HORIZON 2020

ICT - Information and Communication Technologies

Deliverable D3.2
First 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 first year and provides evidence of early mutualisation of platform components and systems and in particular those link ICT-17 and PAWR facilities. Two examples of integration of ICT-17 activities with Linux Foundation projects (OPNFV and O-RAN) are also provided.

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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. The purpose of this deliverable is thus to report on these activities, including preparation of joint demonstration activities, actual demonstrations and later data analysis efforts resulting from joint proof-of-concept demonstrations.

At this stage of EMPOWER (M12) we report in Section 2 on the preparatory steps that are being used to stimulate joint demonstration between ICT-17 project facilities (5G-EVE [1], 5G-VINNI [2] and 5GENESIS [3]) and the United States of America *National Science Foundation (NSF) Platform for Advanced Wireless Research Program (PAWR)* facilities (COSMOS [4], POWDER-RENEW [5]). Another initiative linking ICT-17 to the Arena platform at Northeastern University is also described. These activities all involve joint development work between the EU and USA researchers to enable future joint demonstrations and experimentation. One further initiative introduces hardware provided by an industrial partner, InterDigital, into both PAWR and ICT-17 facilities and integrates it with the 5G software packages maintained by the EU OpenAirInterface [6] initiative.

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 [7] [8]. This is a beneficial arrangement both for the Sophia Antipolis site and for the OPNFV community. For 5G-EVE it benefits from support and use of a commercial Redhat enterprise container framework (OpenShift 4.2 [9]) which is used to build the virtual infrastructure of the site. For OPNFV, the site is used to demonstrate innovations in network function virtualization applications in 5G infrastructure. Furthermore, it will allow the community to evaluate the efficiency of cutting-edge tools for the stringent processing constraints of 5G.

The second example initiates the collaboration between 5G-EVE and POWDER teams aiming to contribute to the O-RAN Alliance [6] 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.

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)

NETCONF is a well-known and heavily used network management interface and protocol which allows remote interrogation, configuration and operational management of networking and telecommunications equipment. It is typically combined with the *Yet Another Next Generation (YANG)* data modelling language allowing for automated and programmable network operations. Today, in the OpenAirInterface RAN and Core Network components, support for configuration is purely static via configuration files passed by the user at runtime. In order to allow proper deployment of OAI for larger networks comprising

a) data-centre deployment of core network and multiple RAN entities, and
b) citywide deployment of RAN radio entities, as is the case for PAWR and ICT-17 platforms

centralized network management is clearly a desirable feature. The COSMOS project is proposing to add such functionality to OAI software entities in order to provide a higher degree of scalability for their experimental activities. The choice of a NETCONF-YANG based system also addresses simpler integration into an ONAP framework. This is necessary for both the objectives of COSMOS which acts as a hosting site for ONAP integration and testing, as well as the French 5G-EVE ICT-17 Node which uses ONAP as an orchestrator for the collection of the French sites (see Section 3.1).

Within the OAI community, Nokia Bell Labs in Paris leads the configuration management activity and will provide assistance via the OAI communication channels (*slack* [11], weekly web conference developer meetings) to COSMOS and EURECOM for the integration of NETCONF-YANG.

2.1.1 Integration plan

An initial physical meeting early October 2019 between EURECOM and COSMOS established the grounds for this collaboration. Later in the month a web conference meeting between EURECOM, COSMOS and Nokia Bell Labs identified the short-term objectives of integrating the open-source *netopeer2* implementation with OAI and providing the following in a first instance

a) An interrogation mechanism to allow a central entity to discover OAI entities and their capabilities
b) a translator from NETCONF-YANG configuration to OAI *libconfig* configuration using a minimal set of configurable parameters. This should be harmonized with the current Kubernetes dynamic configuration descriptions [8]

These short—term objectives are to be achieved by early December, prior to the next ONAP integration meeting hosted by Winlab. In a second instance COSMOS and EURECOM will aim to add the NETCONF-YANG functionality to the OAI configuration module developed by Nokia Bell Labs in the form of a configuration source alongside the static configuration file and command-line arguments.

Finally, effort will focus on operational control of the OAI components using NETCONF-YANG.

2.2 Continuous Deployment of OpenAirInterface RAN and Core Network Components (ICT-17 5G-EVE, COSMOS and POWDER-RENEW)

OAI currently provides a so-called *continuous integration* (CI) community service based on a *git* [9] and *Jenkins* [10] collaborative testing framework for developers as shown in Figure 1. Git is the *de facto* standard version control system for collaborative development and Jenkins is a free and open-source automation server. Users request modifications to the source-code repositories via *gitlab* (RAN) or *github* (Core Network) in the form of merge requests. These requests are served by Jenkins and trigger a set of tests at EURECOM including unitary simulations, static code anaylsis, functional simulation and real-time execution with commercial physical and real-time devices (core network components, off-the-shelf user equipment, etc.). These tests ensure the functionality and integrity of the software components on the test environment which is somewhat ideal, but quite exhaustive. Merge requests that are deemed to pass the tests are merged regularly into the OAI codebase, although not automatically the same day.

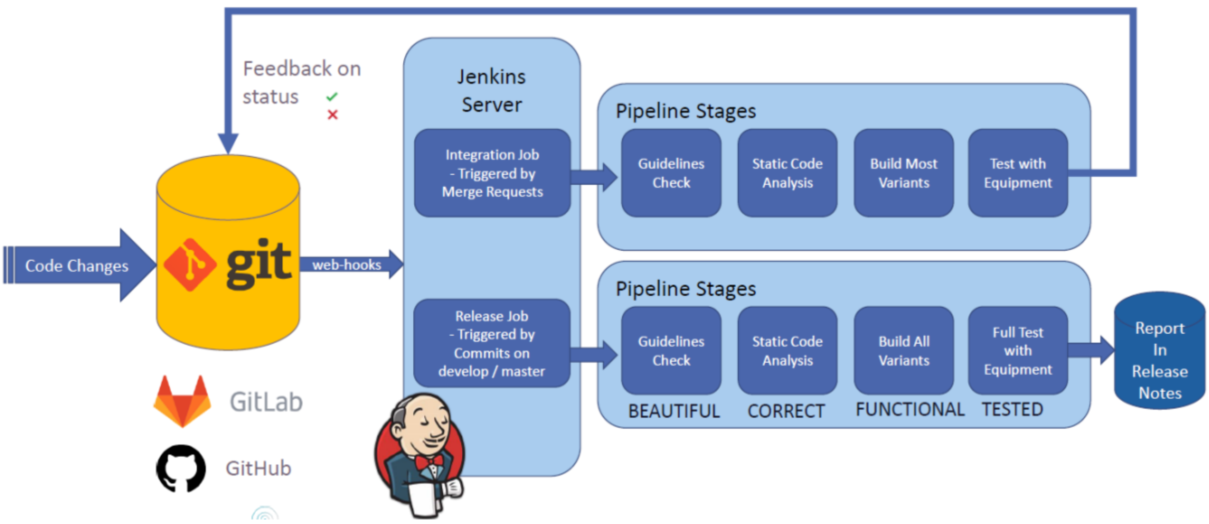

Figure 1 – Current OAI CI Framework based on *git* and *Jenkins*

In addition to the CI at EURECOM, OAI now provides a continuous deployment (or delivery) service making use of a network in France called R2LAB (https://r2lab.inria.fr) at INRIA, Sophia Antipolis which is part of the ONELAB Experimental Facility (https://onelab.eu/). R2LAB provides an anechoic chamber with radio nodes and computing equipment which can be controlled and configured remotely with several software radio configurations in order to perform experiments. This system is reservation based and as such is not suitable for CI. It is however suitable for longer stress testing and testing the deployment of updated software images. OAI is one of the tools provided by R2LAB for its users. In order to support this use case, OAI has configured its Jenkins server to run weekly tests on R2LAB to ensure the proper functioning of its software components on the facility. Users can then be sure the latest version of the software will function on the facility. Versions passing the tests on a particular facility are tagged for users.

Similarly to R2LAB, the COSMOS and POWDER-RENEW platforms are used with OAI for experiments and it is necessary to establish similar testing procedures to ensure that the software components function correctly for the users of these facilities. This will facilitate research with these platforms since the software is continuously tested on the facility. The added benefit for the OAI community is that the PAWR facilities include outdoor and mobile deployment scenarios and are ideal for performing tests that are not covered by R2LAB or by the EURECOM CI framework. The ICT-17 5G-EVE sites will also be used in a similar fashion in 2020. EURECOM has proposed to the PAWR facilities to extend the framework used on R2LAB on their sites and to define new testing procedures to be deployed on the outdoor scenarios. Once the basic framework is in place, it is hoped that the facility owners will assist in the development of the testing procedures and extend the tests to cover the scenarios of their users more completely.

2.2.1 Integration plan

EURECOM will begin porting the OAI automated CD framework to COSMOS and POWDER-RENEW in 2020. It will start by replicating the indoor setting from R2LAB. Once in place, it will work with COSMOS and POWDER-RENEW on defining test cases for the outdoor scenarios and, in particular, the possibility of using mobile scenarios. This will be done in parallel to the European activity carried out in the context 5G-EVE. Because of the large number of nodes in the three facilities, it will allow the OAI development community to improve the scalability of software to accommodate larger networks. This is also directly related to the joint development effort to be carried out with COSMOS as described in Section 2.1.

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

Due to the cost of basic components, millimeter wave radio units with digitally controllable phased-arrays are still difficult to come by for experimental purposes. Only a handful of companies provide the basic components off-the-shelf to build demonstrators combining laboratory equipment (e.g. National Instruments USRPs) and available software-radio packages such as GNU-Radio [1], OAI [2] , srsLTE [12] or openLTE [3]. Moreover these basic components have to be integrated with a digital baseband system and be properly calibrated. InterDigital has manufactured such milimeter-wave radio units for their own internal prototyping needs. They refer to these units as MHU. The MHU convert from an intermediate frequency between 5 and 6 GHz to 26-28 GHz. Moreover, they are integrated with a 64-element antenna array with a discrete number of digitally-controllable beams.

Interdigital has reached-out to the OAI community and PAWR to consider the integration of their MHU with OAI 5G NR software. This solution makes use of both off-the-shelf USRPs (N3x0 series) and potentially InterDigital's hardware MODEM solution for baseband processing. The proposed software-based prototyping solution for deployment is shown in Figure 2. In this example, two MHU are connected to a National Instruments N320 device which provides two RF chains and the necessary digital control outputs to control the beam-stearing of the MHU. This combination would allow for two spatial streams either to a single user-equipment device or two distinct user-equipment devices. The MHU provide an equivalent isotropic radiated power of 20 watts, which is sufficient for outdoor field-trials. The new generation device will provide even more output power.

2.3.1 Objectives of this collaboration

The objective of this collaboration is to allow InterDigital to promote their intellectual property using an OAI-based demonstrator at venues such as the Mobile World Congress. The units will be made available to the PAWR sites since InterDigital is an industrial member of PAWR. The EURECOM ICT-17 site will also benefit from some of the MHU in order to be used for outdoor and indoor field trials at millimetre wave frequencies. It Is expected to be able to use these devices with OAI in the range 26-29 GHz with commercial 5G NR terminals in early 2020. The equipment covers both the American NR band (n261) and European NR band (n258). Through EURECOM's collaboration with Orange, 5G NR pre-commercial terminal equipment operating in both the EU and USA millimetre-wave bands was procured for experimentation. We detail the integration steps in the following subsection.

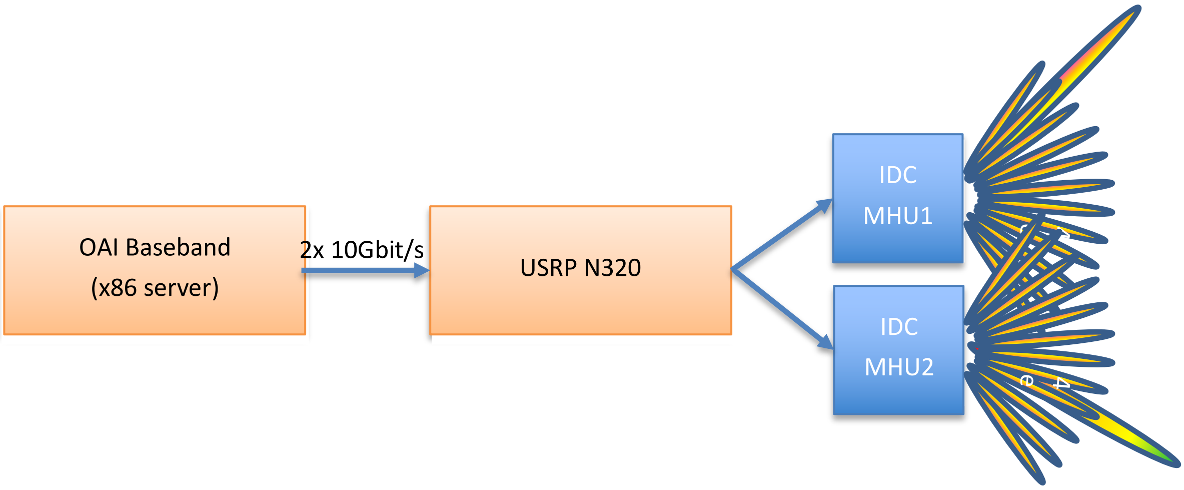

Figure 2 – Integration of InterDigital MHU and OAI Baseband

2.3.2 Integration plan

A physical meeting between EURECOM, PAWR, COSMOS and InterDigital took place at the recent IEEE Future Networks Workshop on 5G Technologies for Tactical and First Responder Networks (Oct 7 2019) to plan the integration. As a result of this meeting, EURECOM will host a team of InterDigital engineers from the USA, Canada and France from 11-15 November 2019 in order to perform the physical integration of the MHU with OpenAirInterface 5GNR implementation. During the months of December and January interoperability testing with a pre-commercial 5G smartphone (manufactured by Sony) will take place in order to prepare a demonstration at the upcoming Mobile World Congress in Barcelona, Feb. 24-27 2020. After this initial demonstration, InterDigital will refabricate new devices for PAWR and EURECOM in order to be used by the respective communities for experimentation and technology demonstrations.

2.4 Intercontinental Slice

Within the 5G-VINNI project and as a cooperation between UC3M, IMDEA Networks and the Institute for the Wireless Internet of Things, Northeastern University, in order to validate the possibility of creating an intercontinental slice. This slice will be used to connect the Northeastern University Arena platform to a 5G Core located in the 5G-VINNI laboratory located in 5TONIC, Madrid.

The Arena platform is a 64-antenna SDR-based Ceiling Grid Testbed for Sub-6 GHz Radio Spectrum Research, which offers SDR capabilities for researches interested in the sub-6GHz band, complementing in this way the PAWR platforms, more focused in the mmWave spectrum band.

Currently, the involved researchers are studying the characteristics of the links that can be used to interconnect both platforms, in order to obtain a view on the mechanisms to be put in place to ensure a good quality of the connection. Next steps will be to configure and validate the attachment of UEs located in USA to the 5G-CORE located in Spain.

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

The objective of this activity is to make use of the 5G-EVE French Node infrastructure in the context of the OPNFV [1] VCO 3.0 (Virtual Central Office 3.0 [2]) project. This project is managed by the Linux Networking Foundation and technically by RedHat in North Carolina. The main venues for demonstration are the Open Networking Summit (ONS North America[3] and ONS Europe [4]) as well as Kubecon (North America [18], Europe [19]). With the help of EMPOWER, EURECOM is acting as liaison for 5G-EVE in the context of VCO 3.0 and the site in Sophia Antipolis has be chosen as the European test site for the project. It constitutes one of the experimental sites for deployment of RedHat's container-based tools such as *OpenShift.*

We provide here an overview of the components used in this collaboration and the main technical objectives that are being demonstrated in the context of the Linux Foundation events.

3.1.1 Overview of 5G-EVE French Node

A high-level pictorial view of the 5G-EVE infrastructure in France is shown in Figure 3. It consists of four physical infrastructure sites : Paris-Chatillon/Warsaw (Orange), Paris-Nozay (Nokia), Sophia Antipolis (EURECOM) and Rennes (B-COM). The site in Paris is central in the sense that it serves as the gateway to the overall 5G-EVE infrastructure and provides interfaces to main experimental portal of 5G-EVE. It also includes the orchestration infrastructure nodes which control the collection of French sites based on the Open Network Automation Platform [7] (ONAP) orchestration system. ONAP is developed in a community fashion in the context of another major open-source project run by the Linux Foundation. ONAP provides a comprehensive platform for real-time, policy-driven orchestration and automation of physical and virtual network functions.

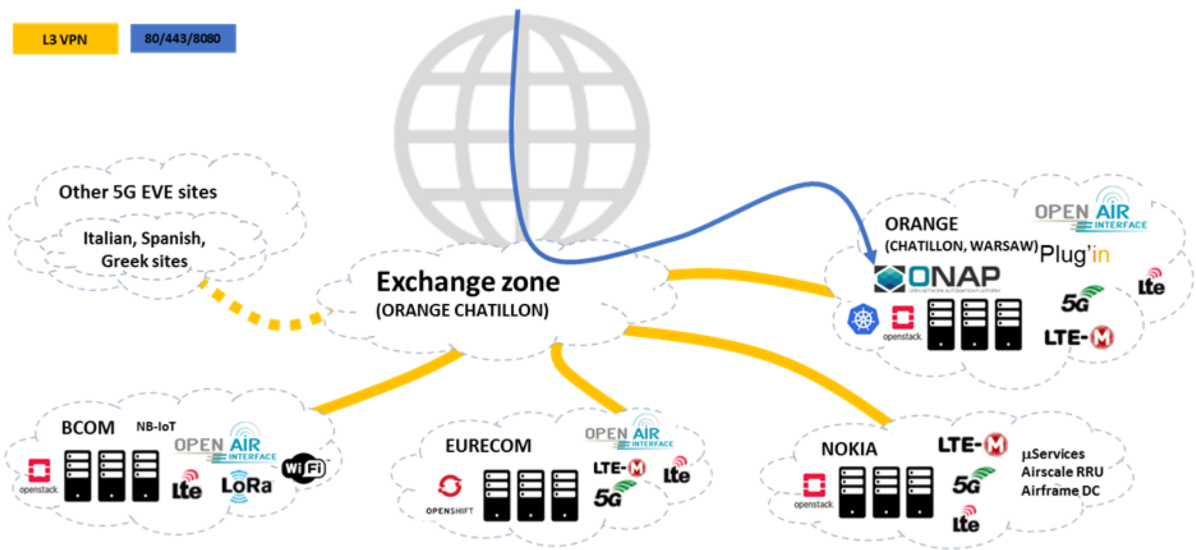

Figure 3 – 5G-EVE French Node Infrastructure

The physical sites provide a combination of commercial and experimental radio and computing systems for running field trials and providing an experimental playground for integration of new vertical applications in the context of ICT-19. The 5G-EVE sites are expected to continue operations well beyond the timeframe of the 5G-EVE project (2018-2021). All sites aim to use modern data-centre methodologies to implement the experimental networking functions. The site in Sophia Antipolis has further chosen to act as liaison with the OPNFV [1] project and to provide its infrastructure in this context of OPNFVs VCO 3.0 activity [2]. The main objectives of the collaboration with OPNFV are to promote the 5G-EVE technologies in a wider and primarily North American context and to collaborate closely with RedHat who manages the OPNFV VCO 3.0 initiative alongside the Linux Foundation.

3.1.2 Overview of VCO 3.0

The VCO initiative is meant to provide the necessary tools to build proof-of-concept demonstrators showing cloud-native deployments of end-to-end 5G systems using modern softwarization paradigms. In addition to the 5G-EVE site, there are additional sites in North Carolina (whose equipment is transported to Linux foundation events) and Montreal, Canada which focus on different areas of cloud-native 5G deployment and that will show some mutualization of tools and interoperability.

In particular, the European site at EURECOM is demonstrating the use of RedHat's latest enterprise container solution, OpenShift 4.2, which is based on Kubernetes. Through 5G-EVE EURECOM has opened its infrastructure to Redhat engineers alongside the greater H2020 experimental community. This allows Redhat to deploy and manage OpenShift as the core technology of the facility and allows experimenters to use this commercial tool freely on the site. EURECOM attends regular meetings with the Linux Foundation and technical meetings with RedHat and other partners in order to coordinate its 5G-EVE activities with OPNFV. In particular, EURECOM animates the *slack channel* [8] dedicated to its 5G-EVE infrastructure and brings partners from OPNFV and various H2020 projects together.

3.1.3 Objectives of the collaboration

The main objective of this collaboration is to highlight the 5G-EVE infrastructure in the context of Linux Foundation events. EMPOWER is instrumental in assisting this collaboration effort. The framework that was put in place will, in particular, be used to allow for on-boarding of software from ICT-19 projects and also European and North American SMEs. This will provide efficient means for their innovations to be demonstrated in the context of future Linux Foundation events. This firstly leverages the Sophia Antipolis site alone which, although interconnected with the rest of the 5G-EVE infrastructure, is locally orchestrated. In a second phase during the first quarter of 2020, RedHat and EURECOM will interact with Orange Labs France to integrate the infrastructure management with the ONAP infrastructure of 5G-EVE. This is also very relevant to the ONAP community because of the fact that the Sophia Antipolis site is a fully container-based infrastructure and the support of which is one of ONAP's longer-term objectives. Most infrastructure sites use virtual-machine based infrastructure relying on OpenStack. This second step will therefore allow demonstrations using other sites from 5G-EVE in addition to Sophia Antipolis.

The other main objective is of a highly technical nature, namely the ability to execute real-time radio processing efficiently in a container-based environment. This is particularly interesting for EURECOM and RedHat.

The first live demonstration of the Sophia Antipolis site will take place during Kubecon 2019 in San Diego [18] where the site will be used remotely during a keynote presentation by Redhat. EURECOM and Redhat will also provide a technical lecture during the event which covers some of the internal workings of the site and deployment technologies.

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

The O-RAN [9] Alliance is driven by Tier-1 operators (AT&T, China Mobile, Deutsche Telekom, Orange, NTT DoCoMo). Its main objectives are to standardize new interfaces allowing for greater control of the 3GPP radio-access network. In particular, these interfaces will allow new players to enter into the telecommunication network ecosystem and moreover foster collaboration with open-source initiatives such as the Linux Foundation. O-RAN together with the Linux Foundation have recently announced the creation of an open-source community to provide reference implementations for the O-RAN interface specifications.

In the spirit of this open-source approach, EMPOWER along with the OpenAirInterface Software Alliance has formed a community-driven effort to provide an implementation of the O-RAN E2 interface within the OpenAirInterface (OAI) 3GPP implementation. As shown in Figure 4 – O-RAN Architecture**Erreur ! Source du renvoi introuvable.**, the E2 interface provides two potential links to the 3GPP protocol stack. The first is with the radio-resource controller (RRC) and allows a higher-level entity to influence the radio resource management, in particular the radio-access network configuration. The second is with the medium-access (MAC) layer and allows the higher-layer entity to influence scheduling policies. The higher-level entity is one of the main outputs of O-RAN, namely the so-called Near Real-Time RAN Intelligent Controller (RIC). The RIC is O-RAN's first contribution to the associated Linux Foundation open-source community. It was provided in open-source under an Apache V2.0 license by AT&T and Nokia Bell Labs.

This effort to integrate E2 into OAI was instigated by AT&T Research and will involve teams from EURECOM, the University of Utah (PAWR POWDER-RENEW project) and Nokia Bell Labs. In practice, EMPOWER will provide the management effort while engineering work will be provided by companion ICT-17/19 projects such as 5G-EVE and 5G-VICTORI. Other members of the greater OAI community have expressed interest in contributing to this effort because of the importance of O-RAN. The main objective will be to integrate the E2AP specifications from O-RAN WG3 and demonstrate the ability to control an OAI-based RAN using the Nokia Bell Labs / AT&T RIC. This can be used both for demonstration and experimentation at the PAWR POWDER-RENEW and EURECOM test sites and internally at Nokia Bell Labs. It will also be demonstrated by default in the context of the VCO 3.0 OPNFV project (see Section 3.1) and 5G-EVE.

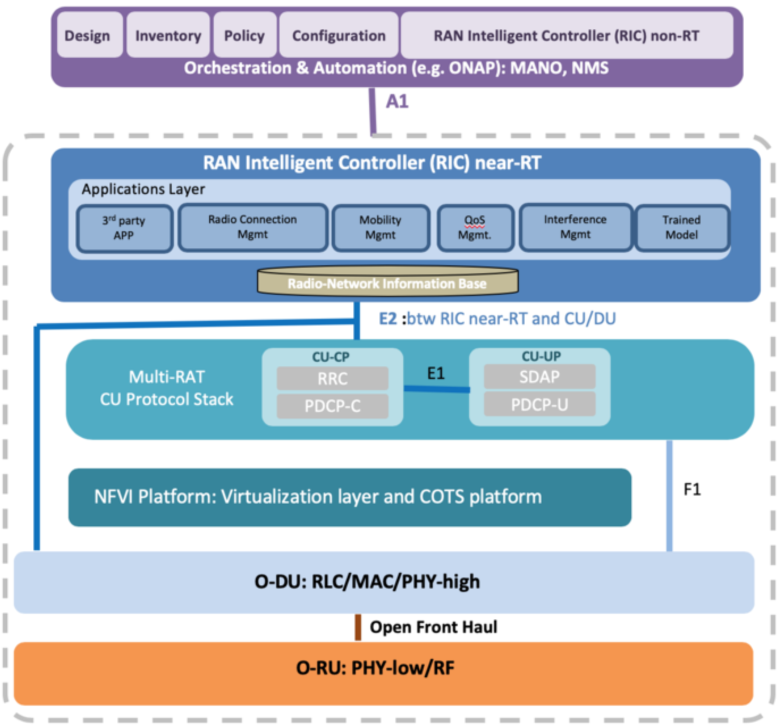

Figure 4 – O-RAN Architecture

4. Joint Demonstration Activities between other EU and US Projects

4.1 Rationale CloudLab and OneLab

CloudLab[1] is an innovative project of the University of Utah, Clemson University, the University of Wisconsin Madison, the US Ignite, the University of Massachusetts Amherst, and Raytheon BBN Technologies. The project is part of the National Science Foundation's NSFCloud program.

CloudLab is a flexible scientific infrastructure for research on the future of cloud computing. Researchers use CloudLab to build their own clouds, experimenting with new architectures that will form the basis for the next generation of computing platforms .It provides researchers with control over compute, storage and network resources and visibility all the way down to the bare metal.

The software stack that manages Cloudlab is based on Emulab[2], a testbed control suite which is used to provision a set of resources or a cloud stack at the physical level and to control the network topologies during the placement of the resources.

As of today, the Cloudlab infrastructure is composed of multiple clusters of resources and provides more than 25 000 cores distributed across different sites.

OneLab[3] is a research facility designed for the federation of Future Internet testbeds in Europe. The team behind has also participated and contributed to several related projects at the national, European and international level, with collaborations across the world.

The OneLab facility is organized in three different groups, the IoT, the Wireless and the Cloud. It provides control and remote access over a large number of resources and offers the possibility to run a large-scale experiment combining multiple heterogeneous resources federated through one single portal.

One of the components of the OneLab facility is the FIT Research Infrastructure. FIT is composed of about 3000 wireless sensors devices and heterogeneous communicating objects deployed on 6 different sites across France. It provides different types of hardware devices such as M3, A8 and WSN430 nodes, as well as mobile robots. These devices can support several Operating Systems (FreeRTOS, Contiki, Riot, TinyOS, OpenWSN, Linux).

CloudLab has heavily contributed to the research community in the domain of Cloud Computing. It complements well with the work of OneLab, thus the decision to federate both infrastructures for this collaboration.

The OneLab team and the CloudLab team have worked closely together to federate the CloudLab testbeds with the OneLab portal and to set up the first cluster in Europe.

OneLab has installed in its facility in Paris a 4.3U HP Moonshot system which is based on an array of ARM processors for this cluster. The Moonshot system is composed of 45 ARM servers and 2 network switches and offers improved performance and less power consumption compared to standard x86 servers. It is more compact which is best suited for smaller datacentres.

ARM servers employ less sophisticated but low-power processor and distribute the processing tasks across hundreds of processors. This is different from standard x86 servers which channel the workload through a few processors.

The specification of each ARM Server is described below :

1 "Cloudlab Scientific Infrastructure", https://cloudlab.us/ 2019
2 "Emulab", https://www.emulab.net/ 2019
3 "Onelab Research Facility", https://onelab.eu/ 2019

CPU Eight 64-bit ARMv8 (Atlas/A57) cores at 2.4 GHz (APM X-GENE)
RAM 64GB ECC Memory (8x 8 GB DDR3-1600 SO-DIMMs)
Disk 120 GB of flash (SATA3 / M.2, Micron M500)
NIC Dual-port Mellanox ConnectX-3 10 GB NIC (PCIe v3.0, 8 lanes)

4.2 Federation

With the federation of OneLab with Cloudlab, OneLab users can now use their OneLab credentials to access all CloudLab sites infrastructure including the sites managed by OneLab/FIT. And both CloudLab and OneLab users can use the experimentation tool developed by CloudLab to reserve resources from the OneLab Cluster.

OneLab has implemented a feature for users to export their credentials to the CloudLab experimentation tool. The later implements the GENI delegation and “speaksfor” mechanisms for the authentication of OneLab users. (Please refer to the how-to use CloudLab with your OneLab credentials).

This new offering complements the IoT and Wireless resources already accessible with OneLab/FIT.

5. Conclusion

In this deliverable we reported on the preparation of joint efforts between ICT-17 projects and PAWR facilities leading to demonstration of mutualized hardware and software components in major venues such as Mobile World Congress and Linux Foundation events. Another initiative linking ICT-17 to the Arena platform at Northeastern University was also described. These activities will all involve joint development work between the EU and USA researchers to enable future joint demonstrations and experimentation. One further initiative focused on the introduction of hardware from an industrial partner, InterDigital, into both PAWR and ICT-17 facilities.

We then reported on the work carried out to coordinate the use of ICT-17 5G-EVE in Linux Foundation projects. One example is where EURECOM has made the 5G-EVE site in Sophia Antipolis available for use in the OPNFV VCO 3.0 project. The site benefits from the technical expertise from Redhat engineers and also from access to commercial software solutions for high-performance computing infrastructure. OPNFV will be able to use the site to demonstrate innovations in network function virtualization applications in 5G infrastructure and furthermore allow its community to evaluate the efficiency of cutting-edge tools for the stringent processing constraints of 5G.

Finally we described the collaboration between 5G-EVE and POWDER teams aiming to contribute to the O-RAN Alliance [6] 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.

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