Network Slices Towards 5G Communications: Slicing the LTE Network

Kostas Katsalis*, Navid Nikaein *, Eryk Schiller†, Adlen Ksentini *, Torsten Braun †

*EURECOM, Communication Systems Dept., Sophia Antipolis, France

†Universitat Bern, Communication and Distributed Systems, Switzerland

firstname.lastname@eurecom.fr, lastname@inf.unibe.ch

Abstract

The upcoming 5G ecosystem is envisioned to build business-driven Network Slices to accommodate the different needs of divergent service types, applications and services in support of vertical industries. In this paper, we describe the Network Slicing concept, by unveiling a novel Network Slicing architecture for integrated 5G communications. Further, we demonstrate its realization, for the case of evolved LTE, using state of the art technologies. Finally, we elaborate on the LTE specific requirements towards 5G and point out existing challenges and open issues.

Index Terms

Network Slicing, SDN, NFV, Cloud Computing, LTE, RAN, 5G Communications

I. Introduction

Due to the recent mobile traffic explosion, Mobile Network Operators (MNOs) have been severely challenged to provide the needed capacity increase. However, there is growing consensus that traditional network capacity increase methods, like vertical and horizontal scaling, cannot cope with this demand, since they create excessive operating and capital expenditures. Furthermore, the upcoming 5G ecosystem will involve a number of vertical markets (like automotive, smart grid and IoT) and will support a number of use cases, with extreme diversity on the required service offering. The concept of Network Slicing through efficient resource and services sharing, is increasingly gaining momentum as a promising solution that is able to meet both challenges. It relies on cloud-based approaches for a flexible sharing of resources including antenna, bandwidth, spectrum, processing power, storage, and networking, while enabling novel business opportunities for Over the Top (OTT) service providers and vertical industries. Note that the concept of Network Slices is not new and has been recently refined by Next Generation Mobile Networks alliance (NGMN) [1], adopted and adapted by the main Telecom manufacturers. In principle, a Network Slice can be defined as a composition of adequately configured network functions, network applications and underlying cloud infrastructures, that are bundled together to meet the requirement of a specific use case or business model on a per tenant basis [1], [2].

In this paper, we devise a novel Network Slicing architecture for 5G systems. Our contributions are three-fold. First, a three layer technology agnostic architecture is described, where we introduce a novel Network Slice Service Layer that is responsible for the whole life-cycle management of the Network Slice. Second, the idea of a Network and Application Store is introduced to facilitate the complex procedure of defining the Network Slice. Third, a realization of the concept of Network Slicing, using the LTE network is described to show the feasibility of the proposed architecture, exploiting the current technological landscape. Indeed, LTE is expected to serve as the cornerstone of wireless access technologies for a rich set of use cases towards 5G communications. Particularly, we describe how to actually slice the LTE network and the relevant supporting technologies, methods and techniques. The proposed architecture is generic and can be used to support both the LTE and evolved LTE, while also the heterogeneous 5G Radio Access Network (RAN). In our approach we exploit cloud technologies, Software-Defined Networking (SDN) [3] and Network-Function Virtualization (NFV) [4] as a means to provide the necessary tools to break-down the vertical system organization, while tailoring Network Slices to particular use cases.

This paper is organized as follows. We present the concept as well as the related work. Then we describe a novel Network Slicing architecture. This is used as a reference for the realization of the approach and the creation of Network Slices in LTE networks.

II. Concept, definitions and related Work

According to NGMN, a 5G Network Slice supports the communication service of a particular connection type with a specific way of handling the control and data (user) plane for this service. It is composed of a collection of network functions and specific Radio Access Technologies (RAT) settings, which are combined together for the specific use case or business model [1]. Work on Network Slicing concepts is delivered in the context of the 5G PPP Architecture Working Group activities, while also delivered in various EU projects. In the METIS II project, the Network Slicing requirements are described [5], resulting on the definition of the main categories of slices. These are related to three generic services: extreme Mobile BroadBand (xMBB), ultra-Reliable Low Latency Communication (uRLLC), and massive MTC (mMTC), while RAN is one of the main enablers. In 5G-NORMA project, SDN and NFV technologies are exploited to enable dynamic sharing of network resources among operators [6]. From the industry perspective, a similar description is provided by Ericsson (5G Systems, white paper, 2015). ITU-T is also in the field, the ITU FG Group IMT-2020 analyses how emerging 5G technologies will interact in future networks and also focus on the topics of Network Slicing orchestration and management. Clearly, from all the existing definitions and approaches, the foundation of 5G Network Slices is built around: virtualization technologies, multi-tenancy and multi-service support, integrated network programmability and the adoption of the SDN/NFV design paradigms [6].

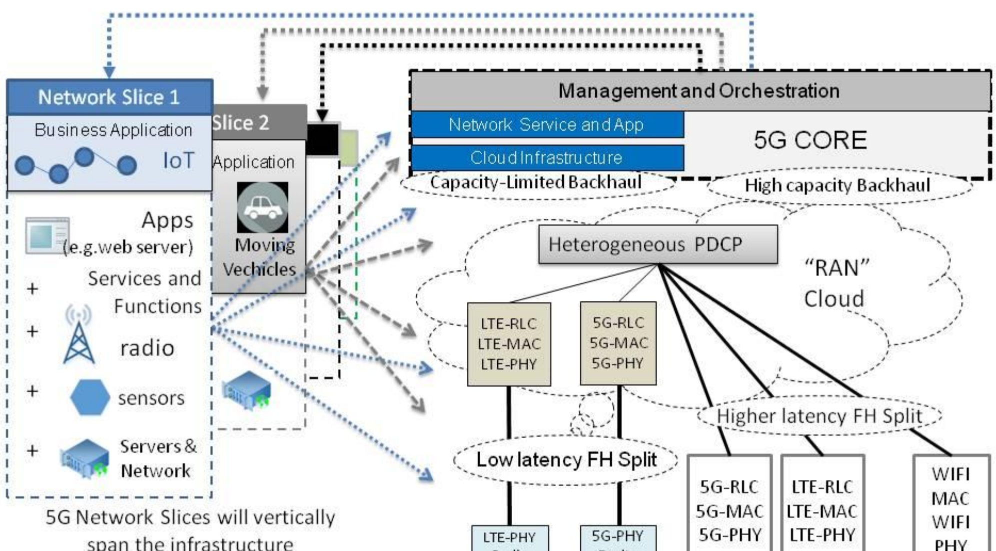

Figure 1: Network Slicing at the 5G RAN. A 5G Network Slice is a bundle of network services, functions, network applications, resources, accouterments

A. Network Slices in the heterogeneous RAN

The wireless domain of the envisioned 5G systems will be heterogeneous and composed by a number of technologies mainly the evolved LTE, a New Radio access technology (e.g. Millimeter Waves) and New Generation Wi-Fi (e.g. 802.11ax). For the LTE domain, 3GPP has agreed on a detailed work plan for Release-15, the first release of 5G specifications. These are described in the 3GPP-Technical Specifications Group (TSG)-72 activities. In the envisioned 5G environment, Network Slices are expected to vertically span the infrastructure environment and actually utilize any available type of physical or virtual resource of the 5G heterogeneous RAN, as shown in Fig. 1. In order to provide vertical Network Slices the necessary control and management procedures must run in a technology agnostic way of the actual access network implementation. To enable Network Slicing in the future mobile network generation, 3GPP SA and 3GPP RAN groups are building technical specifications to integrate Network Slicing in the upcoming specifications. More specifically, the 3GPP SA group is discussing a solution to enforce Network Slicing using the eDECOR concept (3GPP, TR 23.711, release 14). This is a solution recently specified to implement the principle of Dedicated Core Network (DCN). The RAN Sharing concept is studied by the 3GPP RAN groups and is already utilized by Mobile Virtual Network Operators (MVNOs). The aim of these activities is to combine the concept of RAN sharing and the eDECOR to create an end-to-end Network Slice.

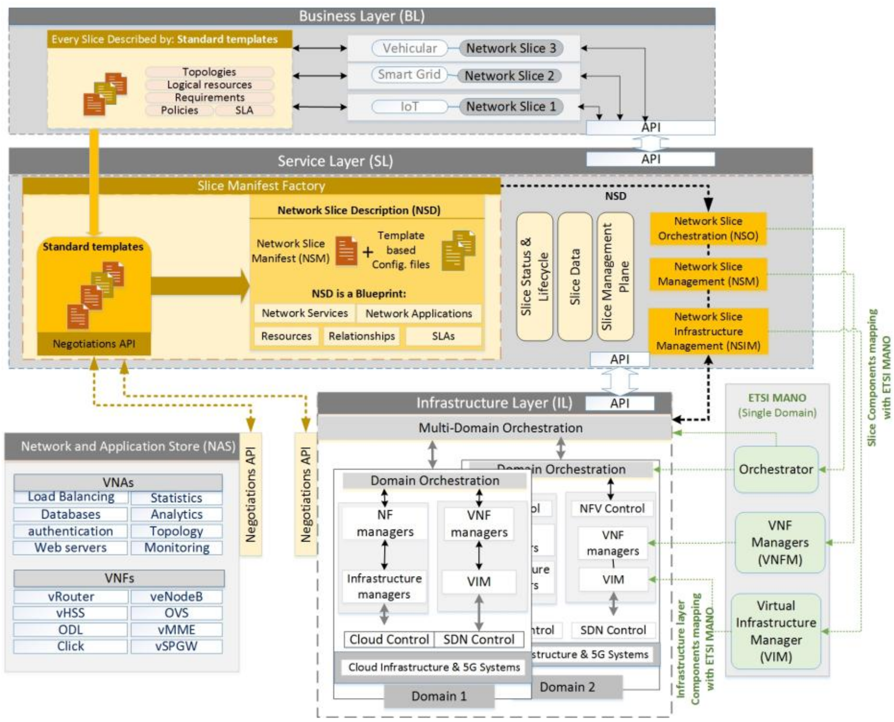

Figure 2: Network Slicing Architecture towards 5G communications

III. Network Slicing-enabled 5G Architecture

In this section, we present the main design elements of a proposed Network Slicing architecture, which is illustrated in Fig.2. Our proposal stands for a three-layer design that includes: a Business Layer (BL), a Network Slice Service Layer (SL) and an Infrastructure Layer (IL), together with the operation of Network and Application Store (NAS). Note that an initial design of the architecture was proposed in [7]. However, in this paper we extend the analysis of the SL operations, while we elaborate in detail on the complex procedures to define and deploy a Network Slice description. We highlight, that despite the multitude of proposed architectures toward 5G communications ([8], [5], [9]), there is no single design available for a unified framework that supports the Network Slicing concept and at the same time is able to:

- efficiently capture the need for integrated network programmability and SDN control,
- support service orchestration and NFV techniques in multi-domain RAN,
- provision for concepts like the Cloud-RAN and the Mobile Edge Computing (MEC).

As the concept of Network Slicing is in an initial state, the proposed architecture can serve as a reference point and alleviate a number of important design issues related to the Network slicing lifecycle and management. The innovation of the approach lies on the design and operation of the SL and the interaction with the NAS and IL. In the following we analyze the different components of the proposed architecture.

A. Business Layer (BL)

5G networks must cope with a wide range of use cases and must be able to satisfy strict performance requirements. These use cases span from public safety, high mobility and business critical applications, to IoT and high speed broadband vehicular access; covering three categories as defined in METIS II project (i.e. xMBB, uRLLC and mMTC). The slice owner on top of the Business Layer creates the desired use case (e.g. IoT) and is the one that actually triggers the building of the Network Slice. Such a use case can be based on standard reference network slice templates that describe the existing business application.

B. Network Slice Service Layer (SL)

This layer supports all the functions used for the life-cycle management of each Network Slice, related to the deployment, instantiation, management, control, scaling and termination of the network slices. It is also the layer where the transformation of network slice templates to an operational bundle of resources and services is made, tailored to a particular use-case. The bundle is described by an end-to-end Network Slice Descriptor (NSD) that also provides details on the data models and interfaces across the network functions and applications.

Network Slice Description (NSD): A NSD is used to describe the slice by means of resources, services, relationships and service functions chains. Due to high complexity of the required components, NSD is a Network Slice Manifest file (NSM) with metadata for a group of accompanying files that are describing a coherent Network Slice. The accompanying files are based on templates that define all the details required by the SL. That is, a service template is particular for a specific service and needs to define the input parameters, configuration primitives, the relationships/dependencies, resources and constraints, units (number of instances) as well as machines (physical or virtual), and domains of operation. NSD also includes the necessary configuration primitives for the slice instantiation and operation. The complex procedure of the NSD/NSM creation is made in a Slice Manifest Factory (see Fig 2, SL center). Note that due to high degree of multi-tenancy, a negotiation component is also required. While a logical definition of services and networks is initially provided by the verticals from the Business Layer to the SL, a negotiation procedure will actually provide the final delimited NSD.

- Negotiation between SL and IL: SL needs to exploit the best/maximum of the infrastructure offering.
- Negotiation between SL and NAS: exploit the best templates that can be re-used for network functions and network applications

After the negotiations, the final NSD/NSM are created and then passed to a Network Slice Service Orchestrator (NSO) entity, in order to provision and deploy service bundles and actually drive the orchestration procedures.

SL Internals: Our design is based on the ETSI NFV-MANO concepts of management and orchestration, delivered by the ETSI NFV ISG [10], while we consider that in this layer the relevant software components operate on a Slice basis rather than a domain-basis. In this layer, all the slice related functionalities are performed including the slice lifecycle management and upgrade procedures. More specifically, in the SL the network services operate under the control of a Network Slice Service Manager (NSM) and a dedicated Network Slice Service Orchestrator (NSO). The NSO orchestrator entity is responsible for the composition and on-demand allocation and creation of all the Physical Network Functions (PNF) and VNFs requested for the virtual slice, combined with their inter-connectivity and support services. The orchestrator entity operates on top of a distributed NSM, which is responsible for the life-cycle management of the entire Network Slice. The NSO in turn, interacts with a Network Slice Infrastructure Manager (NSIM) which handles the allocation of virtual resources (computing, storage, network), through interaction with the Infrastructure Layer. The interaction with the IL is made through communication between the NSIM operating in the SL and a hierarchical multi-domain orchestrator in IL. Note that currently there is no single definition about multi-domain orchestration and indeed multi-domain is an open issue according to the work made in ETSI. Depending on the context it can be administrative based, technology based, area based or operator based. Our design is generic enough to include all these cases. The SL design also considers for additional services, like slice data management and additional supported services required for the slice operation and maintenance.

C. Network and Application Store (NAS)

Supporting complex use-cases on per Network Slice basis, requires the coupling of a rich set of Virtual Network Functions (VNFs) and Virtual Network Applications (VNAs). A marketplace of VNFs and VNAs can be thought of as the network counterpart for mobile application stores, like the Google Play Store for Android applications. Essentially, with NAS, one can deliver customized network function and service templates tailored to particular use-cases. For example, an LTE network slice can result from several templates, which dynamically install, and configure all the LTE network-specific elements for both the packet core and the access network. We consider that NAS must be able to support multiple Stores that will be however exposed to the SL using a common API. The main idea is that in order to create a vertical Network Slice, we can easily discover and consume: a set of VNFs like virtual routers, switches or firewall services; and VNAs like Hadoop clusters, web servers or databases. A distinction between VNAs and VNFs must be made, as their execution environment and SDK are potentially different, while the SL needs to be aware of them during the negotiation. Note that according to the definitions provided by ETSI MEC, Mobile edge (ME) applications are running as virtual machines (VM) on top of virtualized infrastructures and can interact with the mobile edge platform to consume and provide mobile edge services. According to the terminology used in ETSI MEC working group, a ME application can be either a VNF or VNA.

D. Infrastructure Layer (IL)

This layer shall support real-time re-configurable cloud ecosystem and virtualization for fast and ultra-fast services. In addition, it supports connectivity as a service and delivers the resulted bundle of network services. In more detail, the IL includes the bare metal physical infrastructure and the virtualization layer that is responsible for the physical resource abstraction. The relevant design elements include programmable computing, network and storage hardware, programmable RF hardware and software and any type of programmable networks. It also includes the cloud and network (SDN-based) control systems. The SDN network control is about establishing communication between Physical Network Functions (PNFs), VNFs and VNAs on-demand. Furthermore, efficient SDN control methodologies are used to promote network agility and facilitate the SLA-based network configuration. Finally, we consider operation over multi-cloud providers, where both physical and virtual infrastructures are available like Amazon, MaaS, and local environments. A multi-domain orchestrator is running on top of all the PNF/VNF Managers and Cloud/SDN controllers, managing the end-to-end operations in the IL.

IV. From Virtual Slices to Real Deployment: Slicing in LTE Evolution

In this section, we describe a realization of the proposed architecture in the case of LTE networks. Note that the proposed architecture is technology agnostic and can be realized with other wireless technologies as well, like 5G New Radio or New Generation Wi-Fi. We elaborate on the way to create LTE Network Slices using the open source OpenAirInterface (OAI) software platform, supported by the OpenAirInterface software Alliance. OAI offers for a software implementation of the whole LTE protocol stack, and it can operate over commodity hardware for the deployment of the eNodeB and the Core Network (CN).

Although the Network Slicing concept seems as a natural evolution of virtualization, even for some simple use cases, its realization can be extremely complex. In addition the LTE the control procedures are inherently complicated for both the control and data plane and these are related to IL. For the ease of understanding we describe a simple example with the interactions between the layers.

A. Example of a LTE Network Slice with enhanced Mobile BroadBand (eMBB) support and QoS

We consider for a simple modeling approach with the following three phases: planning, provisioning and operation:

- **Planning Phase**: A request for a LTE Network Slice with eMBB support and QoS guarantees is made from the BL to SL, using a logical, technology agnostic, NSD. The request describes the network topology of the EPC and eNodeB elements, together with interconnect requirements and the requested QoS.
    - Negotiation A (between SL and NAS): A policy-based and SLA-compliant set of PNF and VNFs must be exposed to the SL for the specific request. The logical NSD is translated by the NAS into distinct VNFs. The idea is that while for example the SL triggers a request for a Mobility Management Entity (MME), the NAS returns the best-matching VNF by means of policing and

QoS satisfaction. In order to be completely hardware agnostic, the NAS only interacts only with the SL and not with the IL.
    - Negotiation B (between SL and IL): The multi-domain orchestrator is the IL component that interacts with SL. Note that any type of resource or required communication should take into account SLAs of the composed VNAs and VNF bundles.

In our example, because the real-time base-station system (the eNodeB) requires for given delay guarantees and EMBB, a specific scheduling approach and channel mapping procedure needs to be considered. After this negotiation, the final NSD/NSM is derived.

- **Provisioning Phase:** All the hardware/software components are provisioned by messaging in the IL layer (triggered by the IL multi-domain orchestrator), a specific scheduler is used at the eNodeB to satisfy the SLA agreements, and SDN control has being applied to configure the switch fabric. All the software components (like NSIM and NSM) have been initialized in the SL for this specific Network slice.
- **Operation Phase:** Network is operational, end-to-end data bearers are established and traffic performance indicators and network services are monitored, while actions are taken in case of degradation. The lifecycle management and control of the Slice and enforcement of the actions to overcome degradation is made through the NSSO orchestration functions and interactions with the NSSM and the NSIM.

B. LTE Network slices: Technology landscape

In this section, we describe the current landscape of technologies and tools that can drive the actual implementation of the Network Slices for LTE networks. A summary is depicted in Table I.

1) Network Slice Service Layer (SL): Research activities like [11] are describing issues related to SL, however they are more relevant to IL operations. For the actual implementation of the SL, there is no framework that could even partially cover the functionalities required. Regarding the NSD/NSM files recent activities are around the TOSCAN [12] model, while IBMs Blueprint and custom solutions are proposed. However still no mature solution is available.

2) Network and Application Store: Service catalogs with PNFs and VNFs are implemented in the context of FP7-TNOVA, FP7-Unify, FP7MCN, H2020 SONATA projects. Service developers publish their PNFs and VNFs software, which can be used by other developers. A complete VNF marketplace and management system is also supported by the Canonical's JUJU Framework.

Table 1: Technology drivers

Layer	Technology Drivers
SL	**SL** (NSO, NSM, NSIM): Nothing Available. **NSD/NSM**: TOSCAN [12], IBM's Blueprint, rSLA
NAS	FP7-TNOVA (www.t-nova.eu): developers can sell their PNFs and VNF software through auctioning EU FP7-UNIFY (www.fp7-unify.eu): Information Base, where the resource characteristics of PNFs can be stored FP7-MCN (https://www.mobile-cloud-networking.eu/): a Service Catalog lists network services composed of multiple network functions EU H2020 SONATA (www.sonata-nfv.eu): emulation platform to support network service developers to locally prototype and test complete network service chains **Open Source JUJU Charm Catalog** (https://jujucharms.com)
IL	• **Orchestration**: Openstack Tacker, Rift IO, Hurtle, Open-O, Open-Baton, Cisco's Network Services Orchestrator (NSO), Huawei CloudOpera • **VNFM**: Canonical JUJU, Cloudify, Nokia CloudBand Application Manager, Cisco Elastic Services Controller (ESC) VNFM, Ericsson Network Manager (ENM), Huawei CloudOpera • **VIM**: OpenStack, CloudStack by Citrix, Cloudify, Ericsson Cloud Manager (ECM), Microsoft Azure, Google and Amazon clouds, Hypervisor Technologies (KVM, DOCKER, LCX/LXD, XEN, ESCi etc)

C. Infrastructure Layer for LTE Network Slices
In the evolved LTE, Network Slicing is closely related to the concept of RAN Sharing for multi-service offering. 3GPP has defined and ratified different kinds of architectures with varying degrees of sharing (see 3GPP TS 23.251 specification). By means of mobile network resource sharing actually three dimensions of the problem exist.

- Sharing the Processing/Network/Storage Infrastructure: The switch fabric and the core network/system (cpu, storage, memory) are virtualized and shared between tenants, for the deployment of physical or virtual network elements (e.g. SP-GW, MME, HSS) [13].
- Sharing the base station resources: Different sharing schemes and scenarios exist where the focus stays on the way the Physical Resource Blocks (PRBs) in frequency/time/space domain, are shared in the MAC layer to provide isolation, while maintaining the multiplexing gain [14].
- Sharing the Spectrum resources: The spectrum sharing problem is not related to MAC layer operations. It is related to the band of operation or activation of a component carrier. If multiple operators can share bands, the band of operation can be dynamically adjusted. Cognitive radio techniques fall under this category.

1) Cloud & NFV Control, management and orchestration when slicing the RAN: For the deployment of both the EPC and the eNodeB, commodity hardware as the one used for typical processing and Openstack cloud control with hypervisor (e.g. KVM) or container based (e.g., LXC/LXD, Docker) virtual machine technologies can be used. In addition, a pervasive perception, especially from the Telecom operator side, considers for the coupling of cloud technologies with NFV in order to alleviate the problem of LTE services dependency in hardware. In Table I we summarize technologies and frameworks that can be used to support the functionalities required by the IL.

However, natural questions arise in this case: Is the explosion of LTE elements as VNFs feasible? What is the cost of deploying LTE services as VNFs on top of virtualized environments? Or there will be performance degradation? What about the VIM and Orchestration efficiency in the case of LTE networks? Whilst in the following we answer the first three questions through two implementation experience examples, there is no clear answer for the third.

Implementation Experience A: Running LTE components in VMs
In [2], the LTE as a Service slice (LTEaaS) framework was presented, where both the EPC services and the eNodeB were deployed in a virtualized environment, using Openstack and Linux LXC containers. The OpenStacks Heat orchestration Templates (HoT) were used to describe the specification of the LTE network elements. In this approach, all the advantages of using cloud control and services can be exploited to meet a number of challenges, like scalability issues or hardware dependencies. However no control on the slice itself is provided after the deployment.

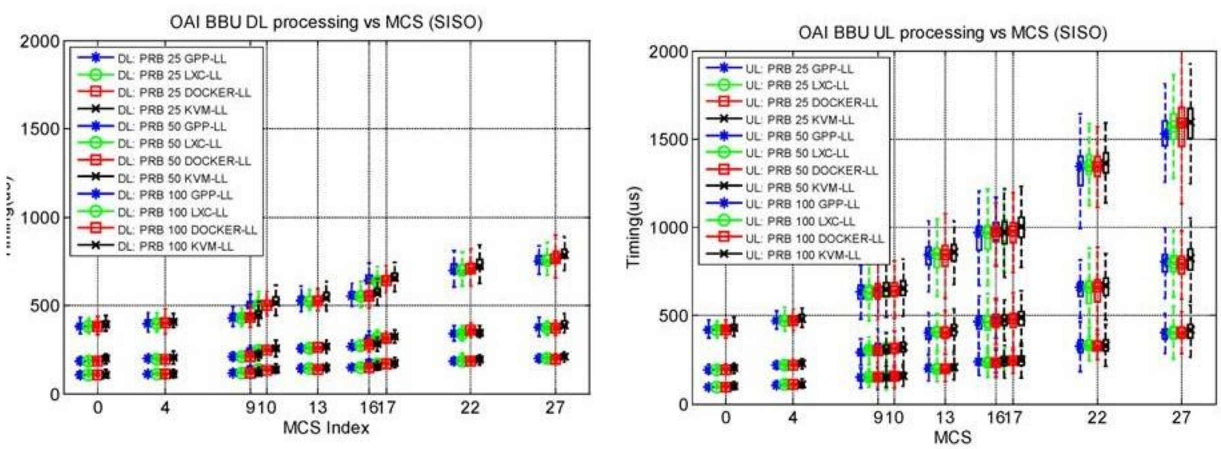

Figure 3: Performance Comparison on running virtualized LTE

Regarding the performance when running LTE services in a virtualized environment, Fig. 3 compares the BBU processing budget of a general purpose processor (GPP) platform with different environments, namely LXC, Docker and KVM for the downlink (left) and the uplink (right). While, on average, the processing time are very close for all the considered virtualization environments, it can be observed that GPP and LXC have slightly lower processing time variability than that of DOCKER and KVM, especially when the data rate increase, i.e. higher Physical Resource Blocks (PRB) and Modulation and Coding Scheme (MCS). Processing load is mainly dominated by uplink and increases with growing PRBs and MCSs. Furthermore, the ratio and variation of downlink processing load rate to that of uplink also grows with the increase of PRB and MCS. Indeed the performance degradation can be negligible when running the LTE services over a virtualized environment. These results however depict the performance assuming no multi-tenancy and no multi-user transmission. In a shared environment, concurrent operation of virtualized services coupled with high processing variability by multiple tenants, can greatly affect the performance of all the different Slices, sharing the underlay infrastructure.

Implementation Experience B: LTE components as VNFs with OAI and the JUJU Framework
Our recent collaboration with Canonical (the company behind Ubuntu), has led to the open-source exposure of the whole OAI LTE protocol stack for the EPC (MME, SP-GW and HSS) and the eNodeB entities using the JUJU VNFM framework. The eNodeB supports both a) legacy 3GPP and b) Base-band Unit (BBU) and Remote Radio Unit (RRU) in support of functional split and Ethernet-based fronthaul.
The NFV concept in JUJU is built around software components called Charms. JUJU Charms are actually the set of scripts that encapsulates the VNF. A charm contains all the needed logic to deploy, integrate, scale and expose the service to the outside world.

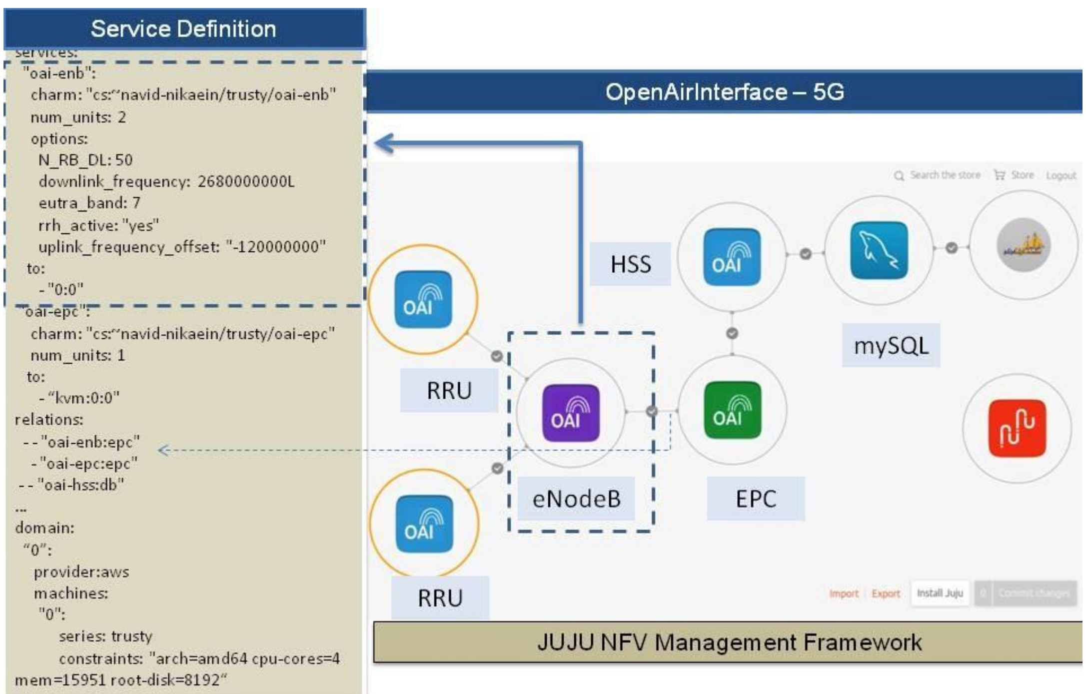

Figure 4: JUJU and OAI: The first open-source LTE VNF solution.

As shown in Fig. 4, the OAI solution can be chained together using JUJU charms relationships, while relationships can be established with IP Multimedia Subsystem (IMS) charms (provided for example by OpenIMS or ClearWater) to rapidly build applications over LTE such as voice and video. A sample definition for a single VNF, where the OAI-eNodeB is exposed, is presented in the left hand-side of Fig.4. Note that in order to have a complete functional VNF system, the total provisioning time derives from a summation of sequential steps: a) VM installation from a local or remote image, b) resolving packages dependencies and c) service installation and actual deployment. To give some insights on the LTE eNodeB deployment as VNF, using the JUJU system over a clean installation requires 600secs, configuration 4sec, while service upgrades may require 122-300sec. These values are greatly affected of course by the available hardware and network and configuration options.

2) SDN control and programmable RAN elements: One important feature that a network slicing architecture should integrate is the ability to control, in real time, the configuration of resources dedicated to one Slice. To this aim, integrated network programmability and open APIs using the SDN approach is the indented way to actually control the network segment in support of Network Slicing.

- *SDN Control on the switch fabric:* SDN control can be used to facilitate network agility through efficient control, coordination, and management of the physical or virtualized EPC core network. For example, SDN control can be used to control the virtual switches used for the virtual network interconnect. In addition, new control plane enhancements are now emerging. For example, SDN control is proposed to facilitate efficient S1-Flex operations. In this case, multiple (MME, S-GWs) elements can serve a common area, while connected by a mesh network to the set of eNodeBs.
- *Programmable eNodeB:* For the realization of Network Slices at the eNodeB, efficient resource allocation and scheduling policy are required on per tenant basis. Dynamic radio network functions chaining is also required to adapt the operation of the eNodeB for each tenant and support a multi-service architecture. These issues are also investigated in the 5G-NORMA project.

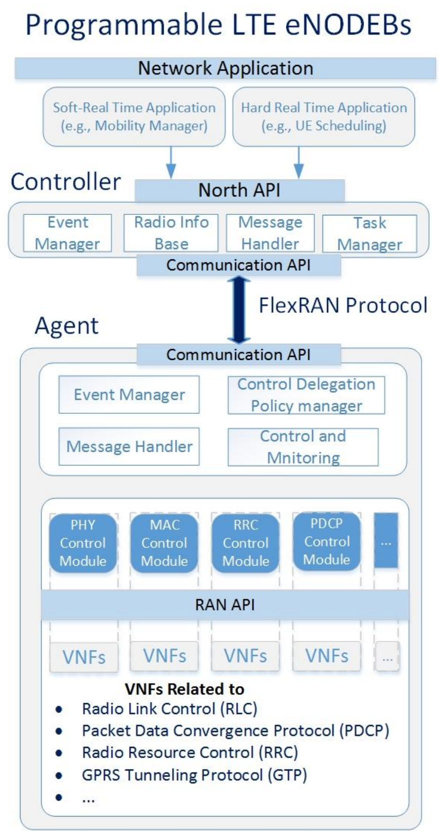

Figure 5: The FlexRAN protocol, Agent and Controller.

Whilst controlling switch fabric and EPC core network could be easily managed by SDN and its southbound API, programming the RAN and managing its resources on run-time is very challenging. Indeed, a programmable RAN underlay is absolutely essential in order to enable active sharing though functionalities that can be exposed to an integrated control plane. Most importantly, real-time constraints in the eNodeB impose extreme challenges, since towards 5G communications, responsiveness in control and coordination must be in sub ms level. Thus, available southbound APIs and protocols like NetConf, Openflow and REST, will not work in that case.
In our approach, we exploit a novel southbound control protocol called FlexRAN, which was first proposed and analyzed in [15], using OAI-based LTE systems. In Fig. 5 a high level representation of the solution is depicted. The standard separation of the control and the data plane is used, with an Agent that resides in the eNodeB communicating and interacting with a real-time Controller entity. In contrast to traditional wired-SDN approaches, time critical zones are considered for the re-programmability of the data plane on the fly by centralized controller or be delegated to the local agent. The agent exposes a set of RAN APIs, which can be used to control one or many local network functions potentially exposed as VNFs in the eNodeB. The considered network functions controlled

by the agent include a) time-critical VNFs like user-specific PHY processing and MAC/RLC scheduling functions and b) non-time-critical VNFs like statistics gathering and PDCP/GTP functions. Note that the orchestrator logic is the one that will trigger per-slice resource and service provisioning; the controller-agent will be responsible for all the management procedures at the eNodeB at multiple time scales.

V. CHALLENGES AND OPEN QUESTIONS

The most important open issues are related to the SL, since there is no solution available. Furthermore, effort must be given for the interfaces and APIs definition among all the architecture layers. Questions related to the NFV management and ETSI NFV MANO equivalence and the role of Network Slicing and the way it can be actually realized in the wireless domain, remain open. Furthermore, the SDN/NFV coupling in native LTE control plane designs can potentially support slice-based SLA-driven RAN designs, that are however missing.

Regarding workflows and service chains control of slice clients, the way we identify the users and guarantee isolation is an open research topic, while for the slice life-management network operator needs to provide APIs for slice/system monitoring.

One additional dimension is related to orchestration procedures and the way the ETSI NFV MANO proposal needs to be extended and actually implemented. What is multi-domain orchestration and how we can achieve it? Which are the domain boundaries? Extending the notion of domain to multi-domain, the idea is that many domains that offer specific functionality are jointly considered and exploited to deliver their functionality as a whole.

V. CONCLUSIONS AND FUTURE WORK

In this paper, we described a novel Network Slicing architecture for integrated 5G communications, featuring the heterogeneous wireless domain. We demonstrated its realization for the case of evolved LTE using state of the art technologies. We also elaborated on the LTE specific requirements towards 5G and point out existing challenges for Network Slicing in the context of multi-domain, multi-tenant environments.

ACKNOWLEDGMENTS

This work has been supported by the 5G-PPP project Coordinated Control and Spectrum Management for 5G Heterogeneous Radio Access Networks (COHERENT), H2020/JP 5G!Pagoda project and FP7 FLEX.

REFERENCES

[1] N. Alliance, “Description of network slicing concept,” NGMN 5G P1, vol. 1, 2015.

[2] N. Nikaein, E. Schiller, R. Favraud, K. Katsalis, D. Stavropoulos, I. Alyafawi, Z. Zhao, T. Braun, and T. Korakis, “Network store: Exploring slicing in future 5g networks,” in Proceedings of the 10th International Workshop on Mobility in the Evolving Internet Architecture. ACM, 2015, pp. 8–13.

[3] V.-G. Nguyen, T.-X. Do, and Y. Kim, “Sdn and virtualization-based lte mobile network architectures: A comprehensive survey,” Wireless Personal Communications, vol. 86, no. 3, 2016, pp. 1401–1438.

[4] S. Abdelwahab, B. Hamdaoui, M. Guizani, and T. Znati, “Network function virtualization in 5g,” IEEE Communications Magazine, vol. 54, no. 4, 2016, pp.84–91.

[5] I. Da Silva, E. Authors, S. El Ayoubi, O. Boldi, O¨ . Bulakci, P. Spapis, M. Schellmann, H. ERC, J. Monserrat, T. Rosowski et al., “5G RAN architecture and functional design,” METIS II White Paper, 2016.

[6] P. Rost, C. J. Bernardos, A. De Domenico, M. Di Girolamo, M. Lalam, A. Maeder, D. Sabella, and D. W¨ubben, “Cloud technologies for flexible 5g radio access networks,” IEEE Communications Magazine, vol. 52, no. 5, 2014, pp. 68–76.

[7] K. Katsalis, N. Nikaein, E. Schiller, R. Favraud, and T. I. Braun, “5g architectural design patterns,” in Communications Workshops (ICC), 2016 IEEE International Conference on. IEEE, 2016, pp. 32–37.

[8] P. Rost, A. Banchs, I. Berberana, M. Breitbach, M. Doll, H. Droste, C. Mannweiler, M. A. Puente, K. Samdanis, and B. Sayadi, “Mobile network architecture evolution toward 5g,” IEEE Communications Magazine, vol. 54, no. 5, 2016, pp. 84–91.

[9] C. J. Bernardos, A. De La Oliva, P. Serrano, A. Banchs, L. M. Contreras, H. Jin, and J. C. Z´u˜niga, “An architecture for software defined wireless networking,” IEEE wireless communications, vol. 21, no. 3, 2014, pp. 52–61.

[10] R. Mijumbi, J. Serrat, J.-l. Gorricho, S. Latre, M. Charalambides, and D. Lopez, “Management and orchestration challenges in network functions virtualization,” IEEE Communications Magazine, vol. 54, no. 1, 2016, pp. 98–105.

[11] K. Samdanis, X. Costa-Perez, and V. Sciancalepore, “From network sharing to multi-tenancy: The 5g network slice broker,” IEEE Communications Magazine, vol. 54, no. 7, 2016, pp. 32–39.

[12] T. Binz, G. Breiter, F. Leyman, and T. Spatzier, "Portable cloud services using tosca," IEEE Internet Computing, vol. 16, no. 3, 2012, pp. 80–85.

[13] A. Antonopoulos, E. Kartsakli, A. Bousia, L. Alonso, and C. Verikoukis, "Energy-efficient infrastructure sharing in multi-operator mobile networks," IEEE Communications Magazine, vol. 53, no. 5, 2015, pp. 242–249.

[14] R. Kokku, R. Mahindra, H. Zhang, and S. Rangarajan, "Nvs: A substrate for virtualizing wireless resources in cellular networks," IEEE/ACM Transactions on Networking (TON), vol. 20, no. 5, 2012, pp. 1333–1346.

[15] X. Foukas, N. Nikaein, M. M. Kassem, M. K. Marina, and K. Kontovasilis, "Flexran: A flexible and programmable platform for software-defined radio access networks," in Proceedings of the 12th International on Conference on emerging Networking EXperiments and Technologies. ACM, 2016, pp.427–441.

BIOGRAPHIES

Dr. Kostas Katsalis is a research felllow in EURECOM, Sophia Antipolis, France. He holds a Ph.D. (2010-2015) and a MSc (2007) in Electrical Engineering both from University of Thessaly, Greece under the supervision of Prof. Leandros Tassiulas. He received his diploma in Electrical and Computer Engineering from University of Patras, Greece in 2005. He was a research associate and a researcher in CERTH-ITI, Greece for 6 years, while he also has 2 years experience in the mobile services industry. He has participated in the technical management activities for the FP7 CONTENT project and 5G-PPP XHAUL, and he is now involved in the 5G-PPP COHERENT and the Fire+ Q4Health projects. His research interests focus on Software Defined Networks (SDN), Network Function Virtualization, Network Slicing and RAN sharing, Stochastic Control Theory and network optimization.

Navid Nikaein is an assistant professor in Communication System Department at Eurecom since 2009. He received his Ph.D. degree in communication systems from the Swiss Federal Institute of Technology EPFL in 2003. Currently, he is leading a research group focusing on experimental system research related to wireless systems and networking. Broadly, his research interests include wireless access and networking protocols (4G/5G), cloud-native and programmable mobile network (SDN, NFV, MEC), and real-time RF prototyping and emulation/simulation.

Eryk Schiller received two M.Sc. diplomas; in Electronics & Telecommunications from the University of Science and Technology and in Theoretical Physics from the Jagiellonian University, Cracow, Poland, in resp. 2006 and 2007. He got a Ph.D. in Computer Science from the University of Grenoble, France in 2010. He was a postdoctoral scholar at the University of Neuchatel, Switzerland. Since 2014, he is with the University of Bern, Switzerland as a senior researcher.

Torsten Braun got his Ph.D. degree from University of Karlsruhe (Germany) in 1993. From 1994 to 1995 he has been a guest scientist at INRIA Sophia-Antipolis (France). From 1995 to 1997 he has been working at the IBM European Networking Centre Heidelberg (Germany). He has been full professor of Computer Science at the University of Bern (Switzerland) since 1998 and a member of the SWITCH (Swiss education and research network) board of trustees since 2001.

Adlen Ksentini received his M.Sc. degree in telecommunication and multimedia networking from the University of Versailles Saint-Quentin-en-Yvelines, and his Ph.D. degree in computer science from the University of Cergy-Pontoise in 2005, with a dissertation on QoS provisioning in IEEE 802.11-based networks. From 2006 to 2016, he worked at the University of Rennes 1 as an assistant professor. During this period, he was a member of the Dionysos Team with INRIA, Rennes. Since March 2016, he has been working as an assistant professor in the Communication Systems Department of EURECOM. He has been involved in several national and European projects on QoS and QoE support in future wireless, network virtualization, cloud networking, and mobile networks. He was a Guest Editor of IEEE Wireless Communications, IEEE Communications Magazine, and two issues of ComSoc MMTC Letters. He has been on the TPCs of major IEEE ComSoc, ICC/GLOBECOM, ICME, WCNC, and PIMRC conferences. He is currently the Vice-Chair of the IEEE COMSOC Technical Committee on Software (TCS).