A C-RAN based 5G platform with a fully virtualized, SDN controlled optical/wireless Fronthaul

Kostas Ramantas, Angelos Antonopoulos*, Elli Kartsakli, Prodromos-Vasileios Mekikis, John Vardakas, Christos Verikoukis*

Iquadrat Informatica S.L., Barcelona, Spain

Tel: (+34) 934678178, e-mail: kramantas@iquadrat.com

** Telecommunications Technological Center of Catalonia (CTTC/CERCA), Castelldefels, Spain*

ABSTRACT

This paper describes in detail the design of a 5G platform based on the C-RAN architecture, with a fully virtualized Radio Access Network (RAN) and an optical/wireless Fronthaul. The wireless and optical domains are controlled by a hierarchy of Software Defined Networking (SDN) controllers, which are responsible for end-to-end optimization of the platform, including the Fronthaul and 5G air interfaces. The proposed architecture adopts a modular eNodeB (eNB) design, where virtualized BBU and RRH entities are implemented with Commercial Off-The-Shelf (COTS) components. Moreover, a mmWave RAU is connected to the BBU via a feeder optical fiber, interconnecting one or more RRH units with the BBU over mmWave interfaces. COTS components and Ethernet interfaces are employed for C-RAN prototyping of our platform, facilitating flexibility, cost reduction and increased scalability.

Keywords: 5G testbed, C-RAN, vRAN, Fronthaul, SDN, NFV.

1. INTRODUCTION

Software Defined Networking (SDN) and Network Function Virtualization (NFV) are two promising technologies that are expected to increase the efficiency of 5G networks, and enhance the flexibility of network configuration and management [1]. In SDN, a centralized SDN controller, which handles network management operations, is physically decoupled from the data plane and enables network programmability. Applications and services running on top of 5G networks will need to be resource- and network-aware, in order to take full advantage of the underlying network programmability, communicating with the SDN layer via a set of Southbound Application Programming Interfaces (APIs) in a way that optimizes the resource allocation and utilization in a centralized way. While SDN is typically associated with wired networks and data centers, several advantages can be realized by SDN at the wireless domain as well. In the wireless domain, SDN enables the implementation of centralized handover and load balancing schemes [2], thus optimally managing the scarce wireless spectrum.

NFV is another cornerstone technology of 5G, which is employed to build an agile and programmable virtualized infrastructure. NFV underpins the delivery, deployment, provisioning, and monitoring of services, while Management and Orchestration (MANO) Frameworks that follow the ETSI NFV reference architecture allow the infrastructure to adapt to service requirements, enabling fast and cost-efficient service management [3]. The next step in infrastructure virtualization is virtualizing the 5G RAN. This approach, which is known as Virtualized RAN (vRAN), is recognized as a very promising area of innovation in the 5G ecosystem, resulting in cost reductions and scalability benefits for 5G deployments. Specifically, it allows developing a C-RAN based 5G architecture with low-cost Whitebox servers and COTS components [4].

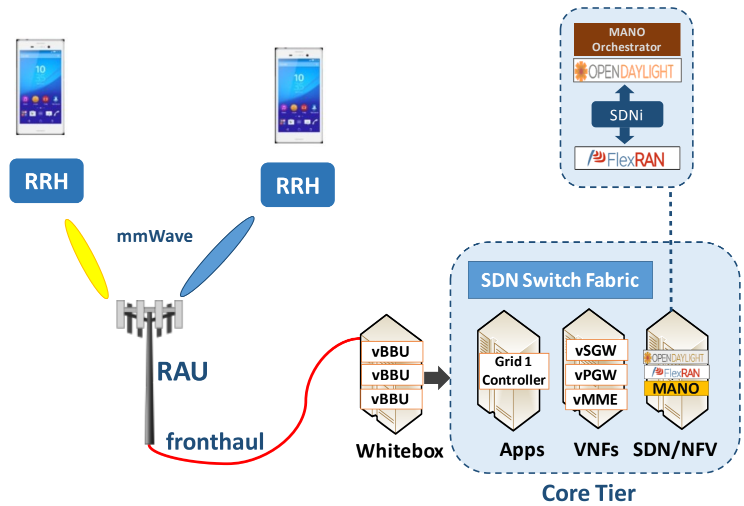

Figure 1: Testbed Architecture

Several large-scale and academic 5G testbeds are currently being developed, allowing researchers to run their own experimental protocols and evaluate future 5G architectures [5]. Small-scale platforms have also been proposed using COTS components that reduce development costs [6]. Other works address the RAN part of 5G networks, focusing on RAN Virtualization or flexible resource allocation [7], [8]. However, these are largely conceptual works and do not consider the associated implementation challenges of real-world RANs. On the other hand, the OpenAirInterface (OAI) software alliance, or OSA, implements an end-to-end 5G testbed based on vRAN [9], which is freely available in the form of open source software. While not currently a production-ready solution, its open source nature and flexibility allows a fast pace of innovation, as community members can contribute and new developments are instantly available for experimentation. Moreover, a recent work in [10] also moves past the theoretical context and focuses on the prototyping challenges of applying SDN principles to solve the Radio Resource Management problem in 5G networks for a number of use cases.

In this paper, we propose a novel architecture for a C-RAN based 5G platform with a fully virtualized, SDN controlled optical/wireless Fronthaul. Our testbed leverages state-of-the-art components from the OpenDaylight ([11]) and OpenAirInterface (OAI) open source projects, and employs the FlexRAN controller ([10]) for centralized SDN control of the RAN. The proposed setup aims to enable the experimentation and validation of novel algorithms and mechanisms in next generation 5G networks.

2. 5G testbed Architecture

The C-RAN based testbed architecture, depicted in Fig. 1, considers the application of the SDN and NFV paradigms to fully virtualize the Core and RAN parts of a 5G network. This approach will allow us to employ COTS components to implement all testbed tiers, significantly decreasing cost and increasing flexibility. Employing a fully programmable, virtualized RAN (vRAN) on top of Whitebox servers and embracing Ethernet and 802.11 interfaces allows a very cost effective C-RAN implementation, which was until recently only available in "black box" carrier-grade equipment.

2.1 C-RAN Fronthaul design

Whitebox servers allow the virtualization of 5G RAN infrastructure entities by virtualizing some (or all) of the baseband functions that run on commercial COTS hardware. This approach, called Virtualized RAN (vRAN) is recognized as a very promising area of innovation in the 5G ecosystem, resulting in cost reductions and scalability benefits for 5G infrastructure deployments [4]. In our testbed we employ Whitebox servers to implement all RAN functionalities, i.e., the Remote Radio Head (RRH), and BaseBand Unit (BBU) with open source software [9], which can be deployed in the form of Virtualized Network Functions (VNFs). Moreover, our testbed leverages a COTS optical/wireless Fronthaul based on 10 GigE and IEEE 802.11ad, allowing the eNB functions to be split between the BBU and the RRHs. Multiple RRH units, effectively serving as small-cells, can be driven by a single BBU which physically resides at the Core site. The RRH units are implemented with Small Form Factor PCs with commodity IEEE 802.11ad mmWave interfaces that are connected to a USRP B210 via USB 3.0, which implements the LTE RF functions. As shown in Fig. 2, COTS Ethernet and IEEE 802.11 interfaces are employed to interconnect all entities of the C-RAN architecture, hence avoiding CPRI interfaces which are only available in carrier-grade, closed ecosystems. Specifically, we employ a 10 GigE optical fiber link to interconnect the BBU with the RAU, while the RRH-RAU link is implemented with a pair of commodity IEEE 802.11ad radios. Finally, a FlexRAN Master Controller is employed for the SDN-enabled centralized control of the RAN. FlexRAN is a flexible and programmable platform which separates the RAN control and data planes and supports the design of real-time RAN control applications. The Master Controller controls the underlying RAN infrastructure and orchestrates their operation, facilitating multiple advanced use cases, such as centralized Resource Block (RB) allocation, load balancing and handover control.

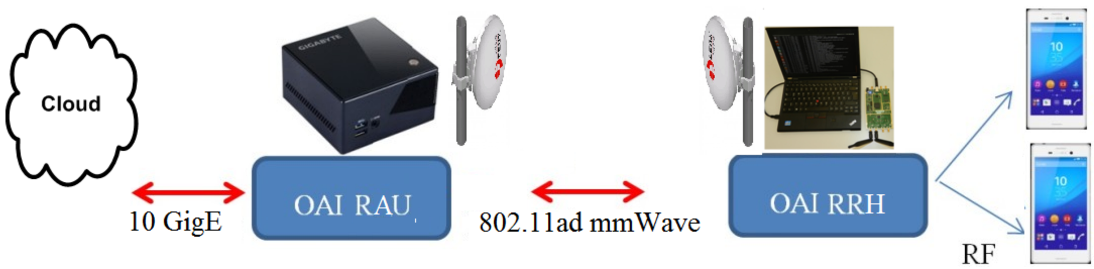

Figure 2: IEEE 802.11ad optical/wireless Fronthaul design

2.2 Core Tier design

Our testbed Core Tier, shown in Fig. 1, employs a virtualized data center based on OpenStack, which hosts Network Services and Over The Top (OTT) applications. For the mobile Core network, we employ a software-based EPC from OpenAirInterface project (i.e., openairCN [9]), which includes the implementation of the Mobility Management Entity (MME), the Home Subscriber Server (HSS), the Service Gateway (S-GW) and the Packet Gateway (P-GW). The software implementation of both EPC and RAN entities facilitates the concept of "5G infrastructure as a service" [12], where the RAN and EPC entities can be deployed in the form of VNFs (i.e., vRRH, vBBU, and vEPC), and hosted by the virtualized data center alongside Network Services and Applications. The ETSI OSM MANO framework is employed for VNF onboarding and orchestration, allowing the full automation of operational processes and tasks related to the placement and lifecycle management of all services. The MANO layer will thus be able to automatically allocate resources to the 5G RAN to accommodate a new service instantiation, e.g., by deploying new vBBUs, hence alleviating the end user from the burden of infrastructure management trivialities. Moreover, SDN is a key enabler in our testbed to realize flexible and end-to-end optimized communication. OpenDaylight controller is employed to centrally control the SDN Switches of the Data Center (Data plane). The consolidation of the SDN controllers for the wired and wireless domains will allow us to further pursue Core/RAN orchestration, taking advantage of the global network view from both SDN controllers. Our current efforts are focused on the implementation of a centralized orchestrator, which works by consolidating APIs form both OpenDaylight and FlexRAN controllers, implementing SDN East/West (or SDNi) APIs. This allows the deployment of end-to-end slicing across the heterogeneous infrastructure.

3. Function split types and their effect on mmWave Fronthaul traffic

Our testbed will rely on 60 GHz wireless interfaces compliant with the IEEE 802.11ad specification to prototype the C-RAN Fronthaul. These devices utilize technology originating from the WiGig MAC and PHY Specifications, which served as the foundation of the IEEE 802.11ad, bringing to market a new class of very competitively priced backhauling solutions with multi-gigabit data rates and ultra-low latencies. One of the key obstacles of C-RAN prototyping is the excessive bandwidth and latency requirements imposed by moving all the baseband functionality to the cloud. However, migrating some functions to the small-cell site can lead to significant Fronthaul traffic reduction, allowing cost effective Ethernet and mmWave interfaces to be employed. On the other hand, as more baseband functionalities are moved to the RRH, the C-RAN advantages are gradually negated. 3GPP has defined 8 function split types in TR 38.801 [13] ranging from option 8, where all baseband processing is performed in the cloud, to option 1 where all the baseband processing is performed at the RRH. OpenAirInterface supports option 8 and option 7 function split types, the latter representing a very efficient trade-off. In this option, the RRH performs the samples Cyclic Prefix (CP) removal, FFT (i.e., transforming the samples to the frequency domain) and removing the guard bands, effectively reducing the Fronthaul requirements by 50%. The core team of the OAI project has estimated that an LTE RRH in a representative scenario with 20 MHz bandwidth, 4 RX antennas and 64 QAM modulation requires a peak rate of 3.93 Gbps for an option 8 split type [9]. This is almost halved to 2.15 Gbps for an option 7 split. In both splits, there is a 250 μs one-way latency constraint [13], which is easily achievable, as IEEE 802.11ad introduced very low PHY overheads and a low latency CSMA protocol with a 3 μsec SIFS period and PHY headers and preambles with a duration <2 μsec. As shown in the following table, which details IEEE 802.11ad achievable rates for different Modulation and Coding Schemes (MCSs) and corresponding SNR values ([14]), the IEEE 802.11ad Fronthaul can easily serve option 7 split type traffic for MCS8 and higher, which corresponds to an SNR of at least -61 dBm. It must be noted that the peak rate of the option 8 function split type narrowly exceeds the capabilities of IEEE 802.11ad, which peaks at 4620 Mbps at the highest MCS12, but could potentially be served with a lightweight compression scheme.

Rx Sensitivity	Supportable MCS	Achievable Rates
−78 dBm	MCS0	27.5 Mbps
−68 dBm	MCS1	385 Mbps
−66 dBm	MCS2	770 Mbps
−65 dBm	MCS3	962.5 Mbps
−64 dBm	MCS4	1155 Mbps
−63 dBm	MCS6	1540 Mbps
−62 dBm	MCS7	1925 Mbps
−61 dBm	MCS8	2310 Mbps
−59 dBm	MCS9	2502.5 Mbps
−55 dBm	MCS10	3080 Mbps
−54 dBm	MCS11	3850 Mbps
−53 dBm	MCS12	4620 Mbps

Figure 3: IEEE 802.11ad table of achievable data rates vs. MCS index and SNR

4. CONCLUSIONS

In this work, we have presented the design of an end-to-end 5G platform based on the C-RAN architecture, with a fully virtualized RAN, an optical/wireless Fronthaul, and a cloud-based backend. Moreover, SDN was employed for both the wired and the wireless domain, where SDN enables the implementation of centralized handover and load balancing schemes as well as end-to-end slicing across the heterogeneous network infrastructure. The main design decisions, i.e., use of open source libraries and COTS components, including Ethernet and IEEE 802.11ad interfaces to reduce development costs were also discussed. Finally, various function split types were presented, along with their effect on Fronthaul traffic, and the most appropriate split types for an IEEE 802.11ad Fronthaul was also discussed.

ACKNOWLEDGEMENTS

This work has been funded by the EC under the auspices of H2020-ICT 5G-PHOS (grant 761989), SPOT5G (TEC2017-87456-P), H2020-MSCA-RISE CASPER (grant 645393), and H2020-MSCA-ITN-ETN 5GSTEPFWD (grant 722429). Part of this work has been supported by the Generalitat de Catalunya under grant 2017 SGR 891.

REFERENCES

[1] H. Kim and N. Feamster, ''Improving network management with software defined networking'', *IEEE Commun. Mag*., vol. 51, no. 2, pp. 114–119, Feb. 2013.

[2] L. Li, Z. Mao, and J. Rexford, ''Toward software-defined cellular networks'', in *Proc. Eur. Workshop Softw. Defined Netw.*, 2012, pp. 7–12.

[3] Chiosi M., et. al., "*Network Functions Virtualisation - Introductory white paper*," 2015. [Online]. Available: https://portal.etsi.org/nfv/nfvwhite paper.pdf

[4] "Cloud RAN. Architecture for 5G". A Telefónica-Ericsson joint White paper. Jul 2016.

[5] T. Huang; F. R. Yu; C. Zhang; J. Liu; J. Zhang; J. Liu, "A Survey on Large-scale Software Defined Networking (SDN) Testbeds: Approaches and Challenges," *IEEE Commun. Surv. Tuts* , vol. 19, no.2, pp.891-917, 2016.

[6] H. Kim, J. Kim and Y. B. Ko, "Developing a cost-effective OpenFlow testbed for small-scale Software Defined Networking" *in Proc. 16th ICACT*, Pyeongchang, 2014, pp. 758-761.

[7] G.Tseliou, F.Adelantado and C.Verikoukis "Scalable RAN Virtualization in Multi-Tenant LTE-A Heterogeneous Networks", *IEEE Trans. Vehicular Technology*, vol. 65, no 8, pp. 6651-6664, Aug. 2016.

[8] S. Costanzo, D. Xenakis, N. Passas and L. Merakos, "OpeNB: A framework for Virtualizing Base Stations in LTE Networks", *in Proc. IEEE ICC 2014*, Sydney, Australia, 10-14 Jun. 2014 pp. 3148–3153.

[9] N. Nikaein, M. K. Marina, S. Manickam, A. Dawson, R. Knopp, and C. Bonnet, "OpenAirInterface: A flexible platform for 5G research", *SIGCOMM Comput. Commun. Rev*, vol. 44, no. 5, pp. 33-38, Oct. 2014.

[10] X. Foukas, N. Nikaein, M. Kassem, M. Marina, K. Kontovasilis, "FlexRAN: A Flexible and Programmable Platform for Software-Defined Radio Access Networks", *in Proc. 12th CoNEXT*, Irvine, CA, USA, 12-15 Dec. 2016.

[11] OpenDaylight: Open Source SDN Platform, Web: https://www.opendaylight.org/.

[12] N. Nikaein, E. Schiller, R. Favraud et al., Towards a Cloud-Native Radio Access Network. Cham: Springer International Publishing, 2017, pp.171–202.

[13] 3rd Generation Partnership Project; Technical Specification Group Radio Access Network, Study on new radio access technology; radio access architecture and interfaces, 3GPP TR 38.801 V2.0.0 (2017-03).

[14] C. Y. Chang, R. Schiavi, N. Nikaein, T. Spyropoulos, and C. Bonnet, "Impact of packetization and functional split on c-ran fronthaul performance," *in Proc. IEEE ICC 2016*, Kuala Lumpur, Malaysia, 23-27 May 2016.

[15] J. Kim, J.-K. Kim, "Achievable rate estimation of IEEE 802.11ad visual big-data uplink access in cloud-enabled surveillance applications", *PLoS ONE*, vol. 11, no. 12, Dec. 2016.