Coherent

Coordinated Control and Spectrum Management for 5G Heterogeneous Radio Access Networks

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Initial Release of the SDK

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Version history

Version	Date	Remarks
1.0	05.04.2016	ToC created.
1.2	27.06.2016	Initial contributions from CREATE-NET
1.3	30.06.2016	Feedback from TCS integrated.
2.0	11.07.2016	Feedback from EURECOM integrated.
3.0	19.07.2016	Integrated revisions from TCS and EICT.
4.0	22.07.2016	Final version ready

Executive summary

This deliverable accounts for the first public release of the COHERENT Software Development Kit (SDK). The SDK currently fully supports Enterprise Wireless Local Area Networks (WLANs) and has preliminary support for Long Term Evolution (LTE) small cells. The entire code has been released on GitHub (https://github.com/5g-empower) under a permissive APACHE 2.0 License for non-commercial applications.

The SDK is being advertised on Twitter (https://twitter.com/5gempower) and a Google Analytics account has been created in order to track website access statistics. Moreover, the platform is also used within three H2020 projects (COHERENT[a], SESAME[b], and VITAL[c]) and by the DA2GC (Direct Air to Ground Communications) EIT[d] Digital project. Several European universities are also deploying internal testbeds based on the COHERENT SDK. At the time of writing the following institutions are using or considering using the COHERENT platform: University of Antwerp, University of Liverpool, University of Athens, University Castilla La Mancha, TU-Berlin, and University of Trento.

The full documentation of the COHERENT SDK has been made available on the official GitHub web site. The documentation includes step-by-step instructions on how to setup a fully programmable heterogeneous Wi-Fi and LTE networks, starting from open source software components and off-the-shelf devices and a few tutorials on how to implement basic control and coordination applications on top of the programmable controller.

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[a] http://www.ict-coherent.eu/
[b] http://www.sesame-h2020-5g-ppp.eu/
[c] http://www.ict-vital.eu/
[d] European Institute of Technology

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List of abbreviations

AP	Access Point
BSS	Business Support System
CPP	Click Packet Processors
LVAP	Light Virtual Access Point
LVNF	Light Virtual Network Function
OAI	OpenAirInterface
OSS	Operational Support System
RAN	Radio Access Network
RT	Radio Transceiver
SDK	Software Development Kit
VBS	Virtual Base Station
UE	User Equipment
WTP	Wireless Termination Points

1. Introduction

1.1 Outcomes

This report accounts for the first version of the COHERENT Software Development Kit (SDK) that has been released to the general public on July 22nd 2016. The COHERENT SDK is based on the 5G-EmPOWER platform. 5G-EmPOWER is an open toolkit for SDN/NFV research and experimentation in mobile networks. More information about 5G-EmPOWER can be found at the official website (http://empower.create-net.org/).

The COHERENT SDK currently fully supports Enterprise Wireless Local Area Networks (WLANs) and has preliminary support for Long Term Evolution (LTE) small cells. The entire code has been released on GitHub (https://github.com/5g-empower) under a permissive APACHE 2.0 License for non-commercial applications. The SDK has been used to stage one demo at the EuCNC 2016 conference and another more advanced demo has been submitted to the ACM WinTech 2017 workshop.

The SDK is being advertised on Twitter (https://twitter.com/5gempower) and a Google Analytics account has been created in order to track website access statistics. Both Twitter and Google Analytics show a steady increase in the number of visitors and users. More specifically, the twitter account has 17 followers while the Google Analytics page shows an average of 50 unique users per week in the last 6 months.

Moreover, the current preliminary releases of the COHERENT SDK is also used within three H2020 projects (COHERENT[a], SESAME[b], and VITAL[c]) and by the DA2GC (Direct Air to Ground Communications) EIT[d] Digital project. Several European universities are also deploying internal testbeds based on the COHRENT SDK.

The full documentation of the COHERENT SDK has been made available on the official GitHub web site. The documentation includes step-by-step instructions on how to setup a fully programmable heterogeneous Wi-Fi and LTE networks, starting from open source software components and off-the-shelf devices and a few tutorials on how to implement basic control and coordination applications on top of the programmable controller.

1.2 Organization of this deliverable

In Section 2 we account for the relationship between T2.4 which is the task responsible for developing the COHERENT SDK and the other Work Packages. In Section 3 we report on the COHERENT SDK and on its role within the COHERENT project. Section 4 provides the pointers to the proof-of-concept implementation, documentation, and tutorials. Finally, in Section 5 we detail the development roadmap for the COHERENT SDK.

[a] http://www.ict-coherent.eu/
[b] http://www.sesame-h2020-5g-ppp.eu/
[c] http://www.ict-vital.eu/
[d] European Institute of Technology

2. Relationship with other Work Packages

In this section we shall describe the relationship between the SDK (Task 2.4) and the other work packages in the project. For the outcomes on abstractions (Task 2.3) we point the reader to deliverable D2.2 [1] and in particular to Section 8 where preliminary results for Enterprise WLANs and LTE networks are provided.

Figure 2-1 depicts the relationship between SDK (T2.4) and WP3. As it can be seen all WP3 tasks provide contributions to T2.3 which is responsible for the definition of the COHERENT abstractions. In particular, T3.1 and T3.2 provide feedback on monitoring information and control primitives for control and coordination of heterogeneous networks as well as for user cooperation. T3.3 on the other hand focuses on new solutions for network coverage extension and mobility management.

In relation with WP3 activities, the design choices of network graphs along with the COHERENT abstractions methodologies in T2.3 (as accounted in D2.2 [1]) and considered in WP3, will be integrated into the 5G-EmPOWER platform in order to produce the actual COHERENT SDK. Furthermore, T2.4 will provide T3.3 with the SDK that will be used in order to implement novel coverage extension and mobility management solutions.

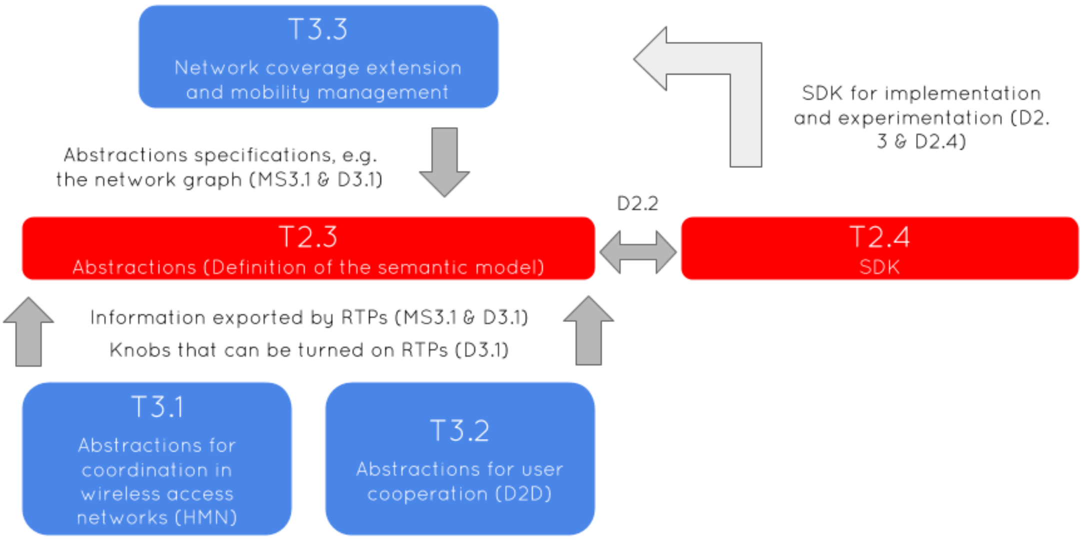

Figure 2-1. Relationship between SDK and the other work packages.

Similar consideration can be made also for WP4 and WP5. In both cases the internal tasks provide T2.3 with requirements which are then fed into the SDK in T2.4. The SDK is then used within WP4 and WP5 to implement novel solutions providing at the same time T2.4 with feedback about the SDK.

3. The COHERENT Software Development Kit

In this section we will first briefly recall the general COHERENT architecture and terminology. Then we will introduce the 5G-EmPOWER platform which is used as foundation for the COHERENT SDK. We shall also provide a high level overview of the current prototype implementation status. Finally, we will conclude with the pointers to the developers' documentation and to the tutorials.

3.1 Overview

The COHERENR SDK is developed based on the 5G-EmPOWER platform. Accordingly, the COHERENT Central Controller and Coordinator (C3) for both Enterprise WLANs and cellular networks is implemented on the 5G-EmPOWER platform.

5G-EmPOWER is an open toolkit for SDN/NFV research and experimentation in wireless and mobile networks. Its flexible architecture and the high-level programming Application Programming Interfaces (APIs) allow for fast prototyping of novel services and applications.

It is worth noticing that in its current implementation the 5G-EmPOWER fully supports 802.11-based WLANs, while support for LTE small cells is currently being added and will be released with D2.4.

The 5G-EmPOWER toolkit consists of the following components:

1. A reference Wi-Fi data-path implementation;
2. A reference C3 implementation supporting the COHERENT northbound interface (NBi) [1];
3. A Software Development Kit (SDK) implementing the COHERENT semantic model and abstractions [1].

The SDK released in this deliverable provides the API that can be used in order to implement control and coordination tasks on top of the C3. We remind the reader that an SDK is typically defined as a set of software development tools that facilitate the creation of software artifacts. In this specific case the COHERENT SDK provides programmers with a high-level interface to their Software Defined Mobile Networks as opposed to the very low-level interfaces exposed by network elements (i.e. the southbound interface).

We refer the reader to COHERENT D2.2 [1] for a complete description of the COHERENT semantic model for Wi-Fi and LTE networks as well as for the system architecture and for the associated functional components and interfaces. The COHERENT Architecture is depicted in Figure 3-1.

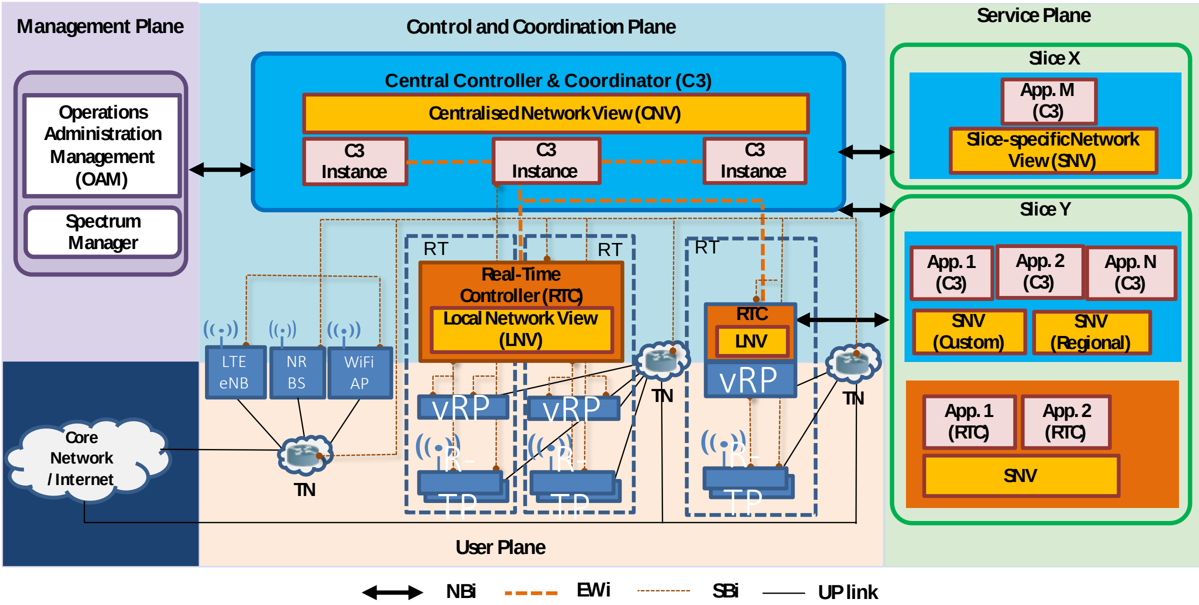

Figure 3-1. The COHERENT Architecture [1]

We shall now summarize the COHERENT terminology defined in D2.2 [1]:

- **Radio Transmission Point (R-TP):** R-TP is a radio access point implementing full or partial RAN node functions while rest of functions are offloaded to and handled by the vRP. An R-TP may include control plane functions.

- **Virtual Radio Processing (vRP):** vRP is a computing platform allowing for centralised processing of full or partial RAN node functions (including the user plane and the control plane) offloaded from one R-TP or multiple R-TPs. A vRP may include control plane functions.

- **Radio Transceiver (RT):** RT is a logical radio access entity with full RAN node functions, which is the flexible combination of R-TP, vRP and RTC functions. A set of RTs is forming a radio access network which is coordinated and controlled by C3. There are multiple physical and virtual resources and components in one RT. Some examples of physical RTs include LTE eNBs in cellular networks or WiFi APs in the WLANs. An RT could be composed by one vRP (virtual device) and one or more R-TPs (physical devices). For example, in the Cloud-RAN architecture the R-TP coincides with the RRH, while the vRP coincides with the BBU Pool, however several other functional splits are considered in this project. In some particular case, e.g., D2D, RT could be an UE, being a relay node.

- **Transport Node (TN):** TN is the entity located between RTs and core network. A set of TNs is forming a backhaul/fronthaul network whose data plane can be configured by the C3. A network switch is an example of Transport Node.

- **Real-Time Controller (RTC):** A logical entity in charge of local or region-wide control, targeting at real-time control operations, e.g., MAC scheduling. It has local network view. It could run directly on one RT or on a virtualised platform and receives monitoring information gathered from one RT or multiple RTs. It can delegate control functionality to the RTC agent on the RTs. RTC communicates with an RTC agent/RTC agents on one RT or multiple RTs.

- **Central Controller and Coordinator (C3):** A logical centralised entity in charge of logical centralised network-wide control and coordination among entities in RAN based on centralised network view. C3 could be implemented with distributed physical control instances sharing network information with each other. Sharing network information among C3 instance creates the logically centralised network view and therefore achieves logical centralised control and coordination.

- **Slice:** A network slice is defined as a collection of specific network services and RAT configurations, which are aggregated together for some particular use cases or business applications. A network slice can span all domains of the network: software programs running on cloud nodes, specific configurations of the transport network, a dedicated radio access configuration, as well as settings of the 5G devices. Different network slices contain different network applications and configuration settings. Some application modules in network slices may be latency-critical. For such a slice, these modules are located in the RTC.

3.2 The 5G EmPOWER Platform

A high level view of the 5G-EmPOWER system architecture is depicted in Figure 3-2. The architecture is conceptually divided into three layers. The bottom layer consists of the physical and virtualised resources composing the data-plane. In the second layer we have the Controller which is in charge of the physical and virtual resources available in the data-plane. Finally, in the third layer we have the actual Network Service slices. Virtual Network Operators use their Operational Support System (OSS) and the Business Support System (BSS) in order to manage and operate their Network Service slices.

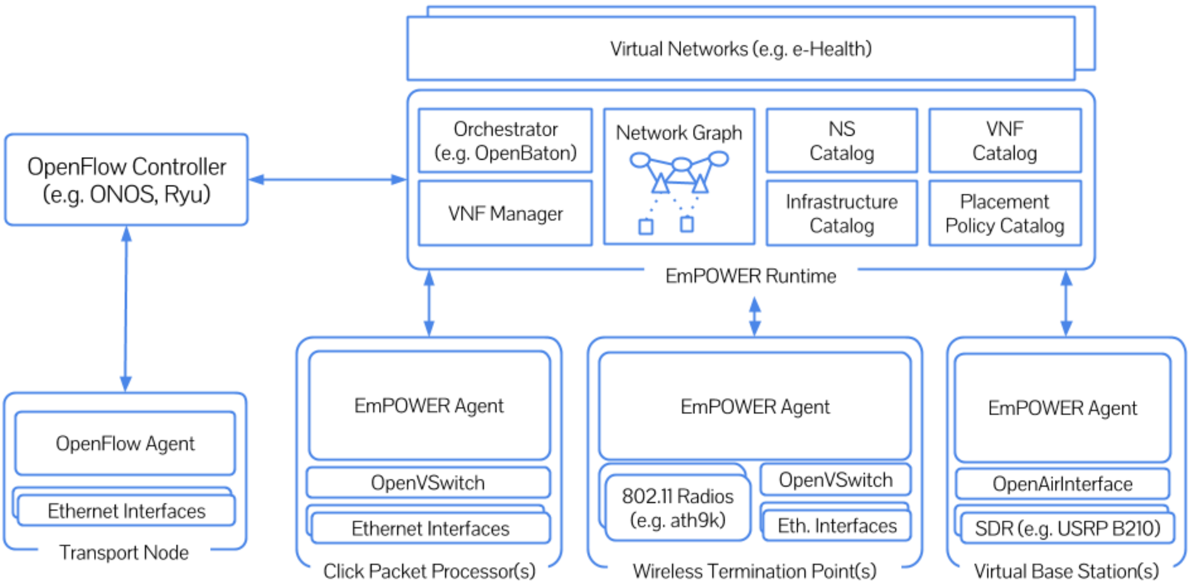

Figure 3-2.The 5G-EmPOWER System Architecture

From an architectural standpoint, the Network Service slice creation resides in the Orchestrator which is in charge of deciding whether a particular Network Service (NS) can be accepted or if it must be refused. If a request is accepted, then the Orchestrator is in charge of mapping the request onto the network by deploying the VNFs on the selected nodes. Information about all supported VNFs and NSes are maintained in the VNF and NS catalogs. The Infrastructure Catalog holds information about available physical and virtualised resources. Finally, the list of placement algorithms is held by the Placement Policy Catalog.

The 5G-EmPOWER platform builds upon a single hardware infrastructure consisting of general purpose hardware (x86) and operating system (Linux), in order to deliver three types of virtualised network resources, namely transport nodes (OpenFlow switches), packet processing nodes (Micro Servers or Click Packet Processors), and radio access network nodes (WTPs and VBSes). The 5G-EmPOWER architecture (see Figure 3-2) loosely follows the ETSI NFV MANO specifications [2].

Table 3-1 introduces the terminology used by the SDK mapping it to the general COHERENT nomenclature and architecture in Figure 3-1. We use the term Wireless Termination Points (WTPs) to refer to the physical devices that form the Enterprise WLAN providing clients with wireless connectivity. WTPs basically coincide with Wi-Fi Access Points (APs). We name Virtual Base Station (VBS) the 3GPP LTE eNodeBs. Moreover, we name Click Packet Processors (CPP), the Micro Servers deployed at the edges of the network. Finally, we use the term Runtime to refer to the logically C3 entity. A secure channel connects the WTPs to the Controller. The Controller[a] can run multiple virtual networks, or slices, on top of the same physical infrastructure. Network applications run on top of the Controller in their own sandbox and exploit the COHERENT programming primitives through either a REST API or a native Python API.

Table 3-1. Mapping between COHERENT Terminology and EmPOWER

COHERENT Terminology	**EmPOWER Terminology**
Central Controller and Coordinator (C3)	EmPOWER Runtime
Radio Transceiver (RT)	Wi-Fi: Wireless Termination Point (WTP) LTE: Virtual Base Station (VBS)
Wireless Client	Wi-Fi: Light Virtual Access Point (LVAP) LTE: User Equipment (UE)

The entire software stack has been released under a permissive APACHE 2.0 for academic use and is available at the official 5G-EmPOWER website: http://empower.create-net.org/. Documentation and tutorials are available in the associated GitHub project: https://github.com/5g-empower/5g-empower.github.io/wiki. Commercial use of the platform is regulated by the APACHE 2.0 License.

As it can be seen from Figure 3-2, the 5G-EmPOWER Architecture has a scope significantly larger than COHERENT. In particular, the 5G-EmPOWER Architecture targets also NFV Management and Orchestration and Mobile Edge Computing use cases (hence the reason for the Micro Servers). A more detailed description of the supported network elements is provided in the following subsections.

The 5G-EmPOWER easily maps to the COHERENT Architecture. As summarized in Table 3-1, the C3 maps directly to the EmPOWER Runtime. Similarly, the COHERENT RTs (Radio Transceivers) maps to the WTPs (in the case of WiFi elements) and to the VBS (in the case of LTE elements).

In 5G-EmPOWER the physical and virtualised network is abstracted into network slices. Each slice defines a particular connectivity service and consists of a set of VNFs with the associated control logic (see Figure 3-3). Each network slice can be fully customized in order to support the requirements of the service in term of coverage, capacity, latency, and security. We point the reader to the COHERENT Deliverable D2.2 for an extensive account on how we address network slicing and multi-tenancy.

[a] Notice how throughout this deliverable we use the terms control (controller) and coordination (coordinator) interchangeably.

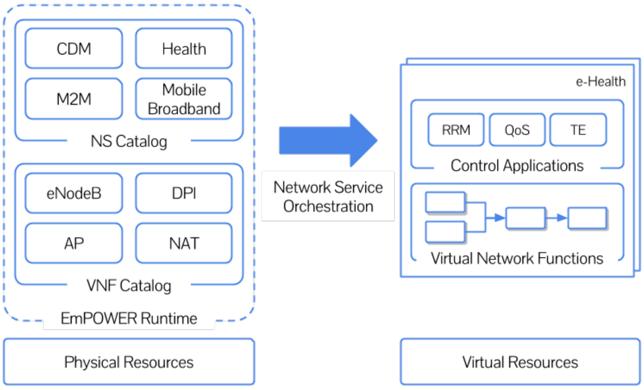

Figure 3-3. The network service slice concept in the 5G-EmPOWER Platform.

3.3 Central Controller and Coordinator (C3)

The controller implementation leverages the Tornado Web Server [7] as the web framework. The main reason for choosing Tornado is its non–blocking network I/O which allows continuing serving incoming requests, while the others are being processed. In the following, we elaborate on some of the main features of the Controller:

- **Slicing.** The Controller can accommodate multiple virtual networks or slices on top of the same physical infrastructure.
- **Soft State:** The only persistent information stored at the controller is the clients' authentication method and the list of currently defined slices. All the state is kept within the network in a distributed fashion and is synchronized when the network elements (WTPs, CPPs, and VBSes) connect to the Controller. As a result, the Controller can be hot–swapped with another instance without affecting the active clients. Moreover, the network itself can still function in its last known state even if the controller becomes unavailable.
- **Modular Architecture:** with the exception of the logging subsystem, every other task supported by the controller is implemented as a plug–in (i.e., a Python module).

3.4 Supported Data-plane devices

The 5G-EmPOWER platform supports four types of data-plane devices, namely:

1. Wireless Termination Points, or WTPs.
2. Virtual Base Stations, or VBSes.
3. Click Packet Processors, or CPPs.
4. Transport nodes, i.e. the OpenFlow switches.

Wireless Termination Points (WTPs). Each WTP consists of two components: one OpenvSwitch instance managing the communication over the wired backhaul; and one EmPOWER Agent implementing the 802.11 data–path. The Agent is implemented using the Click Modular Router. Click is a framework for writing multi–purpose packet processing engines and is being used to implement just the WTPs/Wireless Clients frame exchange, while all the decision logic is implemented at the EmPOWER Runtime. Communications between the Agent and the Runtime take place over a persistent TCP connection. The WTPs in our deployment are a mix of PCEngines ALIX (x86) and Gateworks Cambria (ARM) embedded platforms running the

OpenWRT[a] operating system. WTPs can be equipped with multiple Wi-Fi. Instruction on how to configure a WTP can be found here [4].

Click Packet Processors (CPPs). These nodes essentially combine an OpenFlow switch with a general purpose x86 CPU. As the name suggests, CPPs leverage on multiple instances of the Click Modular Router in order to implement packet processing. Each CPP includes an OpenVSwitch instance, one or more Click instance, and one Agent. The latter is in charge of monitoring the status of each Click instance as well as of handling the requests coming from the controller. CPPs in our testbed are built upon the Soekris 6501-70 platform consisting in single 1.6 GHz Intel Atom CPU, 2 Gbyte of SDRAM, and 12 Gigabit Ethernet Ports. CPPs run Ubuntu 15.04 Server as operating system. Instruction on how to configure a WTP can be found here [5].

Virtual Base Stations (VBSes). These are essentially LTE eNodeBs. The 5G EmPOWER platform currently supports both open and commercial LTE Small Cells. In order to communicate with the EmPOWER Runtime, the small cells must implement the EmPOWER Agent. Such Agent, which is part of the EmPOWER platform, has a modular architecture allowing it to be adapted to different platforms (both open source and commercial). Open small cells are implemented using the OpenAirInterface (OAI) framework [3]. The OAI is a full implementation of the LTE standard (release 8) realised by EURECOM. OAI can run on several SDR platforms, such as the Ettus USRP devices. The OAI is currently being extended in order to support the EmPOWER Agent. Support for other commercial small cells is also being considered. In its current state, the EmPOWER agent supports basic measurement & reporting capabilities from both the VBS and the attached UEs. Support for dynamic (re)configuration of measurements and reports as well as for control functions are currently under development and will be release in D2.4. Instruction on how to configure a VBS can be found here [6].

Transport Nodes (TN). These are the entities located between RTs and core network. A set of TNs is forming a backhaul/fronthaul network whose data plane can be configured by the C3. An OpenFlow switch is an example of Transport Node.

3.5 Tutorials

A set of tutorial have been prepared in order to guide new developers through the process of creating a new control application on top of the 5G-EmPOWER controller using the COHERENT SDK.

Mobility Manager (Wi-Fi). This tutorial illustrates how to implement a mobility management application for Enterprise Wi-Fi networks. The application takes into account the channel quality as exposed by the network graph in order to implement handover decisions. The tutorial is available at the following address: https://github.com/5g-empower/5g-empower.github.io/wiki/Writing-a-Simple-Network-Application-(Mobility-Manager).

Network Graph (Wi-Fi+LTE). This tutorial illustrates how to build upon the network graph API in order to gather the global network view encompassing both Wi-Fi Access Points and LTE Small Cells. The tutorial shows how to dynamically adapt the monitoring primitives on both Wi-Fi and LTE data-paths. The tutorial is available at the following address: https://github.com/5g-empower/5g-empower.github.io/wiki/Writing-a-Network-Graph-Application-(Network-Graph). At this stage, this is an early release of the database representation of the Network Graphs approach. For the future release, various optimizations will be considered in this design in order to satisfy the requirements set for the efficient C3 operation.

[a] https://openwrt.org/

4. Conclusions

In this report we accounted for the release of the first version of the COHERENT SDK. The SDK builds upon the 5G-EmPOWER platform developed by CREATE-NET and is made available under a permissive APACHE 2.0 License for academic use.

The platform is currently witnessing an increasing popularity as demonstrated by its adoption by other H2020 projects and by institutions not directly linked with the COHERENT project.

The planned enhancements for the platform are significant:

1. We plan to release a live-cd environment with suitable for both Wi-Fi and LTE environment which can allow developers to implement and test new solutions without requiring a physical testbed.

2. We plan to integrate selected results from WP3, WP4, and WP5 into the SDK. In particular, we plan to integrated results on probabilistic monitoring, spectrum management, RAN sharing, and traffic steering.

3. We plan to evolve the current platform by leveraging on the results on the CAP Theorem produced in T5.1 EmPOWER effectively delivering the first distributed controller for heterogeneous networks.

4. We plan to extend the platform to fully support both open and commercial LTE small cell. In the case of open small cell, we plan to further leverage on the OAI, while the selection of the commercial small cells to be supported is still undergoing.

References

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