EuWireless RAN Architecture and Slicing Framework for Virtual Testbeds

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Abstract. The most recent evolutionary steps in the development of mobile communication network architectures have introduced the concepts of virtualisation and slicing also into the Radio Access Network (RAN) part of the overall infrastructure. This trend has made RANs more flexible than ever before, facilitating resource sharing concepts which go far beyond the traditional infrastructure and RAN sharing schemes between commercial Mobile Network Operators (MNO). This paper introduces the EuWireless concept for a pan-European mobile network operator for research and presents its vision for RAN slicing and network resource sharing between the infrastructures of the EuWireless operator, commercial MNOs and research organisations around Europe. The EuWireless approach is to offer virtual large-scale testbeds, i.e., EuWireless experimentation slices, to European mobile network researchers by combining the experimental technologies from the local small-scale research testbeds with the commercial MNO resources such as licensed spectrum. The combined resources are configured and managed through the distributed EuWireless architecture based on interconnected local installations, so-called Points of Presences (PoP).

Keywords: Virtual testbed · Radio access network · Network resource sharing · Slicing · Virtualisation

1 Introduction

The Radio Access Network (RAN) architecture specified by the 3rd Generation Partnership Project (3GPP) has evolved from the metro-site topology, where all base station functionality is integrated into proprietary hardware at the cell site, towards more flexible deployments with the 3G and 4G technologies. An important step has been the separation of the radio front-end and the baseband

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processing units, which has made it possible to split the base station functionality into several network components inter-connected with optical fibre. Centralised RAN (C-RAN) [10] is a RAN architecture which takes advantage of this functional split and the concept of virtualisation to cope with the challenge of flexible resource provisioning for RANs.

In C-RAN, the base station functionality is divided into two RAN elements, i.e., the Baseband Unit (BBU) and the Remote Radio Head (RRH). All functionality related to baseband processing and protocols on the Physical Layer (PHY) and above is provided by the BBU. The RRH handles the radio functionalities. The C-RAN approach centralises multiple BBUs in one location (i.e., Centralised RAN) and can further enhance the flexibility of the architecture by virtualising some functions of the BBUs in a common resource pool (a.k.a Cloud-RAN). The additional steps of BBU resource virtualisation and pooling in the Cloud-RAN approach enable the use of Commercial Off-the-Shelf (COTS) servers for processing the majority of the BBU routines and utilisation of data centres to host the required equipment [9].

The latest evolutionary steps in mobile network architectures go even further in the virtualisation of the network functions. The 3GPP system architecture evolution for 5G with its Service Based Architecture (SBA) approach relies on a fully virtualised 5G Core Network (5GC) [22]. 5G supports also the virtualisation of the radio access nodes, i.e., 5G NodeBs (gNB), with new functional split defined for the Next Generation RAN (NG-RAN) [8]. The ability to built a full 5G network by utilising Virtual Network Functions (VNF) enables flexible end-to-end slicing for mobile networks. This in turn facilitates the sharing and joint management of network resources between Mobile Network Operators (MNO) and other stakeholders in the future. The widespread adoption of open standardised interfaces, a feature seen by the MNOs as one of the key enablers for flexible deployment of future networks, would further open up the mobile network infrastructures for a variety of new sharing scenarios and business cases.

The EuWireless project is focusing on a design of a pan-European mobile network operator for research. The EuWireless concept includes both the system architecture and the operation model for the EuWireless operator. The main objective behind the project is to provision a European level mobile network that facilitates open large-scale experimentation. This is achieved by combining research stage technology components from local small-scale testbed with commercial equipment and resources from MNO networks into a single virtual testbed [25]. The configuration, management and orchestration of the shared resources can be performed by the EuWireless experimenter using the virtual testbed through the provided online portal.

This paper introduces the key components of the EuWireless concept and architecture focusing on the virtualisation and sharing of RAN resources. The overall EuWireless architecture and the technology enablers for resource sharing in the RAN domain are reviewed. In addition, the plans to introduce virtualised RAN functions into the utilised virtualisation architecture as well as the foreseen usage scenarios and configurations for the RAN part of the EuWireless virtual testbeds are presented. As at the time of writing the EuWireless project is still in its first phase finalising the overall concept and architecture design, this paper also discusses some challenges regarding the large-scale implementations planned for the second phase of the project.

The rest of the paper is organised as follows. Section 2 reviews the related work in the field of large-scale wireless testbeds, whereas Sect. 3 introduces the EuWireless concept in more detail. Section 4 presents the RAN virtualisation and slicing techniques required to bring the EuWireless concept into life and Sect. 5 discusses the challenges related to their implementation. Finally, Sect. 6 concludes the paper.

2 Related Work

Several testbed initiatives and projects already offer possibilities for researchers and telecommunication engineers to experiment in real mobile network infrastructures. Different approaches ranging from infrastructures fully owned and operated by the projects to Virtual Mobile Network Operator (vMNO) models relying on commercial MNO infrastructures have been taken to provide these experimentation platforms to the research community.

The 5G Infrastructure Public Private Partnership (5G-PPP) initiative launched three large-scale end-to-end 5G test facilities as part of the European Horizon 2020 programme in 2018. These facilities and their infrastructure is developed, operated and owned by dedicated projects called 5GENESIS, 5G EVE and 5G-VINNI. For example, 5GENESIS [20] comprises of five interconnected large-scale local sites in different European countries which together provide a pan-European test platform addressing multiple vertical use cases. 5G EVE and 5G-VINNI have similar approaches with different sites and vertical industry focus areas. The RAN part of these facilities is based on commercial 5G equipment, but the coverage is limited to the local sites.

Another set of inter-connected test facilities in Europe are made available to the researchers by the Future Internet Research and Experimentation (FIRE) initiative, which provides technology laboratories equipped with components to perform experimental research also in mobile networks. However, the experiments must usually be executed inside the laboratories where the RAN part of the infrastructure is simulated or offered as local amendments to the wired infrastructure in pre-defined local sites as in the 5GINFIRE [36] project.

The Global Environment for Network Innovations (GENI) program offers large-scale Internet testbeds for researchers in the US. The SciWiNet [7] project has added support for wireless networking systems research into the platform based on the vMNO model. SciWiNet offers cellular connectivity via Sprint's 3G, WiMAX, and LTE networks. Consequently, SciWiNet is able to provide a test facility for a variety of mobile network services and vertical industry use cases. However, the underlying RAN infrastructure is not under full control of the testbed provider and the testbed user.

EuWireless extends these existing test infrastructure concepts by introducing the possibility to share and combine resources of the existing research testbeds with those of commercial MNO networks. Integration with MNO networks offers enhanced coverage for large-scale field tests and better access to scarce regulated resources such as licensed spectrum. In order to avoid the CAPEX/OPEX challenges related to fully owned network infrastructures and the limited possibilities to manage the network infrastructure as a vMNO, EuWireless combines the advantages of both by relying on a virtualisation concept. The selected approach allows the creation of generic connectivity slices as the baseline infrastructure for a virtual testbed. The desired network and service functionality can then be built on top of the baseline virtual infrastructure with additional slices defined by the EuWireless user.

In the European Horizon 2020 Research and Innovation programme, a variety of projects have also studied the reference architectures and technology enablers for 5G systems. Majority of these projects have been executed under the coordination of 5G-PPP, which has managed the jointly funded 5G project portfolio in Europe since 2015. EuWireless have studied the key results of the projects from 5G-PPP Phase 1 and Phase 2. The final concept, architecture and utilised technologies for the European mobile network operator for research will be defined to be in line with the 5G vision of the European research community and the telecommunications industry.

3 EuWireless Concept

The implementation of the EuWireless architecture should consider its own resources, MNO resources and the resources from local small-scale research testbeds. Typical MNO resources enabling large-scale testing in realistic operational environments are the licensed spectrum and the physical locations to install new functionality or equipment to the access, core and transport networks. Typical resources from local small-scale research testbeds include experimental network functions and all the equipment necessary to perform the experiments of the EuWireless user.

The sharing and combining of resources from these different domains is approached from two different angles in the EuWireless project. First, an overall architecture enabling flexible resource sharing is defined, including the required functionalities and interfaces to enable smooth interaction between resources from different network domains. Second, the sharing options for the network resources in the radio access, core and transport networks are specified in conjunction with the requirements for the virtualisation of different network functions and network slicing.

3.1 Overall Architecture

The EuWireless architecture follows the network slicing approach for the creation of virtual large-scale testbeds, combining resources from the EuWireless infrastructure, commercial MNO networks and local research testbeds as shown in Fig. 1. EuWireless operator offers the required interfaces for the users of the infrastructure, i.e., the EuWireless experimenters, to create and control their virtual testbeds through an online portal. Application Programming Interfaces (API) are used to directly interact with the virtual testbeds and the EuWireless infrastructure. The other considered design options and the rationale behind the choices made to define the EuWireless architecture are described in [32].

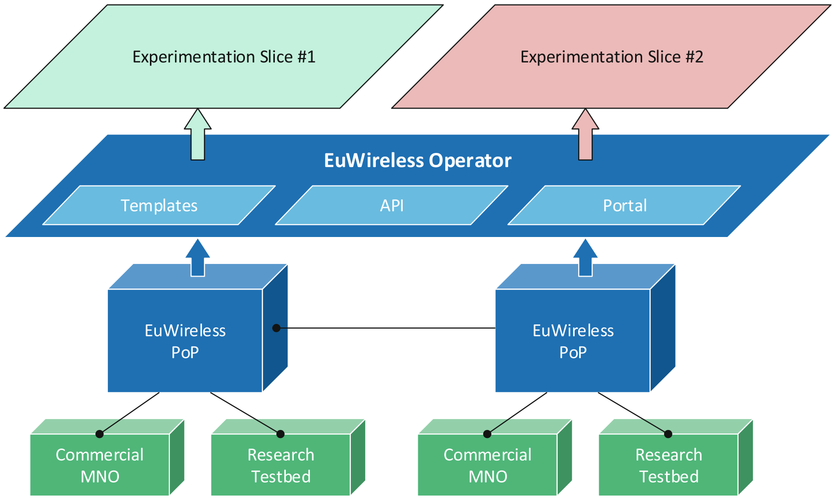

Fig. 1. EuWireless overall architecture.

The EuWireless slicing approach is supported by a flexible virtualisation platform provided by the GÉANT Testbeds Service (GTS) [14] and its Generic Virtualisation Model (GVM) architecture. GTS allows the creation of raw connectivity slices on top of the pan-European GÉANT backbone network infrastructure and additional sub-slices which can be used to build the required experimentation functionality on top of the raw connectivity slice. EuWireless operator will create and provide to the EuWireless experimenters a generic main slice template and, based on the main template, several sub-templates, which will fit the requirements of specific experimentation use cases. After the slice is defined with the provided templates, the required resources will be reserved from the available infrastructure. When the resources have been reserved, the slice will be instantiated and control handed over to the EuWireless experimenters. They can then perform their experiments with absolute control of the virtual testbed, i.e., the EuWireless experimentation slice, assigned to their use.

The EuWireless owned infrastructure resources will be deployed into Points of Presences (PoP). PoP is a core object in the EuWireless overall architecture and acts as an intermediate component between the MNO network resources and the local research testbed resources. PoPs consist of selected network functions capable of configuring and managing the end-to-end slices created for the experiments. A single PoP can be run as an independent node or as a part of a network of PoPs. That is, PoPs must be able to independently provide services in a certain geographical or logical area, but also to interconnect in a seamless and decentralised way in order to guarantee scalability. Based on PoPs as the leading design principle, the EuWireless infrastructure can be built as a flexible and incremental deployment. This means that the EuWireless owned resources can be added or relocated according to the needs of the EuWireless experimenters or the availability of funding.

3.2 Key Enabling Technologies for Resource Sharing in RAN

In order for EuWireless to go beyond traditional RAN sharing when combining resources from the EuWireless, MNO and local research testbed infrastructures, the overall architecture relies on few key enabling technologies introduced below. These technologies lay the foundation for the centralised management of the combined resources in the end-to-end experimentation slices provided for the EuWireless experimenters.

Spectrum Sharing. In the EuWireless project, the sharing of radio spectrum is studied from two perspectives. First approach is to view the RAN functions and their cooperative use as described later on in this paper. Second approach is to share radio spectrum between the EuWireless operator and commercial MNOs with dynamic spectrum access techniques. Dynamic spectrum access, in the form of spectrum sharing, is seen as one of the key enablers for the 5G and beyond systems [37]. Currently, there are two prevailing methods for shared access to the licensed frequency bands, i.e., Licensed Shared Access (LSA) in Europe and Spectrum Access System (SAS) in the US. LSA overcomes the inefficiencies of the generic TV White Space (TVWS) communication system approach with a defined economy flow between the Incumbents and the LSA Licensees. Incumbent is the primary user of the shared spectrum resource, whereas LSA Licensees are operating their wireless systems under a sharing agreement. LSA provides guaranteed quality of service in a given geographical area, frequency band and time period [26].

From the point of view of dynamic spectrum management, EuWireless needs to provide the experimenters a unified interface from which suitable frequency bands can be reserved for research purposes. The negotiations of the spectrum access for a certain geographical area and time window must follow the national regulations and laws. The required negotiations are to be carried out by the EuWireless operator locally with the MNOs. Depending on the size of the experiments being carried out by the EuWireless experimenter, the need for licensed spectrum resources might vary greatly. The experiments can concern only a limited area of a few cells or even only a single base station, or require the same frequency bands to be available across multiple EuWireless PoPs located in several countries. For the former case, the RAN slicing methods discussed in Sect. 4 can be utilised. The latter case is out of scope of this paper.

Network Slicing. 5G network slicing, as introduced in [27], allows the creation of multiple isolated logical networks on top of a single shared physical infrastructure by relying on virtualisation techniques. This slicing concept enables the EuWireless operator to offer each experimenter a virtual testbed composed of shared resources. An abstraction layer distributes those resources to the virtual testbeds and maintains their isolation. One key advantage of network slicing is that the same abstraction and sharing principles can be applied to resources that are not owned by the entity providing the service to the end users [6]. This approach is the essence of the EuWireless concept and offers the EuWireless operator the opportunity to extend the functionality and services included in the experimentation slices by entering into agreements with commercial MNOs providing key resources such as licensed spectrum.

The 5G network slices are identified and differentiated by using a Single Network Slice Selection Assistance Information (S-NSSAI) parameter, which is used as a unique slice ID in all control signalling [4]. The S-NSSAI parameter not only identifies a network slice, but it also contains information on the service type provided or supported by the slice in question. Hence, it provides the basic means for the separation of the slices and traffic handling on per-slice basis also in the RAN. Currently, the 3GPP Release 15 specifications lay down the high-level basic functionalities required to enable slicing of the NG-RAN resources [3].

Network Functions Virtualisation and Software-Defined Networking. Virtualisation and programmability of the network functions and services offer the required flexibility and act as the key enablers for network slicing. The NFV framework, as defined by the European Telecommunications Standards Institute (ETSI), offers the means to realise previously proprietary hardware-based Physical Network Functions (PNF) as virtual software-based components on top of a COTS cloud computing platform [12]. The NFV framework defines the architecture and interfaces to arrange the VNFs, the underlying NFV Infrastructure (NFVI) and the required Management & Orchestration (MANO) functionality. As a result, the desired network functions can be flexibly chained to provide the overall functionality and performance fulfilling the requirements of a given use case or service.

Software-Defined Networking (SDN) provides the required programmability to the networking fabric by separating the control and data planes. This separation facilitates the end-to-end centralised control for SDN-enabled network domains [21]. The SDN controller is a key component in the network and can be made to play a central role in the management of 5G network slicing and/or NFV. The complementary nature of the functionalities provided by network slicing, NFV and SDN has resulted into numerous approaches to utilise them in parallel when creating and maintaining virtual networks [13,30,31]. In order to better support the specific performance requirements of some RAN and legacy system components, most of them allow a mix of VNFs and PNFs to be used in a single service function chain.

3GPP Service Based Architecture. Building on the key enabling technologies introduced above, 3GPP Release 15 defines an SBA for 5G networks. Essentially, SBA integrates spectrum sharing, NFV and SDN principles into the RAN and core networks so that flexible 5G network slicing is enabled end-to-end. In SBA, the interconnections between network functions are no longer defined with reference points between individual network functions. In the earlier generations of mobile communication networks this approach resulted in fixed multi-hop signalling paths in the core network [17]. Instead, network functions in the SBA provide and consume services following the REpresentational State Transfer (REST) architecture design [23]. This approach based on RESTful APIs and a set of principles on how to create and deploy distributed services enables direct interactions between network functions and facilitates flexible service function chaining and slicing in 5G networks.

The new network functions in the centre of the SBA are the Network Repository Function (NRF) and the Network Exposure Function (NEF). The creation of virtual networks and service function chains in the SBA is performed through the NRF and RESTful APIs following a three step procedure. In the service registration phase, a network function registers with the NRF the services it provides to the other network functions. In the service discovery phase, a network function queries the NRF for the services it requires and the NRF responses with a list of other network functions that are able to provide these services. In the session establishment phase, an interconnection is established between two network functions for direct interaction. By repeating this procedure between network functions, a service function chain providing the required overall network functionality can be created. NEF, on the other hand, enables service discovery from the SBA for external 3rd parties such as vertical industries. NEF exposes the properties of the network functions in the SBA towards the 3rd party services via a northbound RESTful API.

4 RAN Functions Virtualisation and Slicing Framework

In order to enable sharing of the physical and virtual RAN functions in the EuWireless, MNO and local research testbed infrastructures, the project follows the advancements in the virtualisation of RAN functions from different forums. As 3GPP specifications define the technologies deployed in commercial mobile networks worldwide, the baseline RAN architecture for EuWireless is based on 3GPP Release 15 NG-RAN. 3GPP studied a variety of different options for a cloud-based RAN architecture in its study item for New Radio Access Technology [1], where different options to split the Evolved NodeB (eNB) and gNB functionalities were analysed.

After the assessment of the advantages and disadvantages of different split options, the Higher Layer Split (HLS) Option 2 was chosen as the main functional split for 3GPP Release 15 NG-RAN [8]. The main advantage of the HLS Option 2 is the increased flexibility in the implementation and deployment of NG-RANs as a mix of VNFs and PNFs. In addition, the HLS Option 2 benefitted from the already existing 3GPP specifications on Long Term Evolution (LTE) Dual Connectivity (DC) functionality.

In HLS Option 2, the Central Unit (CU) contains the Radio Resource Control (RRC), Packet Data Convergence Protocol (PDCP) and Service Data Application Protocol (SDAP) functionalities. The Distributed Unit (DU) contains the Radio Link Control (RLC), Medium Access Control (MAC) and PHY functionalities. DU can be further divided into the DU and the Radio Unit (RU). RU can contain either the low-PHY and the Radio Frontend (RF) functionalities corresponding to the Lower Layer Split (LLS) Option 7 [1], or only the RF functionality as in LLS Option 8 and in traditional C-RAN architectures.

A simplified representation of the resulting NG-RAN architecture is depicted in Fig. 2. The logical interfaces inter-connecting the RAN functions are the NG interface between the 5GC and the CU, the F1 interface between the CU and the DU, and the so called F2 interface between the DU and the RU. The F2 interface is not defined in 3GPP Release 15, but it is currently used to represent the interface between the DU and the RU, e.g., in several industry forums. The 5G air interface is called the Uu interface.

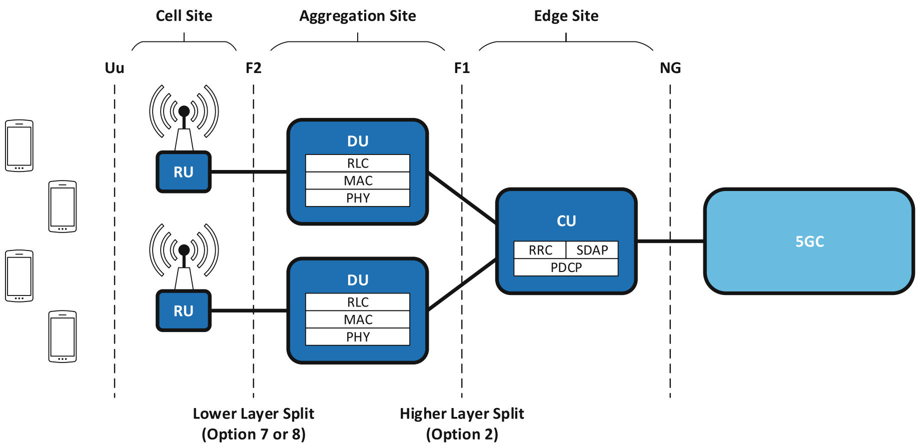

Fig. 2. 3GPP Release 15 NG-RAN architecture.

The different CU-DU-RU configurations and deployment options as well as the additional interfaces interconnecting the different logical entities can be found from the 3GPP Release 15 RAN specifications [2,3] and from [28]. They are also further discussed in the following subsections focusing on the EuWireless studies on RAN virtualisation and slicing.

4.1 RAN Functions Virtualisation

As already mentioned above, the baseline RAN architecture for EuWireless studies is NG-RAN. In addition to the division of the NG-RAN functionalities into the CU, DU and RU as shown in Fig. 2, the Control Plane (CP) and User Plane (UP) functionalities are also separated allowing centralised control for the RAN functions.

There are three main deployment scenarios defined for the 3GPP Release 15 NG-RAN [28]. The first scenario represents a basic case where both the CP and UP functionalities are centralised in the CU as in Fig. 3. This approach enables the installation of all CU functionality near the 5GC services and applications. The CU can reside, e.g., in the MNO's data centre, facilitating the cooperation and management of the overall network. However, if the data centre hosting the CUs is far away from the DUs, the transport latencies can cause RAN performance issues in very demanding use cases. This first deployment scenario is the most interesting one from the EuWireless perspective as it provides the means to centrally coordinate both CP and UP in case of a shared infrastructure with a commercial MNO. It also facilitates the deployment and testing of more elaborate communication schemes in the RAN part of the overall architecture, e.g., with coordinated use of Multiple Radio Access Technologies (multi-RAT) or multi-RAT scheduling.

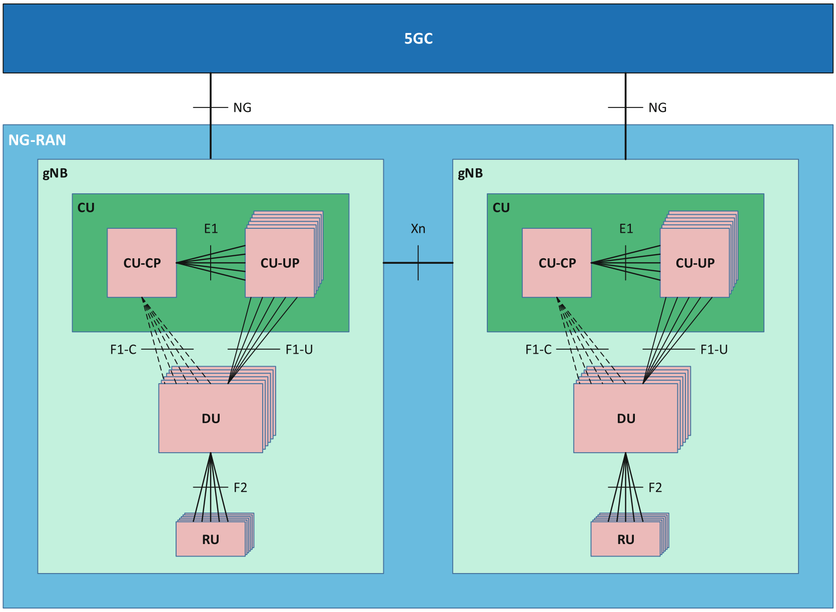

Fig. 3. NG-RAN functional split with centralised CP and UP.

The second and third deployment scenarios allow optimisation either for the control signalling or user data, respectively. In the second scenario, the CP functionality is distributed to the DUs and the UP functionality is centralised in the CU. This approach enables low latency control signalling between the network and the User Equipment (UE). It also decreases the amount of CP traffic in the transport network. In the third scenario, the CP functionality is centralised to the CU and the UP functionality is distributed to the DUs. This allows extremely low latency access to the user specific service and application data, which is cached at the network edge.

Another important reference for future RAN architectures comes from the industry-led O-RAN Alliance, which is currently working on a number of specifications for open and intelligent virtualised RAN architectures [29]. The O-RAN Alliance Reference Architecture is compliant with the 3GPP NG-RAN specifications and extends it with additional open interfaces and design for an intelligent RAN controller entity. The 5G-PPP view on 5G architecture [5] also provides enhancements to the baseline NG-RAN architecture. The main addition in the 5G-PPP RAN architecture is the controller layer, which interfaces with the CUs and adds programmability to CP functionality.

Based on the current consensus in the industry, the virtualisation of the non-real-time part of the gNBs is the natural first step towards fully virtualised RANs. Following the current trends, the O-RAN Alliance Reference Architecture provides a good starting point for EuWireless RAN virtualisation studies and validation tests on top of the GTS platform. Starting from the CU functions, the project will define the virtual object configuration and the related Resource Control Agent (RCA) functionality needed to run RRC, SDAP and PDCP as virtualised resources in GTS.

In the end, atomisation and orchestration of the radio resources between the EuWireless operator and commercial MNOs is needed across multiple cells, administrative domains and heterogeneous operational environments. In addition, the different domains can contain 4G, 5G, WiFi and other wireless access technologies. Consequently, analysis of the possibilities to virtualise the DU functions are performed based on both the nominal performance of the utilised virtualisation and networking technologies, and the measured performance of the GTS architecture and EuWireless PoPs. The final aim is to be able to support as many of the functional split options from [1] as the performance limits of the EuWireless virtualisation framework allow.

4.2 RAN Functions Chaining Scenarios

Flexible distribution and chaining of the virtualised and physical RAN functions open up new possibilities for RAN sharing between EuWireless, MNOs and local research testbeds. Depending on which RAN functions are selected from which infrastructures, the combined virtual testbed/experimentation slice will enable the EuWireless user to do different things. A few example scenarios for the chaining of the RAN functions in EuWireless experimentation slices have been defined for the purpose of Proof of Concept (PoC) testing in the second phase of the project.

The first Service Function Chaining (SFC) [24] example is presented in Fig. 4. In the first simple example, the EuWireless experimenter wants to deploy a large-scale virtual testbed with a simple spectrum sharing scenario based on the selection of RUs from different infrastructures. The RUs are all operating on different frequency bands, but supporting the same Radio Access Technology (RAT). Hence, based on the temporal availability of bandwidth at the different frequencies, the EuWireless experimenter can utilise the RU providing largest amount of free resources on its frequency band at any given time. The actual selection process can be based on historical spectrum occupancy data, real-time measurements or a combination of databases and sensing at different frequency bands.

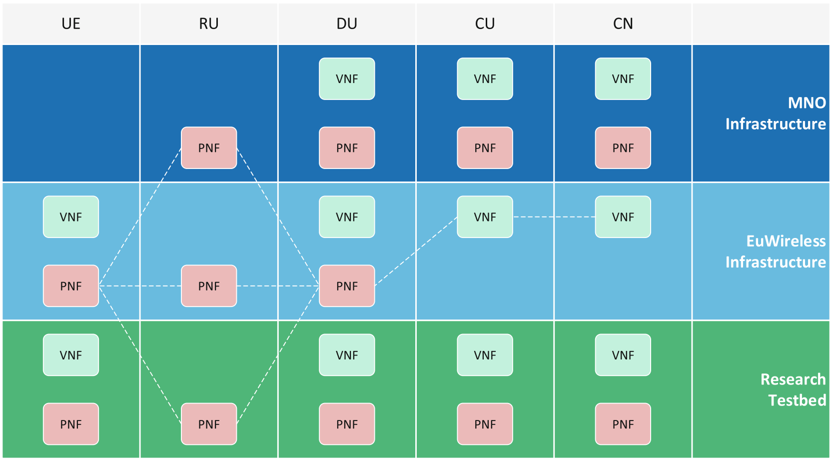

Fig. 4. SFC example between EuWireless, MNO and local research testbed resources.

In order to get the desired functionality into the virtual testbed in this example, the EuWireless experimenter combines the Core Network (CN) and CU VNFs from an EuWireless PoP as the baseline architecture. Similar services would have been available for chaining also from the MNO infrastructure as well as from the local small-scale research testbed either as VNFs or PNFs. In order to reach higher performance in the air interface, the EuWireless experimenter selects the DU PNF from the EuWireless PoP. He/she interconnects it with RU PNFs residing in the same geographical area from the EuWireless PoP, MNO infrastructure and local research testbed. The UE utilised in the tests is a smartphone equipped with an EuWireless SIM card.

The second example scenario is based on the sharing of both the DUs and RUs between the EuWireless PoP, MNO infrastructure and a local research testbed. By following a similar approach for the CN and CU as in the first example shown in Fig. 4, but selecting several DUs and RUs from different network domains, the EuWireless experimenter can deploy a virtual testbed that supports, e.g., multi-RAT and coordinated transmission schemes in the shared RAN.

In the third example scenario, the virtual testbed comprises of shared CUs, DUs and RUs. By extending the sharing of resources to the CU, a more global picture of the shared RAN is available for the EuWireless experimenter, who can now deploy test cases including, e.g., proactive Quality of Service (QoS)/Quality of Experience (QoE) assurance or load balancing between the different network domains.

All of the presented example scenarios require interworking interfaces between the chained VNFs and PNFs. This means that all of the utilised CUs, DUs and RUs should support open standardised interfaces or be from the same vendor if proprietary interface and protocol implementations are utilised. The latter can be the case when legacy RAN components or special functionalities related to smart antennas are desired to be tested as part of the virtual testbed.

4.3 RAN Slicing Implementation Options

Depending on the selected resource sharing and SFC scenarios, the implementation of the virtual testbed, i.e., the experimentation slice, in the RAN can differ from various perspectives. The definition of a RAN slice can be a simplified realisation either with a dedicated RU and frequency band for the EuWireless traffic or with traffic prioritisation using 5G QoS flows [22]. These options provide a straightforward way to implement at least rudimentary slicing in the RAN, but both of them have limitations. When slicing is based on dedicated frequency bands for each slice, the isolation between the RAN slices is good, but the end result is inflexible and uses radio resources inefficiently. On the other hand, when slicing is based only on QoS flows, the setup is flexible and multiplexing of several slices on the same frequency band is possible, but the isolation between the RAN slices is poor.

As already mentioned before, network slicing in the 3GPP Release 15 networks is based on the S-NSSAI parameter, which identifies a network slice and contains information on the service type provided and/or supported by the slice in question. Hence, the provided slicing framework for 5G networks offers a lot more options to find the best compromise between slicing flexibility, efficiency and isolation. The authors in [11] analyse the impact of the high-level functional requirements for RAN slicing in 5G networks from the RAN protocol architecture, network function and management framework design perspectives. The authors in [15] extend the analysis to the level of specific protocol functionalities, messages and parameters at different gNB protocol layers. They propose a solution to implement the slice configuration and management functionality into the NG-RAN protocol stack. They also present simulation results demonstrating the different levels of isolation achieved between RAN slices, depending on the configuration of the shared and dedicated resources at different protocol layers of the RAN slices.

Regarding the different options to implement slicing in the RAN, the authors in [35] analyse four different approaches from the traffic (e.g., overload situations) and radio-electrical (e.g., mutual interference) isolation perspectives. The analysed RAN slicing approaches are based on spectrum planning, Inter-Cell Interference Coordination (ICIC), packet scheduling and admission control functionalities. These approaches are hierarchical in the sense that if resource slicing is performed at the highest spectrum planning level, the configuration of ICIC, packet scheduling and admission control functionalities can be customised for each slice. Similarly, if slicing is implemented utilising ICIC, the packet scheduling and admission control functionalities can be configured slice-by-slice, and so on. The higher in the hierarchy the slicing approach is, the larger is the area and the longer the time window it covers, and the better is the traffic and radio-electrical isolation that can be achieved. On the other hand, the RAN slicing options lower down in the hierarchy, especially the ICIC and packet scheduling-based approaches, offer higher granularity for reconfigurations. Hence, they offer more flexibility and adaptability for dynamic slice management than RAN slicing implemented with high-level spectrum planning.

From the EuWireless perspective, the main RAN slicing feature should be the guaranteed isolation between the MNO resources used for commercial operations and the resources shared with the EuWireless operator. From this starting point, the network functionalities and the level of runtime control over the shared resources offered for the EuWireless experimenter are defined. Hence, for EuWireless, the default option to realise RAN slicing is on the spectrum planning level, e.g., with dynamic spectrum sharing methods. RAN slicing realised with joint packet scheduling between network domains offers an interesting possibility for EuWireless in the future. When the development of commercial network infrastructures continues towards fully virtualised, open and programmable RANs, more and more possibilities for the use of shared resources from different domains with guaranteed isolation become available.

5 Implementation Challenges and Future Work

In the end of the first phase of the EuWireless project, the concept and architecture design for the European mobile network operator for research is finished. With the set of selected key technologies and the initial PoP implementation in Malaga, Spain, the next step in the realisation of the pan-European EuWireless operator is a pilot implementation comprising of multiple PoPs around Europe. With the pilot implementations, feasibility studies for different components of the EuWireless design will be performed on top of the GTS infrastructure. Some high-level challenges and test cases for the next phase of the EuWireless project are introduced below.

RAN Controller Design. One of the key challenges in the creation of virtual testbeds is the design of the RAN controllers and their placement in the overall architecture. When following an SDN-like approach [5,13], the dynamic nature of the wireless medium and the mobile network architecture complicate the task distribution process and information sharing between different controller entities [18]. Additional challenges come from the heterogeneity of the interfaces and protocols used especially in legacy RANs. In addition, the support for the mobile network control functionalities in the current SDN protocols is still missing [34].

The RAN controller architecture also plays an important role in network reliability, scalability, and security. A centralised controller architecture may provide a global network view and facilitate network programmability, but it may cause a single point of failure leading to less reliability. The centralised controller architecture also has scalability issues. Increase in the amount of network devices may limit the performance of the controller since a single controller needs to perform all network control routines requiring large computing resources. On the other hand, a distributed controller architecture overcomes the scalability, reliability and security limitations of the centralised controller at the cost of the global network view and the ease of the MANO implementation. Hence, a hybrid controller architecture can provide a fine trade-off between the centralised and distributed architectures. However, the components and functionalities to be centralised and distributed still need to be defined based on the end user requirements, which in turn may vary greatly between individual use cases, services and applications [33]. Figure 5 shows an example of a hybrid RAN controller architecture.

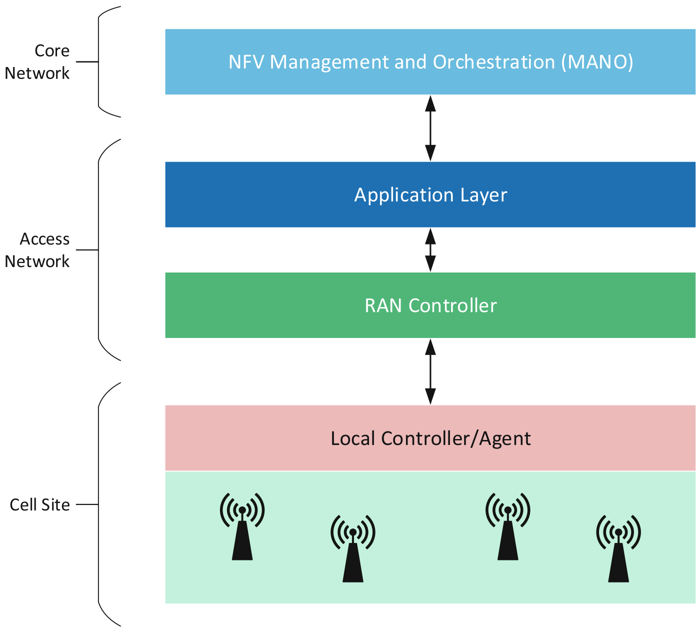

Fig. 5. Hybrid architecture for a software-defined RAN controller.

Virtual RAN Performance. Complex virtualised systems contain a variety of potential performance bottlenecks if not designed and implemented properly. The softwarisation of the RAN requires splitting of the CP and UP functionalities based on the SDN concept, which in turns requires splitting of the 3GPP radio protocol stack. Many protocol functionalities are sensitive to signalling delays and a number of the foreseen 5G use cases rely on high data rates and low end-to-end latencies. Consequently, issues such as excess delay and jitter caused by the SDN CP [19] or by the location and required amount of virtualised RAN functions in the overall architecture become crucial [16]. Poor isolation between the RAN slices can also result in performance issues in the shared infrastructure [31].

Southbound and Northbound Interfaces. The split of the radio protocol stack and the introduction of the RAN controller requires new implementations or at least functional extensions to the current state-of-the-art southbound interfaces between the CP and UP. Since the radio protocol stack and the control functionalities of the cellular network are completely different than the normal computer network protocols/functionalities, new southbound and northbound interface specifications are required for performance-oriented network management and monitoring [18].

Multi-domain Orchestration and Interoperability. Orchestration and interoperability of the network functions becomes a necessity when sharing and combining resources across multiple network domains. First problem in multi-domain orchestration is the availability and dissemination of the required information on configuration and state of the network functions between the different domains. Second problem is the amount and timely processing of the information when it is made available. Related to both, the methods to describe the information so that it is understood by all involved parties [16] and to automate the related processes [31] are of utmost importance.

Cooperation with MNOs. From a non-technical perspective, an essential enabler for the realisation of the EuWireless concept is the willingness of the commercial MNOs to share their network resources with the EuWireless operator. There is a need for new business models and incentives for the MNOs to do closer collaboration with the research community and share both the infrastructures and innovations between the two. These business models and incentives have also been identified as one of the most important outcomes of the EuWireless project. Consequently, business development plans for the EuWireless operator will be prepared to complement the created architecture and technology definitions.

6 Conclusion

This paper briefly introduced the overall concept and architecture for the EuWireless pan-European mobile network operator for research, focusing especially on the RAN. The key enabling technologies to realise the EuWireless vision of virtual large-scale testbeds available everywhere in Europe were reviewed and the designed RAN function virtualisation and slicing framework was presented.

By combining the key resources and assets from the local research testbeds and commercial MNO infrastructures, the EuWireless experimenter is able to pick and choose the functionalities required to deploy the virtual testbed for his/her specific testing needs. The EuWireless PoPs provide a set of selected network resources and all the required interfaces for the EuWireless experimenter to find, reserve and manage the resources belonging to their virtual testbed. As the first phase of the EuWireless project draws to an end with a complete architecture design and individual technology PoC implementations, the second phase will take the presented concept into the large-scale piloting and validation stage.

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