A SDN/NFV based C-RAN architecture for 5G Mobile Networks

Gianluca Camillo Valastro, Daniela Panno, Salvatore Riolo
Dept. of Electrical, Electronics and Computer Engineering, University of Catania, Italy
Email: gianluca.valastro@unict.it, daniela.panno@dieei.unict.it, salvatore.riolo@unict.it

***Abstract*—A novel architecture design for Radio Access Networks (RANs) to address critical elements in resource management and to achieve the 5G mobile network requirements is needed. Cloud Radio Access Network (C-RAN) and Software Defined Networking (SDN) / Network Function Virtualization (NFV) technologies are recognized as key enabling solutions for the future mobile networks. C-RAN is a new mobile network architecture, characterized by a redistribution of functionalities. More specifically, the baseband processing resources are centralized in remote locations, known as Base Band Unit (BBU) Pool, whereas the radio functionalities, known as Remote Radio Head (RRH), remain in edge locations. SDN focuses on decoupling control and data plane, while NFV performs the functionalities abstraction from the underlying hardware. In this paper, a hierarchical layered software-defined architecture for future 5G networks is proposed. We deploy a Next Generation Fronthaul Interface (NGFI) based architecture, in order to overcome issues related to massive MIMO deployment. Furthermore, in order to implement dynamically different functional splitting options, a virtualized Remote Aggregation Unit (RAU) is proposed. As further contribution, our solution aims to provide new features that facilitate SDN/NFV integration in wireless/mobile environments.**

***Index Terms*—5G, Cloud-RAN, SDN, NFV, NGFI, RAU, Centralization, Fronthaul**

I. Introduction

In the next decade, future mobile networks will fulfill multiple 5G requirements in terms of guaranteed user data rate, high throughput, low delay, number of User Equipments (UEs), and mobility support at high speed [1]. In this context, cell densification is considered as a key solution in order to realize these enhancements. The basic idea is to deploy the access nodes as close as possible to the end users, in order to satisfy the required Quality of Service (QoS) and maximize the system throughput. Due to the increasing users' density, small cells become smaller and denser, leading to the ultra-dense networks concept. In [2], a quantitative measure of the cell density from which a network can be considered ultra-dense (10^3 $cells/km^2$) is provided. In this line, future networks will be realized as a set of multiple base stations with different features, in terms of connected users, transmitted power and coverage areas, i.e., small cell and macro cell deployment. Among the main aspects available in literature concerning densification, we focus on Dual Connectivity and centralization.

As regards the Dual Connectivity, we consider the Phantom Cell Concept (PCC) proposed by the Japanese telco NTT DOCOMO [3], as a solution for the next ultra-dense networks.

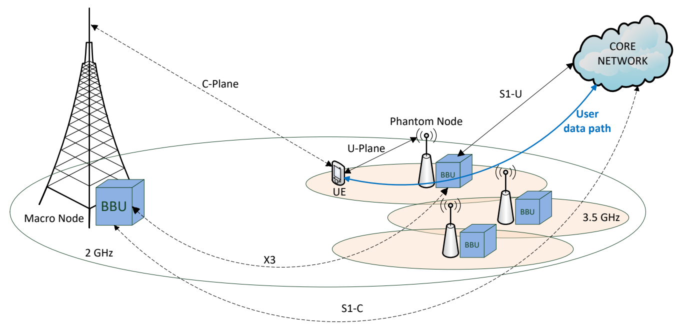

Fig. 1. Docomo splitting solution.

As shown in Fig. 1, this solution is mainly focused on a splitting between control plane (C-Plane) and user data plane (U-Plane). Moreover, different frequency band allocation in Macro cell and small cell coverage areas is considered. In particular, for a UE in a phantom cell coverage area, C-Plane is provided by the Macro eNodeB (eNB) at low frequency band (e.g., 2 GHz), in order to improve connectivity and mobility management, whereas U-Plane is provided by the Phantom base station at higher frequency band (e.g., 3.5 GHz), in order to boost user data rate. On the basis of this basic concept, 3GPP standardized Dual Connectivity (DC) for small cell enhancements in Release 12 [4] as a functionality to allow User Equipments (UEs) to simultaneously receive data from both a macro and a small cell eNBs.

As regards the centralization aspect, we observe that in the traditional LTE Radio Access Network (RAN), see Fig. 2a, the eNB is composed of a radio front-end entity, referred as Remote Radio Head (RRH), and a base band computational unit, called Base Band Unit (BBU). In this context, BBUs are located in a distributed mode (i.e., each BBU is co-located with the related RRH). In the last few years, mobile RAN is slightly evolving to a full centralized architecture, known as Centralized RAN [5]. In this architecture, base band computational resources are pooled in remote locations, still hardware-based, known as BBU Pools, whereas RRHs are placed in edge locations, as shown in Fig. 2b. Centralization feature provides notable advantages in terms of CAPEX/OPEX, since enables operators to centralize hardware, significantly reducing energy consumption and maintenance costs.

Exploiting the positive aspects of Dual Connectivity and centralization feature in ultra-dense scenarios enables to per-

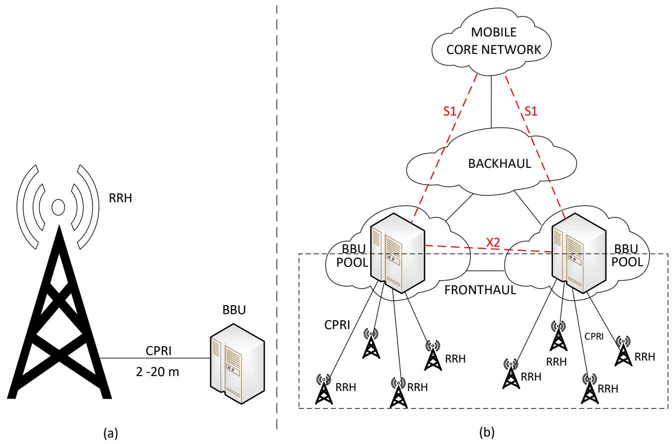

Fig. 2. (a) eNodeB in LTE RAN - (b) CPRI based Centralized RAN.

form a centralized radio resource management capable of addressing significant issues, such as severe interference between co-tier small cells. Furthermore, this RAN evolution is also required in order to support Multi-Radio Access Technology (Multi-RAT) feature and seamlessly integrate new radio access technologies (e.g., millimeter waves) with existing ones (inter-technology compatibility). These significant requirements cannot be achieved without new key features as softwarization, programmability, virtualization, resource coordination, and fronthaul and radio interface redesigning. At this aim, as described in [6], Software Defined Networking (SDN) and Network Function Virtualization (NFV) paradigms are considered as the enabling technologies to realize these enhancements.

SDN permits to realize the control and data plane splitting proposed by DOCOMO. In fact, in its native wired nature, SDN focuses on decoupling control and data plane of network forwarding elements, such as switches. The communication between these forwarding entities and the control entity (i.e., the controller) is performed by the OpenFlow protocol. In particular, the so-called Southbound interface enables a programmable management of the underlying network elements, whereas the so-called Northbound interfaces allow applications to interact with the controller. Accordingly, the data plane is performed by OpenFlow enabled switches, whereas the control plane is performed by logically centralized but physically distributed SDN controllers. In order to take full advantage of SDN capabilities in mobile and wireless environments, a first critical issue is related to its possible integration.

Network Function Virtualization (NFV) focuses on the abstraction of the hardware-based network functionalities. In fact, network functions traditionally run on proprietary and dedicated hardware. By adopting NFV features, virtualized network functions in general purpose servers can be deployed. We can take advantage of these enhancements in a Centralized RAN architecture by virtualizing the BBU entities forming the BBU Pool, in other words, by realizing the hardware based baseband functionalities in a software fashion. These enhancements make RAN architecture more scalable and reliable, since a programmable management of virtualized functionalities is achievable.

Following the above assumptions, in a further evolution of the Centralized RAN, BBUs can be not only centralized but also virtualized and coordinated by a centralized entity, in order to optimize resource allocation, leading to Cloud-RAN (C-RAN) or Virtual-RAN. Accordingly, C-RAN, SDN and NFV are recognized as the key enabling solutions for future mobile networks.

In this paper, we propose a hierarchical layered software-defined architecture for future 5G networks. We aim to provide new features that facilitate SDN/NFV integration in wireless/mobile environments. As further contribution, we suggest to implement the DOCOMO's Phantom Cell Concept in ultra-dense scenario by exploiting our proposed C-RAN architecture, as a Case Study. The rest of the paper is organized as follows. Section II provides an overview of Related Works. In Section III the proposed solution is described. In Section IV the DOCOMO's PCC Case Study is analyzed. Finally, in Section V conclusions are given and the work in progress is described.

II. Related Work

As mentioned above in terms of centralization and architecture redesigning, in the last few years mobile RAN has already slightly evolved to a centralized and coordinated fashion, known as Centralized RAN. The transport network connecting RRHs to the related BBU Pool is called Fronthaul. The main drawback of this fully centralized RAN architecture is the high bandwidth and latency requirements imposed on the Fronthaul links, when the Common Public Radio Interface (CPRI) is used to carry the in-phase and quadrature (IQ) samples. This interface is adopted in the traditional distributed LTE RAN and in the full Centralized one, as shown in Fig. 2, which represents two extreme solutions. In both cases, the use of optical fiber is mandatory. In order to reduce these fronthaul requirements, several functional splits over the LTE networking stack have been proposed by different organizations, e.g., SCF [7], NGMN [8] and 3GPP [9]. This latter proposal is shown in Fig. 3. Each option represents a separation point between the protocol stacks on the BBU Pool (the centralization point) and the protocol stacks at the edge of the network (the distributed points).

On the basis of the adopted split option, Fronthaul links could be implemented adopting solutions other than optical, such as Ethernet or millimeter wave communications. Among the different splitting options depicted in Fig. 3, we focus on Option 6 (known as partial centralization), Option 7 (hybrid centralization) and Option 8 (full centralization).

In the full centralization option, only RF functionalities are deployed in the RRH site, while PHY Layer and upper Layers are in the BBU Pool site. This solution maximizes the coordination of the RAN, by allowing efficient support of functions such as coordinated multipoint (CoMP) or load balancing, and makes easier operation and maintenance. On

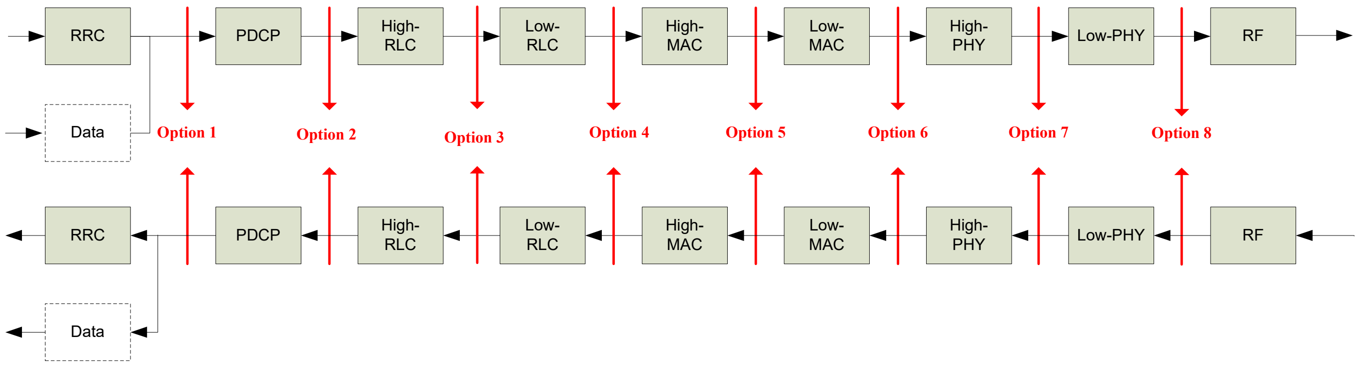

Fig. 3. 3GGP Functional splitting options - Source: 3GPP TR 38.801 V.14.0.0.

the other hand, as exposed in [10], due to the high bandwidth and overhead related to IQ data transmission, it may cause important constraints on network topology.

In the partial centralization option, coinciding with option 6, PHY layer functions are all implemented in the radio front-end entity (i.e., in a distributed manner), while upper layers are in the central unit (BBU Pool). Typically, the enhanced radio front-ends performing base band processing are called Radio Remote Units (RRUs), instead of RRHs. In comparison with the fully centralized option, bandwidth and overhead requirements are reduced, since the demodulated signals are carried rather than the modulated ones, but the pooling gain is limited. Since the MAC layer is in the BBU Pool, joint transmission and centralized scheduling are still possible. The main drawback of this option is the required subframe-level timing interactions between MAC layer in the BBU Pool and PHY layer in RRU because of the hybrid automatic repeat request (HARQ) process.

Between partial and full centralization options, an intermediate option is available, known as hybrid centralization. In this option, part of the physical layer functions are implemented in RRUs, while the remaining functions in the BBU Pool. Multiple realizations of this option are possible, including asymmetrical options for Uplink and Downlink. The main benefit compared to Option 6 is the facilitate management of traffic load between E-UTRA and New Radio (NR) transmission points.

In conclusion, both partially and hybrid centralized solutions are characterized by lower requirements than fully centralized, in terms of bandwidth and latency. On the other hand, the fully centralized option is better in terms of pooling gain, since aggregating computational resources related to the entire protocol stack permits to implement more advanced processing algorithms.

As regards the interface design, we observe that CPRI was developed for local link between BBU and RRH in antenna sites, as shown in Fig.2a. However, as shown in Fig.2b, first implementations of C-RAN fronthaul are still CPRI-based. As described in [11], different Centralized RAN solutions are present in literature. In particular, two examples of Centralized RAN are considered. The first example is China Mobile Research Institute Cloud-RAN proposal [5], deploying a centralized control, in particular virtualized BBU Pool are connected to RRHs through fiber connections. The second example is proposed by DOCOMO and is considered as an Advanced C-RAN, since implements Phantom Cell Concept, based on carrier aggregation and small-cell technologies [12]. These two solutions are based on a full centralization, thus suffer from the IQ data transport related issues, which causes a bottleneck in Fronthaul Network. In order to resolve it, in [13] Akyildiz *et al.* propose a Software Defined architecture based on hybrid centralization (Option 7), but still implementing the CPRI as Fronthaul Interface.

In next few years, with the increase of the distance between RRHs and the BBU Pool, the fronthaul link will be extended in the range of Kms, therefore traditional CPRI will not be the proper solution. In fact, the strict 5G requirements in terms of high bandwidth and low delay, leads to a further evolution of fronthaul and interface redesigning. In addition, one of the most significant issues of CPRI is that the required data rate is related to the number of antennas, rather than the actual mobile traffic load. This means that the bandwidth demand will be dramatically growing when the scale of antenna array becomes larger and larger, as effect of massive MIMO deployments [1].

In this line, in recent times IEEE NGFI working group defines a new transport fronthaul interface for future mobile networks, called Next Generation Fronthaul Interface (NGFI). This solution aims to resolve the above mentioned issues related to CPRI, thanks to features such as adaptive bandwidth, statistical multiplexing, support for high-gain coordinated algorithms, required data rate decoupled from the number of antennas, support for different air interface technology. As shown in Fig. 4, according to [14], BBU Pool and RRU functionalities are redefined, since part of BBU functionalities are moved to the edge location. Consequently, Remote Radio System (RRS) concept is introduced. In particular the RSS concerns network elements as antennas, RRUs and Remote Aggregation Unit (RAU). The RAU will be a logical entity, between a group of RRU and the related BBU Pool, performing local aggregation functionality and part of BBU processing. Accordingly, BBU will be redesigned as Radio Cloud Center (RCC), since will exploit softwarization and virtualization features. The RCC

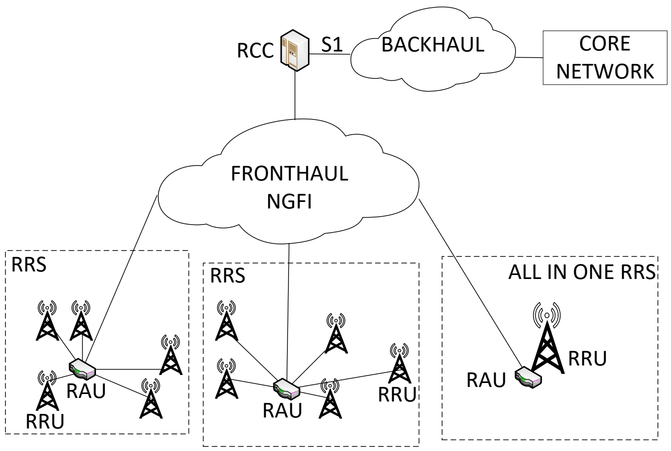

Fig. 4. NGFI based Centralized RAN.

will perform the remaining BBU processing. Futhermore, the fronthaul network will be redesigned, since fronthaul links will evolve from point-to-point to multipoint-to-multipoint, exploiting the aggregation feature of the RAU. According to this redesign, since bandwidth requirements will be relaxed, the fronthaul transport technology would be packet based (i.e., Ethernet), in order to facilitate NGFI standardization and real deployment.

III. SDN / NFV 5G Architecture

In this paper, a hierarchical layered architecture for future 5G networks is proposed. The solution exploits SDN/NFV features, in order to deploy a programmable and virtualized architecture. We aim to propose new features that could facilitate SDN/NFV integration in wireless/mobile environment. The hierarchical architecture scheme includes different logical layers, as shown in Fig. 5. In the next Subsections a detailed description of the proposed architecture is provided.

A. Infrastructure and Baseband Layers

The considered scenario concerns a Public Land Mobile Network (PLMN) area. As opposed to the CPRI-based SoftAir proposal, we design a NGFI based architecture, deploying an edge aggregation unit inspired by the RAU. This assumption permits to overcome the CPRI related issues still present in SoftAir proposal and to deploy an Ethernet based fronthaul network. In addition, as regards the base band processing functionalities, the use of RAUs permits to redistribute the entire computational capacity between RAUs and BBU Pools. In order to deploy a flexible, programmable and virtualized RAN, as novelty we propose to softwarize and to virtualize also the RAU.

The virtualization of the RAU permits to redistribute in a flexible manner the entire computational capacity of our proposed C-RAN between the RAUs and the BBU Pools. More specifically, we design virtualized base band functionalities both in BBU and RAU, creating virtual RAU (vRAU) and virtual BBUs (vBBUs), in order to apply configurable and dynamic functional splitting options, from Option 6/5 to upper layer Options. The flexibility of the designed virtualized base band processing in RAU, permits to adapt the fronthaul link requirements to various Use Cases. In fact, the choice of the proper splitting option depends on some factors related to radio network deployment scenarios, constraints and intended supported services [15]. It depends on the QoS requirements of the offered services (e.g., low latency, high throughput), on the users' density, on the load demand, and on the different performance levels of the transport networks. The splitting option could be ”negotiated” taking into account capabilities of the BBU and the RAU, or the fronthaul topology. This enhancement is appropriate when a fronthaul link suffers from a fault or the capacity of a BBU Pool is not sufficient in relation to the experienced data traffic.

The softwarization of the RAN means to deploy an Openflow agent upon certain RAN entities. In particular, we deploy an OpenFlow agent upon both the RAUs and the fronthaul switches, in order to perform a programmable forwarding on the basis of SDN Controller rules. Accordingly, the RAUs are connected to the BBU Pools through these OpenFlow enabled forwarding entities, forming the fronthaul network.

B. Lower and Upper Control Layers

The control layer is composed of a set of SDN controllers, each one takes care of several management aspects, performing various functionalities. The control layer is logically centralized but physically distributed, as a set of Slave Controllers and Master Controllers.

Master Controllers, forming the upper control layer and located in remote sites, manage a group of macro cells, keep into account long-time scale and less fine grained parameters, while acting as reference entities for Slave Controllers.

Slave Controllers, forming the lower control layer, located in edge sites, as opposed to Master Controllers, keep into account short-time scale and more fine grained parameters, while acting as management entity for a group of cells [16]–[18].

As shown in Fig. 6, in order to realize these enhancements, it is necessary to customize Northbound and Southbound interfaces. In particular, the Southbound interface is performed by the OpenFlow interface, enabling programmable management of underlying network elements. Northbound interfaces allow applications to interact with the controller. On the basis of the reports sent by the RAN entities, the application algorithms compute the related output.

C. Logical Controller Areas and New Proposed Functionalities

As shown in Fig. 6, the proposed Slave Controller focuses on different features, which can be seen as logical areas corresponding to the related Northbound applications. These proposed functionalities could allow to fulfill the strict 5G requirements. In fact, on the basis of reports sent by the RAN entities and, consequently, the output of the application algorithms, the controller dictates optimum rules in terms of

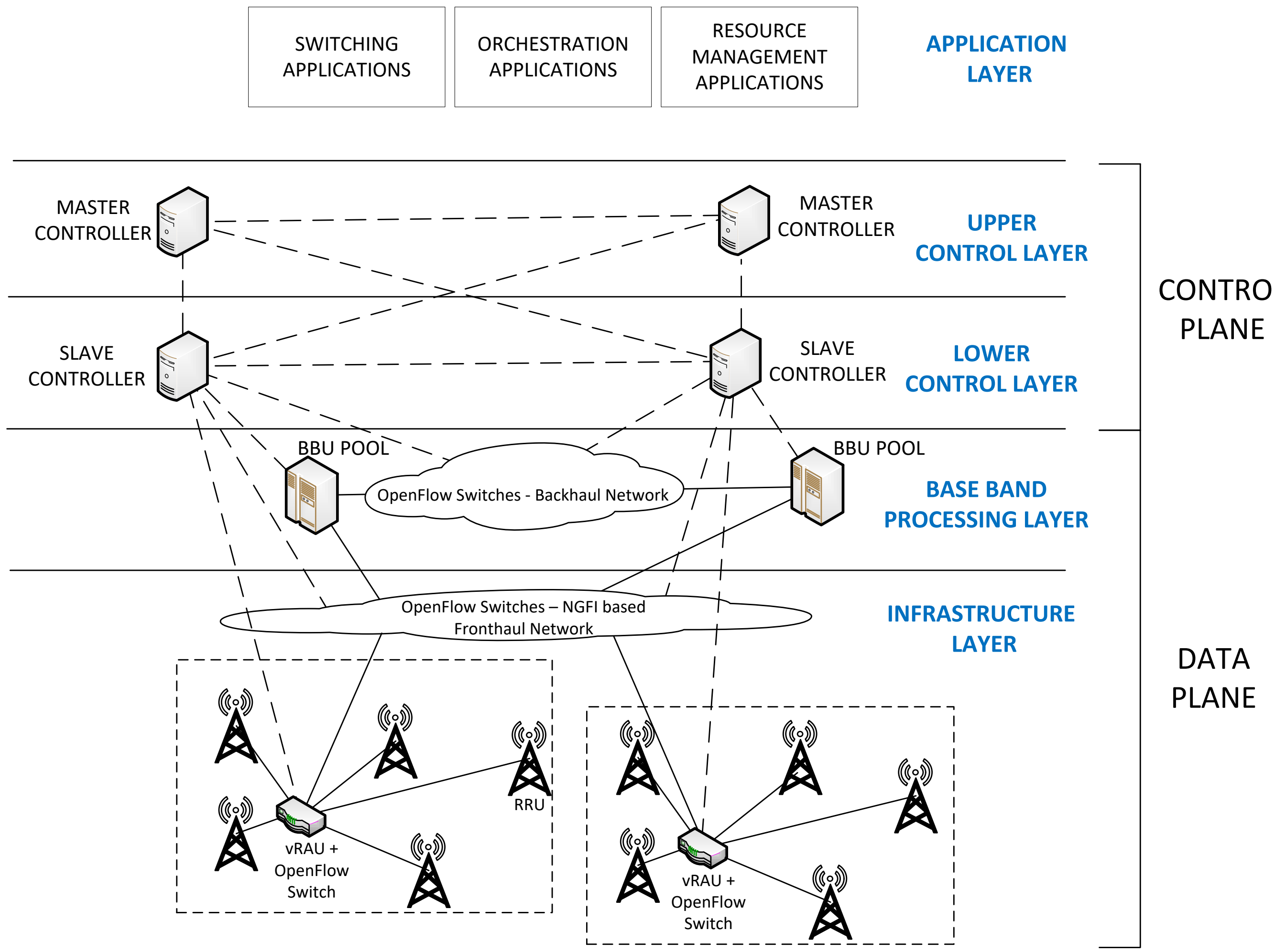

Fig. 5. Proposed Hierchical Layered Architecture

switching, resource allocation and virtual function instantiation/migration.

SDN Controller logical area. We design this logical area as strictly related to the particular designed fronthaul network. In fact, in our design, fronthaul network evolves from a point-to-point CPRI-based network to a multipoint-to-multipoint NGFI/Ethernet based one. Since this fronthaul topology is more complex than the traditional centralized network, it is necessary to manage forwarding in a fast, programmable and dynamic fashion. At this aim, we exploit OpenFlow protocol, realizing control and data plane splitting related to forwarding functionalities. This SDN enhancement in the proposed mobile RAN architecture is deployed in the OpenFlow native scope, i.e., wired network forwarding, but it could be very useful to achieve strict 5G mobile network requirements. The proposed functionalities related to this area are described as follows.

- **Forwarding functionalities in fronthaul network**. As exposed above, this controller allows to manage the mobile network in a centralized way, coordinating forwarding behavior among OpenFlow enabled network entities, such as RAU and switches. This enhancement is achievable only through a centralized entity which has an overall and continuously updated view of the network state. An Ethernet-like fronthaul permits to exploit actual OpenFlow capabilities. Moreover, through an extended OpenFlow protocol, we can add new matching fields, in order to implement different forwarding rules on the basis of the type of data received by the OpenFlow enabled switches. For instance, we can define different forwarding rules between control packets and data packets, or between cell-related and UE-associated messages, or between downlink and uplink packets. It would be created a Virtual cluster, that is, a set of RRUs of the same technology, which are dynamically associated with a BBU Pool and, consequently, with a Slave Controller.
- **Forwarding functionalities in Multi-RAT RAN**. As the 5G wireless environment is expected to support Multi-RAT, we propose this new functionality. In order to comply with 5G delay requirements, the interconnection of different wired and wireless involved subsystems should

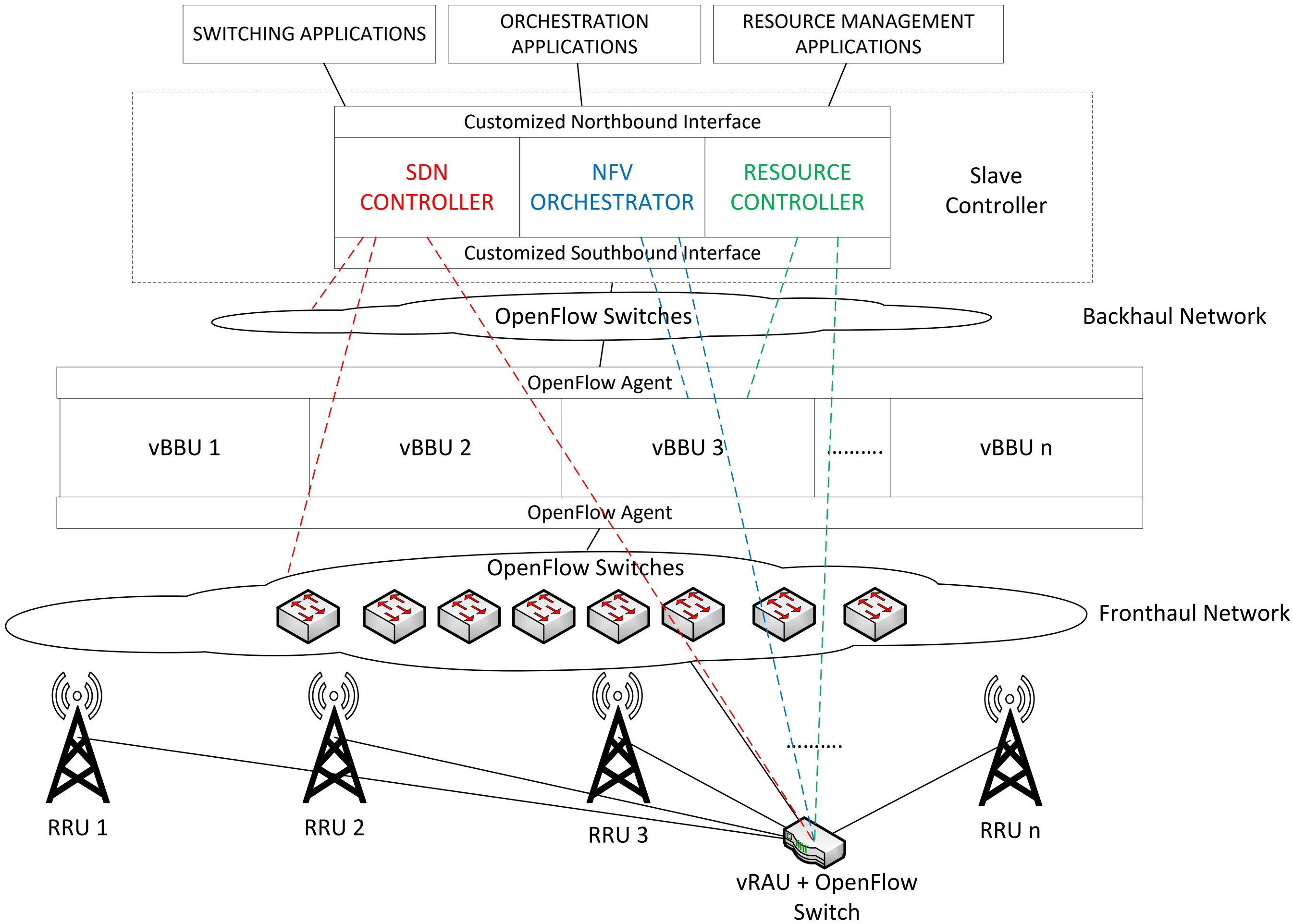

Fig. 6. Slave Controller

be possible only through the deployment of an intelligent and fast forwarding. In fact, it will be necessary a convergence entity able to select optimum options in terms of switching, security issues and reliability. These enhancements could be realized by our Slave Controller, in association to the aggregation feature performed by the RAU. As opposed to the above mentioned functionality, in which Slave Controllers would manage a group of cells based on the same technology, in this case our Slave Controller would manage a group of access point based on different technologies. This would be achievable exploiting a Virtual Multi-RAT Cluster, dynamically related to a BBU Pool and consequently to a particular Slave Controller.

NFV Orchestration logical area. We design this logical area in order to realize a NFV Orchestrator, which is able to dynamically allocate computational resources related to BBU Pool. The novelty introduced with this logical area comes with the enhancements described as follows.

- **Dynamic instantiation of BBU/RAU/RRU related functionalities**. Since part of the protocol stack is implemented in a virtualized fashion, it would be possible to dynamically instantiate virtualized base band processing functionalities based on fronthaul link requirements. More specifically, we can dynamically deploy different functional splitting options, by activating or de-activating the related virtual entities. These variations could be related to the capacity required in a particular time interval or period of the day.
- **Dynamic instantiation/migration of Slave Controller**. In order to follow capacity demands or the need for a convergence controller in Multi-RAT environments, it would be possible to instantiate or migrate Slave Controllers, which are implemented in a virtualized fashion. In this case it could be useful to make a ”lighter virtualization”, in a container fashion.

Resource Controller logical area. This logical area is designed to allocate radio resources on the basis of instantaneous requirements in terms of achievable capacity, required data rate and link state, through the related resource management algorithms. Moreover, it would be possible to deploy a mobility management in a single or Multi-RAT environment.

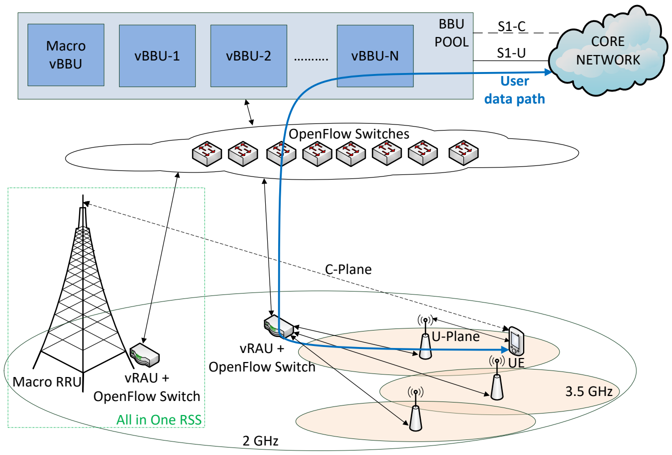

Fig. 7. Specific use case proposed architecture.

- **Resource management in single or Multi-RAT RAN**. This functionality concerns the implementation of algorithms based on a programmable resource management. The Slave Controller elaborates the optimum resource allocation on the basis of parameters regarding the actual state of the network. This logical area would permit to achieve an efficient allocation through cooperative concepts such as CoMP, enhanced Inter-cell interference coordination (eICIC), etc., exploiting the overall view of the Slave Controller, in the above mentioned Virtual Cluster.
- **Resource management for single or Multi-RAT handover**. This functionality concerns the implementation of algorithms and resource reallocation based on the related requested service. Thanks to the concept of Virtual Multi-RAT cluster, it would be possible to associate the best Multi-RAT neighbor, in order to manage a transparent handover between related technologies.

IV. A Case Study: DOCOMO's Phantom Cell Concept

On the basis of the 5G architecture described in the previous Section, we design a proper architectural solution for the DOCOMO's Phantom Cell Concept, which realizes the Control and Data Plane splitting, by exploiting the SDN/NFV features. In [3] DOCOMO proposed two C-plane/U-plane Split configurations, namely, Split with Separate Nodes and Single Node Split.

The first configuration is provided by two separate nodes (i.e., the Macro Node and the Phantom Node), representing different transmission points with independent baseband processing, as shown in Fig. 1. The relationship between the Macro and the Phantom Node is provided by the X3 interface (master-slave connection). This backhaul link can be relaxed, therefore optical fiber is not necessarily required. The main drawback of this solution is that each Phantom Node has to be composed of RRH, BBU, and an independent S1-U interface to the Core Network.

The second configuration requires that the baseband processing is performed in one node, even if the C-plane and the U-plane have different transmission points. More specifically, all Phantom Cells are implemented as RRH only, whereas the baseband processing is all performed at the Macro cell. Therefore, the Macro Cell and a Phantom Cell can be logically seen as a single node. The main drawback of this solution is that the requirements, in terms of bandwidth and latency, are so restrictive that a fiber link between the Macro cell and each Phantom Cell is mandatory.

Our proposed solution aims to implement the DOCOMO's PCC with a new configuration which try to overcome the drawbacks of these extreme solutions. We suggest to implement the PCC by exploiting our proposed C-RAN architecture, as shown in Fig. 7.

To overcome the issue of having to deploy phantom nodes, each one composed of RRH, BBU and an S1-U interface, we propose to group some phantom RRU into a single RAU. The splitting option between the RRU and RAU can be 6 or 7 (i.e., partially or hybrid centralization). We take advantage of the proposed virtualization and softwarization of the RAU. The virtualization of the RAU leads to dinamically implement different splitting options between RAU and BBU Pool (from Option 6/7 to upper Options), in order to relax this link requirements, so to adopt Ethernet or wireless technology instead of fiber optic. In addition, the softwarization of the RAU means to deploy an Openflow interface upon the RAU, in order to manage forwarding in a programmable way, following the rules indicated by the Slave Controller.

As regards the Slave Controller location, on the basis of different considerations regarding the strict throughput and delay requirements, we propose to locate the Slave Controller in the same site of the macro Node, in order to exploit as well as possible the enhancements related to the proposed architecture.

In conclusion, our proposed solution enables network operators to increase the number of Phantom Cells in a simple and economical way. In fact, with respect to the first configuration, they could add simple RRUs and connect them to one or more existing RAUs, without the need to locally deploy new BBUs and local S1-U interfaces. Moreover, with respect to the second configuration, fiber optics cables between RRUs and the Macro eNode B are not required, thanks to virtual RAUs.

V. Conclusions and Work in Progress

In this paper, we propose new functionalities, on top of a SDN/NFV architecture inspired by work in [13]. As opposed to the SoftAir proposal, we deploy a NGFI based architecture, in order to overcome CPRI issues related to massive MIMO deployment. Furthermore, in order to implement dynamically different functional splitting options, a virtualized RAU entity is proposed.

In addition, in order to design the proposed SDN enhancements, an optimized controller is designed. This controller is logically centralized but physically distributed, as a set of Slave Controllers and Master Controllers. Master Controllers, forming the upper control layer and located in remote sites, manage a group of macro cells, keep into account long-time scale and less fine grained parameters, while acting as reference entities for Slave Controllers. Slave Controllers, forming the lower control layer, located in edge sites, as opposed to Master Controllers, keep into account short-time scale and more fine grained parameters, while acting as management entity for a group of cells. In particular, the proposed Slave Controller focuses on different features, which can be considered as different logical areas, corresponding to related Northbound applications. These proposed functionalities could allow to fulfill the strict 5G requirements. In fact, on the basis of reports sent by the RAN entities and, consequently, the output of the application algorithms, the controller dictates optimum rules in terms of switching, resource allocation and virtual function instantiation/migration.

Finally, on the basis of our proposed 5G architecture, we design a proper architectural solution for the DOCOMO's Phantom Cell Concept, which realizes the Control and Data Plane splitting, by exploiting the SDN/NFV features.

Now, we are designing a simulation testbed, in order to evaluate a first subset of the proposed functionalities. A programmable and virtualized RAN architecture will be implemented. In our simulations we will firstly focus on the control and data plane splitting aspect of the proposed architectural design. Regarding the OpenFlow integration in the simulation scenario, we have already implemented a first software defined implementation of the proposed RAN architecture trough ns-3 simulator. In particular, we configure two different ns-3 modules, known in literature as LENA ns-3 LTE Module [19] and the OFSwitch13 module [20]. The LENA ns-3 LTE Module permits to simulate a LTE RAN / LTE-EPC standard architecture. The OFSwitch13 module is an OpenFlow based module, deploying the OpenFlow 1.3 protocol in ns-3 simulation model. First results demonstrate an efficient OpenFlow integration in our LTE simulation environment. Future goals are integrating and deploying Software Defined Radio as real-time-like RAN entities, exploiting OpenAirInterface and SDR capabilities in order to implement RRU entities, whereas RAU and BBU functionalities will be implemented upon virtual machines in an OpenStack environment.

As future works, we aim to evaluate the performance provided by the different functional splitting options, in order to establish the Use Cases in which they can be applied. Then, we aim to evaluate the benefits introduced by the proposed flexible splitting.

ACKNOWLEDGMENT

This research was partially supported by the Italian Ministry of Economic Development under Grant Prog. n. F/050270/03/X32 - CUP B68I17000370008, "SUMMIT - Supporto Multipiattaforma per Applicazioni IoT"

REFERENCES

[1] 5GPP, "View on 5G Architecture," 5GPP, Whitepaper, 12 2017, version 2.0.

[2] M. Ding, D. Lopez-Perez, G. Mao, P. Wang, and Z. Lin, "Will the area spectral efficiency monotonically grow as small cells go dense?" in *2015 IEEE Global Communications Conference (GLOBECOM)*, Dec 2015, pp. 1–7.

[3] H. Ishii, Y. Kishiyama, and H. Takahashi, "A novel architecture for LTE-B: C-plane / U-plane split and Phantom Cell concept," in *2012 IEEE Globecom Workshops*, Dec 2012, pp. 624–630.

[4] 3GPP, "Study on Small Cell enhancements for E-UTRA and E-UTRAN; Higher layer aspects," 3rd Generation Partnership Project (3GPP), Technical Report (TR) 36.842, 01 2014, version 12.0.0.

[5] C. M. R. Institute, "C-RAN - The Road Towards Green RAN," China Mobile Research Institute, Whitepaper, 12 2013, version 3.0.

[6] I. F. Akyildiz, S. Nie, S.-C. Lin, and M. Chandrasekaran, "5G roadmap: 10 key enabling technologies," *Computer Networks*, vol. 106, pp. 17 – 48, 2016.

[7] SCF, "Small cell virtualization functional splits and use cases," Small Cell Forum (SCF), Technical Report (TR), 06 2015, version SCF159.05.1.01.

[8] NGMN, "Further study on critical C-RAN technologies," next generation mobile networks (NGMN), Technical Report (TR), 03 2015, version 1.0.

[9] 3GPP, "Study on new radio access technology: Radio access architecture and interfaces," 3rd Generation Partnership Project (3GPP), Technical Report (TR) 38.801, 04 2017, version 14.0.0.

[10] A. de la Oliva, J. A. Hernandez, D. Larrabeiti, and A. Azcorra, "An overview of the CPRI specification and its application to C-RAN-based LTE scenarios," *IEEE Communications Magazine*, vol. 54, no. 2, pp. 152–159, February 2016.

[11] I. F. Akyildiz, S.-C. Lin, and P. Wang, "Wireless software-defined networks (W-SDNs) and network function virtualization (NFV) for 5G cellular systems: An overview and qualitative evaluation," *Computer Networks*, vol. 93, pp. 66 – 79, 2015.

[12] Docomo, "DOCOMO 5G White Paper 5G Radio Access: Requirements, Concept and Technologies," Docomo, Whitepaper, 2014.

[13] I. F. Akyildiz, P. Wang, and S.-C. Lin, "Softair: A software defined networking architecture for 5G wireless systems," *Computer Networks*, vol. 85, pp. 1 – 18, 2015.

[14] C. M. R. Institute, "White Paper of Next Generation Fronthaul Interface," China Mobile Research Institute, Whitepaper, 2014.

[15] 3GPP, "Study on new radio access technology: Radio access architecture and interfaces," 3rd Generation Partnership Project (3GPP), Technical Report (TR) 38.801, 04 2017, version 14.0.0.

[16] A. Dudnikova, D. Panno, and A. Mastrosimone, "Measurement-based coverage function for green femtocell networks," *Computer Networks*, vol. 83, pp. 45 – 58, 2015.

[17] A. Di Maria and D. Panno, "A radio resource management scheme in future ultra-dense phantom networks," in *2017 IEEE 13th International Conference on Wireless and Mobile Computing, Networking and Communications (WiMob)*, Oct 2017, pp. 1–6.

[18] S. Riolo, D. Panno, and A. Di Maria, "A new centralized access control for mmWave D2D communications," in *2017 IEEE 13th International Conference on Wireless and Mobile Computing, Networking and Communications (WiMob)*, Oct 2017, pp. 1–8.

[19] N. Baldo, M. Miozzo, M. Requena-Esteso, and J. Nin-Guerrero, "An open source product-oriented LTE network simulator based on ns-3," in *Proceedings of the 14th ACM International Conference on Modeling, Analysis and Simulation of Wireless and Mobile Systems*, ser. MSWiM '11. New York, NY, USA: ACM, 2011, pp. 293–298.

[20] L. J. Chaves, I. C. Garcia, and E. R. M. Madeira, "Ofswitch13: Enhancing ns-3 with OpenFlow 1.3 support," in *Proceedings of the Workshop on Ns-3*, ser. WNS3 '16. New York, NY, USA: ACM, 2016, pp. 33–40.