figure 1.

Figure 1: Photograph of the MWC 2022 live demonstration at the AMD-Xilinx stand (from left to right I. Ghauri OAI, R. Rao Xilinx-AMD, S. Rahman Meta, H. Wang OAI, R. Knopp EURECOM, L. Pereira Albesmart Portugal. Photograph taken by A. Gosain, Northeastern Univ/OpenAirX-Labs)

In addition to the demonstration, a panel organized by AMD-Xilinx including both EU (R. Knopp EURECOM/OAI) and USA (Abhimanyu Gosain, Northeastern/OAX-Labs) members of OpenAirInterface illustrated the benefits of the experimental solutions on display and the collaboration effort between EU-USA academia and major industry. A link to the panel overview can be found here: https://www.mwcbarcelona.com/agenda/session/5g-leadership-with-technology-and-solutions. A picture of the panel is shown in Figure 2.

Figure 2: Picture from MWC 2022 (A. Gosain, 2nd from left, R. Knopp 3rd from left, moderator R. Rao Xilinx-AMD)

2.7 NVidia Aerial Platform Integration Effort

In late 2021, a three-way collaboration between EURECOM, OpenairX-labs and NVidia was launched in order to introduce the NVidia Aerial GPU platform [3] for virtualized radio-access network functions (vRAN) into the ICT-17 site at EURECOM and Colosseum [4] at Northeastern. Aerial is a GPU-based implementation of 3GPP 5G NR radio-access on high-end NVidia GPUs. It runs inside an Intel x86-64 server for higher-layer integration. NVidia sees the combination of the OAI layer 2 protocols and core network as a means to introduce the Aerial-SDK to research labs to promote the use of GPU technology for advanced wireless research. NVidia provided a full platform consisting of two services equipped with their high-end GPU platforms and the Aerial-SDK to EURECOM's ICT-17 site and Colosseum in addition to FoxConn O-RAN compliant O-RU. The integration is currently underway and should be completed during the summer of 2022. The resulting platform will be made available to other research organizations in EU and USA. The project should be extended to include National Instruments who is planning to provide O-RAN compliant O-RU functionality in their USRP X410 in 2022. This will facilitate adoption in academic research labs. A further extension will be to use additional GPUs for Artificial-Intelligence / Machine-Learning algorithms at the edge, and in particular to support O-RAN edge applications.

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

This section provides links to ongoing collaboration efforts between the ICT-17 site in Sophia Antipolis and Linux Foundation projects, in particular the Cloud-Native Networking Foundation and the Magma foundation. It also includes some information regarding the upgrade of the Sophia Antipolis site for use in these initiatives.

3.1 Upgrade of 5G-EVE infrastructure in Sophia Antipolis for CNNF Proof-Of-Concept Demonstrators

Work with RedHat (USA and Germany) on upgrading the infrastructure in Sophia Antipolis was carried out in 2021-22. The main objectives of this upgrade were to

1. align the infrastructure with running Linux Foundation projects in the Cloud-Native Networking Foundation in which RedHat plays a key role. This was meant to continue the work started in the context of the OPNFV VCO3 project (see [3]).
2. to allow for collaboration with other EU sites using RedHat's OpenShift Technology (e.g., the 5G-VINNI [2] site at Telenor).

The new infrastructure is being used to allow for collaboration with Linux foundation projects in the context of running H2020 5GPPP projects and future SNS JU Stream C/D projects.

3.2 Linux Open-Source Software Summit Seminar and Demonstration (online)

EURECOM presented an overview of the use of open-source software for performance evaluation of cloud-native telecommunication network functions at the Linux Open-Source Summit. This was done jointly with Qualcomm and Northeastern University. The main objective of the presentation was to provide an overview of the objectives of the OpenAirInterface software alliance's open-source offering targeting telecommunication networks and in particular the collaboration model. The cloud-native focus of the current implementation was described as a reference software architecture and implementation for performance evaluation. The presentation included a live demonstration of a full 5G network deployment running on the 5G-EVE site in Sophia Antipolis and provided links with the other open-source initiatives within the Linux Foundation.

An overview of the seminar can be found here: https://osselc21.sched.com/event/meXu/virtual-an-account-of-openairinterfaces-open-software-in-5g-ran-core-network-and-mosaic5g-raymond-knop-openairinterface-software-alliance-osa.

4. Collaboration Activities with ONF

Both Sorbonne and EURECOM officially joined ONF (Open Network Foundation) in 2021 in order to foster collaboration between their lab platform activities. ONF and the OAI software alliance have also engaged in a strategic collaboration agreement to ensure interoperability between their respective solutions for 5G network prototyping. To this end, in order to prepare future activities Sorbonne has engaged in deploying ONF Aether and SD-RAN solutions in their infrastructure in Paris and EURECOM has similarly started deploying SD-Fabric and the ONF UPF function. We report here on these collaboration activities.

Aether is an open source 5G Connected Edge platform, optimized for multi-cloud deployments that provides mobile connectivity and edge cloud services for distributed enterprise networks. Aether integrates several ONF based solutions, including SD-RAN, ONOS, CORD and OMEC, to provide a fully-fledge solution for the deployment of the cellular network in an end-to-end manner. It combines three main components, a control and orchestration interface for the RAN, an edge cloud platform, and a central orchestration and management cloud.

4.1 Sorbonne University usage of ONF open-source cloud technologies

As part of the collaboration between Sorbonne University and ONF, this section describes the setup that was followed to successfully deploy the 5G experimentation platform Aether and the capabilities that result from using it. SU has been working with ONF to deploy a ONF Aether Node in its facility in Paris. The main objective is to explore the capabilities of the platform and to study the features it could eventually bring to the researchers. SU has been working on deploying the central cloud for the orchestration and management, as well as the edge services. SU has also acquired equipment (small cells) for the deployment of the radio part and in particular end-to-end testing.

In order to deploy a cloud-native network, various open-source, cloud technologies were used. OpenStack was used to create isolated virtual instances on Sorbonne site servers. This allows multiple scalable deployments to be distributed that can be managed under the OpenStack platform. In addition, for the easiest life-cycle management of the network functions of an end-to-end network, the Kubernetes container orchestrator was utilized. With Kubernetes, it is effortless to deploy the network functions mainly of the core network and monitoring solutions can be easily integrated for their proper operation. In addition, for the easiest life-cycle management of the network functions of an end-to-end network, the Kubernetes container orchestrator was utilized. With Kubernetes, it is effortless to deploy the network functions mainly of the core network and monitoring solutions can be easily integrated for their proper operation. Such technologies used are Prometheus which exports metrics from network functions and Grafana which displays them in graph dashboards.

4.2 Aether – All in a Box Deployment

Aether provides documentation for an end-to-end 4G network deployment on real hardware devices: Aether-in-a-Box on Hardware Radios. More information can be found here:

https://docs.aetherproject.org/master/developer/aiabhw.html

The Core network can be installed in a single-click fashion through the Kubernetes framework, after first making some configurations in the MCC MNC through configuration YAML files. The Aether ROC provides a GUI and API for dynamically configuring Aether. So, one can easily add IMSIs to the network. Also, through the web interface it is possible to manage the slices between the UE of the network (Provisioning a new Slice, Editing and Deleting a slice) as well as to define QoS at three levels: Per-Device-Per-Application, Per-Device and Per-Slice. The AiaB deployment is installed on Ubuntu 18.04 Bionic Server Cloud VM managed by OpenStack.

For the connectivity between the Core and the RAN network, it is necessary to have the appropriate hardware. Necessary hardware requirements are to have one available 4G or 5G small cell eNodeB. In our setup, Sercomm CBRS LTE small cell eNodeB (3920 Firmware version) was used. Sercomm Cell provides an easy-to-use web interface through which one can configure the Cell in the corresponding Core Network (PLMN) configurations.

The eNodeB can be connected to the server over the local network. Also, through some custom Prometheus / Grafana Dashboards the AiaB is easily monitored. The status of Core and RAN as well as the throughput between the subscribed UEs can be easily monitored.

This setup is the beginning of experimentation on the ONF's SD-RAN project which is building open-source components for open RAN, complementing the O-RAN Alliance's focus on architecture and interfaces by building and trialing O-RAN compliant open-source components. SD-RAN fosters true multi-vendor RAN solutions, demonstrating what is possible by mixing-and-matching RAN components and helping to invigorate innovation across the RAN ecosystem as shown in Figure 3.

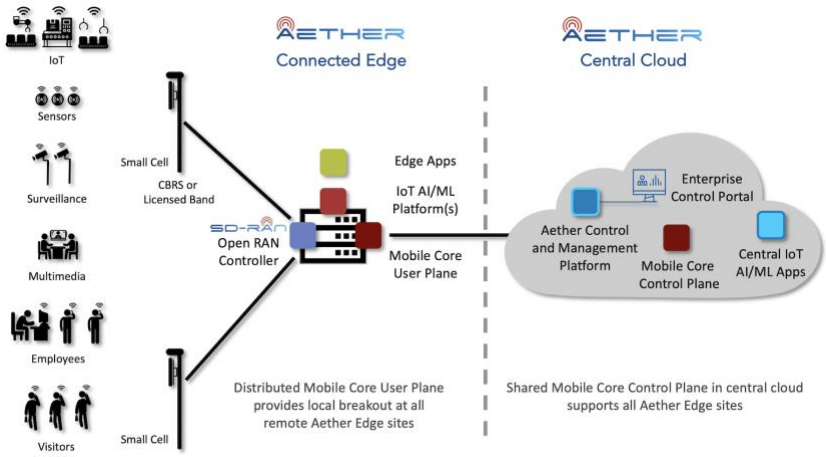

Figure 3: SD-RAN Architecture

4.3 ONF-EURECOM/OAI Activities

EURECOM's main objectives are firstly to deploy the ONF SD-Fabric on its infrastructure to innovate in the area of reconfigurable edge networking paradigms, in particular to address Public-Private breakout networks. The latter is particularly important in many of its 5GPPP projects in support of integration of new vertical use-cases. Due to the underlying P4 chipsets in the target switches which is exploitable for these purposes, the ONF SD-Fabric is an extremely versatile way to configure whitebox switches for edge networking. EURECOM currently uses less configurable switching fabric for its operational production network and will use a second interconnected fabric for experimentation in breakout scenarios.

The second objective is to deploy the ONF 5G UPF function on one of the P4 Edgecore switches at EURECOM used for SD-Fabric. This is an implementation that was open-sourced recently based on the work reported in [10]. It is an explicit collaboration effort between the OAI and ONF community to ensure interoperability between the ONF P4 UPF and the OAI 5GC.

More generally, OAI has been working with ONF in recent years at providing interfaces/interoperability between ONF network functions and OAI network functions. A previous example was collaboration on the E2 interface. An initial version of a RIC-agent implementing the O-RAN E2 interface by the University of Utah (POWDER-RENEW) allowed interconnection between ONF SD-RAN and the OAI eNB via the E2 interface. The ONF fork of OAI with the RIC agent that is interoperable with ONOS ONOS/SD-RAN can be found here [11]. OAI is currently building upon this to add to the current 5G standalone implementation (see [9]).

5. OpenSourceMano-OpenAirInterface Hackfest

An online Hackfest was co-organized by ETSI and EURECOM/OAI September 13-17, 2001. The hackfest was dedicated to OAI 5G Core Network Functions packaging and onboarding to OSM Release TEN bringing yet a new challenge to OSM and OAI users and developers. The online information about this event can be found here: https://osm.etsi.org/wikipub/index.php/OSM-MR11_Hackfest.

During the Hackfest kick-off, an overview of the OSM NF Onboarding in Guidelines was provided by OSM community experts. Participants were then organized in teams to collaborate on the onboarding tasks. Through the Hackfest week and with the mentoring of OSM and OAI community experts, they were challenged to build the packages, including NFV standardized descriptors, instantiation on Day-1, and on Day-2 operations, and bringup of a functional 5G Core. On the last day, each team had the opportunity to demonstrate their achievements and an award was given to the best onboarding demonstration.

The considered OAI 5G Core network functions were

- Access and Mobility Management Function (AMF)
- Session Management Function (SMF)
- User Plane Function (UPF)
- Network Repository Function (NRF)
- Deployment of OAI 5G Core network functions

The target attendees included:

- Network Function vendors, who wanted to learn to onboard their NF in OSM following best practices
- System Integrators, who wanted to develop their expertise with OSM and OAI
- Service Providers, who wanted to get a first-hand operational experience with OSM and OAI
- Students and Researchers, who are using or considering OSM and OAI for their research activities in networking
- OSM users and developers willing to share, learn and test with the community

Figure 4: Screenshot of OSM-OAI Hackfest

6. Conclusion

This report summarized all joint EU-US demonstration efforts carried out by EMPOWER's final year as well as some new preparatory events to foster future joint EU-US technology demonstrations. We provided evidence of mutualisation of platform components and systems and in particular those aiming to link ICT-17/19/42 facilities and USA initiatives including PAWR facilities and Magma Foundation Projects. Some new concrete examples of collaboration with PAWR were detailed and are 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 are also provided. Links to online and live demonstrations that occurred in 2021-22 were reported upon and corresponding links to online material were included. In particular, we note the 2022 demonstration at Mobile World Congress Barcelona which was an extremely high-profile event including contributions from both EURECOM and OpenAirX-Labs.

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