# The Challenges of Applying SDN/NFV for 5G & IoT

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*Abstract*— The exponential growth of mobile data services driven by mobile Internet have substantially challenged networks to handle the requirements of high bit rate, low latency, high availability and performance in heterogeneous converged connectivity environments of wireline and wireless communication. Currently, SDN and NFV are recognized as key technologies studied for enhancing mobile network. However, associating SDN and NFV with the capability of programmability for application, control, and even data plane from radio access to core mobile network has not been yet considered appropriately in the context of the mobile network. In this research, we propose a new comprehensive architecture in which SDN and NFV play important roles; therefore, and the network is capable of becoming a deeply programmable network for all of the three planes. As the result, the mobile network can be sliced into distinct slices across from access to core network. We also explored the challenges for applying these technologies for 5G and serve as a critical tool for Internet of Things (IoT).

***Keywords—Software Defined Network (SDN); 5G Mobile Network (5G); Network Functions Virtualization (NFV); Internet of Things (IoT); Wireless Sensor Network (WSN).***

## I. INTRODUCTION

The increasing end-user devices such as laptops, smartphones, tablets, actuators, sensors, appliances, as well as the rapid growth of mobile traffic have posed requirements of high bit rate, high availability, low latency, and high performance in heterogeneously converged connectivity environments. However, existing mobile networks often struggle with many limitations such as expensive equipment, complex control protocols, and heterogeneous configuration interfaces. These obstacles become substantial barriers to innovation for novel services, networking systems, architecture and technologies. In this context, software-defined networking (SDN) and network function virtualization (NFV) become two of the most prominent technologies, which serve as key enablers for the future mobile networks to meet the mentioned requirements. In addition, they are also expected as critical tools for IoT.

In this paper, firstly, we investigate the adoption of SDN and NFV for mobile networks, and then propose an architecture toward 5G and IoT, called Full-Software Defined Mobile Network (Full-SDMN). The objective of the architecture is to provide network administrators higher capabilities of programmability and deployment of mobile services as network applications. Finally, challenges of applying SDN/NFV for Full-SDMN will be examined and described. Additionally, this paper also confirms that SDN/NFV not only efficiently address the crucial challenges of Full-SDMN but also significantly benefit to the next generation mobile network.

The remainder of the paper is organized as follows: Section II defines the requirements that have to be addressed when integrating SDN/NFV in Full-SDMN; Section III proposes a Full-SDMN architecture; Section IV describes several challenges for Full-SDMN; and finally, Section V concludes the present study.

## II. REQUIREMENTS FOR FULL-SDMN ARCHITECTURE

Firstly, applying SDN/NFV orchestration for the dynamic deployment of virtual mobile network (VMN) is important. SDN/NFV are expected to obtain scalability, cost-efficiency and flexibility for VMN deployment. These technologies are appealing that they enable VMNs to flexibly control their virtual core mobile network, RAN and Enhanced Packet Core (EPC) based on the actual traffic load.

Secondly, using DCN (Data Center Network) with ultra-low latency is a vital solution that it enables network functions and core mobile network can be deployed on it. As the result, this can provide an ability to manage network traffic within the cloud. Moreover, reducing latency in DCN lead to the new way of processing and forwarding flows in the cloud, which will accommodate IoT applications and mobile Internet.

Thirdly, to deal with on-demand services and multiple mobile network service providers, Full-SDMN architecture need to adopt the everything as a service (XaaS) to provide virtual core and virtual radio access network for VMNs, and ensure isolation among VMNs. Therefore, Full-SDMN is considered as an ideal choice for network providers for expanding their footprint networks, which including the SDN controller applications and the data plane functions run as scalable services; and the physical infrastructure is managed as a service because it provides several benefits such as high scalability, low-cost services.

Finally, the comprehensive Full-SDMN architecture facilitates independent network protocols in data plane as a

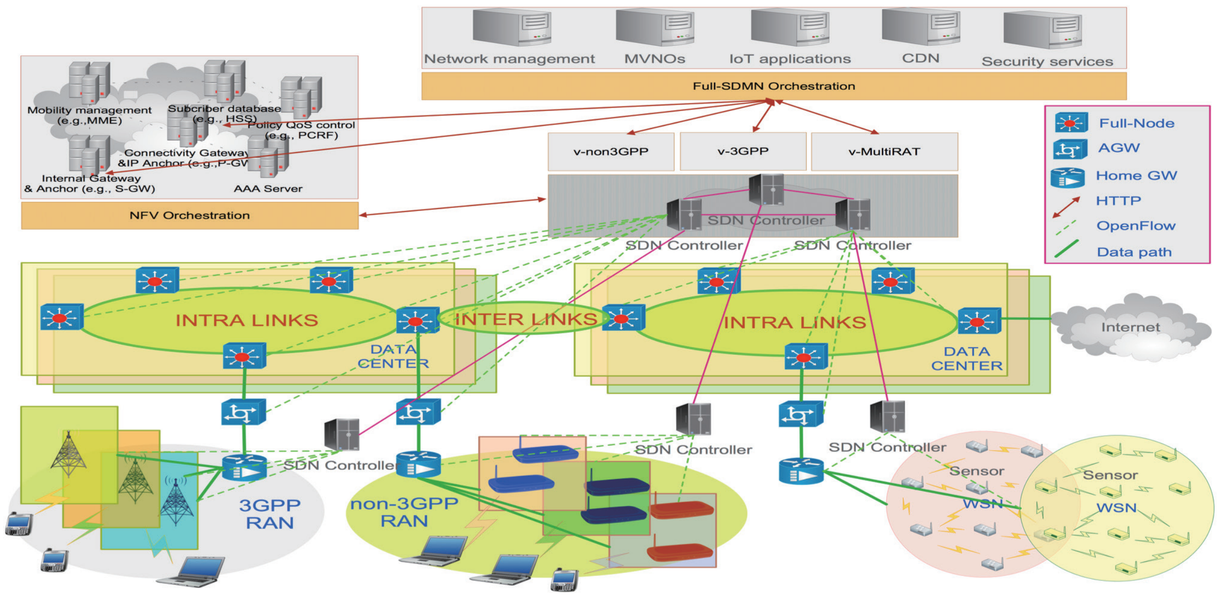


Fig. 1. Full-SDMN Architecture

new factor to inspire innovations. In other words, it provides programmable controllers, applications, and data planes.

## III. FULL-SDMN ARCHITECTURE DESIGN

The proposed architecture, shown in Fig. 1, examines three key enablers, it has capabilities to provide the fully programmable on both the core and access mobile network and seamlessly connect across through access and core mobile network.

### *A. Softwarization of the Core Mobile Network*

Firstly, network functions such as the policy and charging rules function (PCRF), home subscriber server (HSS), Authorization and Accounting (AAA), mobility management entity (MME), decoupled EPC control plane (S-GW, P-GW), and all signaling are running on commodity servers in DCN. This permits NFV orchestration controls those components quickly and easily. Likewise, the decoupled data plane stays in the infrastructure of DCN aim to maximize the network performance by using programmable Full-nodes.

Secondly, the Access Gateways (AGWs) must be deployed at the edge of DCN so that they can connect to various types of Radio Access Networks (RANs), such as 3GPP (e.g. LTE-E-UTRAN, UMTS-UTRAN, GPRS-GERAN), non-3GPP (e.g. WIMAX, CDMA2000, WiFi), Wireless Sensor Network (WSN), and new RAN or Multi-RAT (Multi-Radio Access Technology).

NFV orchestration, Full-SDMN orchestration and SDN controller cooperate with one another to ensure that: Full-SDMN orchestration manages services and applications such as network management as a service, MVNOs (Mobile Virtual Network Operators), IoT applications, CDN (Content Delivery Network), security, etc. Based on the service, Full-SDMN orchestration generates flows to program the network components to create virtual core networks (VCNs). Once a VCN is created, Full-SDMN orchestration can request information from virtual network functions such as S-GW and P-GW to monitor various VCN parameters. Finally, NFV orchestration empowers SDN controller to program Full-Nodes and AGWs through controller applications.

#### *1) Full-Node – Data Center*

A Full-Node, which is an integrated node, is considered as the main component of the data center. It comprises of the FPGA-based NIC (network interface card), all-optical top of the rack (ToR) switch, top of cluster (ToC) switch with the capability to program the data plane by utilizing emerging programmable optical technologies such as programmable transponder, spectrum selective switches, and using computing and programmable hardware (e.g. FPGA, CPU, Network processor (NPU)), and storage. ToC can combine different optical technologies, which are underlying hardware such as optical packet switching (OPS), optical burst switching (OBS), and optical circuit switching (OCS). A virtual OpenFlow Switch (vOFS) is also implemented in an embedded Linux server platform. Depending on the inserted flow entries, each vOFS automatically controls the underlying hardware to establish cross-connections among their ports [1][2]. Adopting VNODE [2] and LIGHTNESS [3] are expected to provide deep programmability in the data plane, the network will be sliced, and then each slice will run with different protocol, as shown in Fig. 2.

Each of NICs, optical ToRs and ToCs are controlled by the logically centralized SDN controller through a uniform control software interface, exposed by dedicated Full-Node agents. The agents are specific devices, which implementing the proposed extended OpenFlow protocol, gaining useful information from the hardware devices; therefore, the SDN controller can update the current state of the network, and then push the controlling commands to the physical devices.

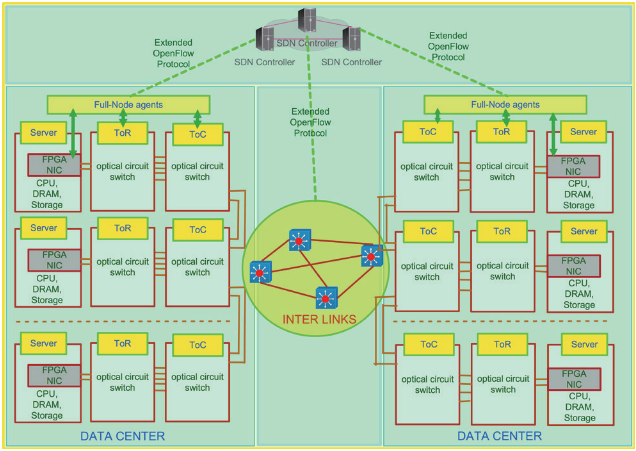


Fig. 2. Full-Node and data center architecture

The Inter-Links (in Fig. 2) connect among DCNs comprising a set of Full-Nodes, optical fiber transmission and CORD [4], which can be selected as an advanced solution.

*2) AGW*

An AGW is an access gateway that plays the role of both the S-GW and P-GW to communicate between VRANs and VCNs. The IEEE 802.1ad is known as Q-in-Q VLAN tunneling will be implemented in communication.

*3) Full-SDMN Orchestration*

Full-SDMN Orchestration is a framework for assembling and composing flexible services such as MVNOs, core network as, access mobile network, network managements, IoT applications, etc. It unifies VNFs (provided by NFV Orchestration), controller applications (provided by SDN controllers), data plane, and cloud services. In this context, SDN controllers receive requirements from Full-SDMN Orchestration, and then they co-operate with one another to generate static flows, which are pushed in the physical network infrastructure to create VCNs and VRANs.

*4) NFV Orchestration*

VNFs are stored in forms of VM images or containers in the NFV Orchestration, and they can be also deployed centrally on a single server or a cluster lying under OpenStack operating mechanism. Moreover, they are also configured to control a virtual network via SDN controllers. In this case, NFV Orchestration creates an individual instance for each virtual network.

In the architecture shown in Fig. 1, all of the functionalities are running as controller applications on the top of SDN controller instead of on data plane. As the result, the relating applications can co-operate with one another. For example, when a UE attaches at the first time, the AGW does not have any UE's information, therefore, AGW will send a Packet-in message to SDN controller. In this case, the AAA, which is used as an SDN controller application, is registered to listen to this type of message, after verifies that the UE is allowed to use the network services, the AAA feedbacks the UE's profile to S-GW, P-GW for further process. Furthermore, other applications such as Network Management, MVNOs, IoT applications, CDN, security services can be also deployed on other NFV orchestration with similar way.

*5) SDN Controller*

SDN controllers, which are organized as a distributed control architecture, play three significant roles in the network: Program the data plane; manage flows across the network nodes; and provide the platform for hosting controller applications. Moreover, SDN controllers co-operate smoothly with one another to directly implement v-3GPP, v-non3GPP, v-MultiRAT.

During operation, SDN controller receives a set of requirements from Full-SDMN Orchestration to control the VCNs, and VRANs. Meanwhile, Full-SDMN Orchestration can also request the information of VNFs to monitor various VCNs and VRANs' parameters.

SDN Controller is extended to support other network devices. Full-Node agents are specific devices to implement the proposed extended OpenFlow protocol such as the NIC OpenFlow agent, ToR and ToC OpenFlow agents.

*B. Softwarization of the Access Mobile Network*

In the proposed mobile network architecture, similar to the core, the RAN also needs to be programmed to create virtual access networks based on specific requirements. Under those circumstances, RAN resources, which consist of physical access mobile network infrastructure resources (e.g. APs, eNodeBs, storages, computing, etc.,) and physical radio resources (e.g. radio links between APs, or eNodeBs and end-user devices), can also be abstracted and shared for the purpose of better utilization. This also facilitates the extension of slices created from the core network and access mobile networks, even including end-network devices.

Regarding 3GPP, RAN and VRAN resources have been extensively studied in the literature, such as SoftRAN [5], V-Cell [6], Cloud-RAN [7]. Most of them focus on abstracting physical access resources such as base stations, routers, and Ethernet links. Some of them focus on virtualizing the radio of the LTE system [8]. In Full-SDMN architecture, the authors adopted the main ideas from these papers for virtualizing both eNodeB and the LTE radio resource. The controller application running on top of the SDN Controllers, named v-3GPP application, is in charge of controlling physical layer to create virtual eNodeBs from the physical eNodeB resources and scheduling the on-demand radio resource (e.g., OFDMA sub-carriers) among virtual eNodeBs.

Home GW is an edge network component located in the customers' sides, which ensures that a slice can accommodate in a scalable and flexible way for different types of RAN. Thanks to FLARE [9], an edge network virtualization technology, in which the FLARE Nodes are a small form of network virtualization nodes, consuming less power and supporting deeply programmable data plane; therefore, FLARE is surely suitable for this context. On the other hand, the impressive CORD solution and other network technologies supporting VLAN will become an edge network carrier. Fig. 3 shows the creating of a VRAN, in which the flows successfully reach the proper slice in the destination in the core network.

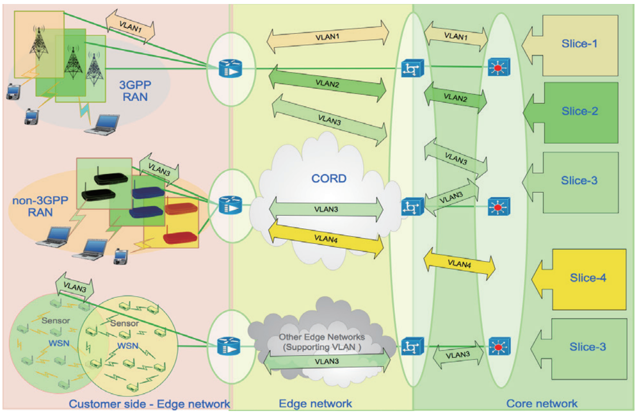


Fig. 3. Mapping logically flows from VRANs into slices

In the context of non-3GPP RAN, we consider virtualizing both the radio resources and network infrastructure [10] [11]. Each wireless interface of an Access Point (AP) is treated as the radio resource, and then, v-non3GPP application can create virtual APs from the multiple radio resources. On the other words, v-non3GPP enables multiple physical APs to be constructed virtual APs, and the flows that are generated by a virtual AP will be attached VLAN ID in order to differentiate from those of other virtual APs.

WSN is pivotal in IoT, which consists of sensor nodes deployed in a structured or unstructured manner. SDN and NFV should be applied to improve the efficiency of WSN as well as foster interoperability of WSNs with certain mobile networks. SDN-based sensor nodes should work as a peer compatibility with other SDN networks and normal sensor nodes [12]. Hence, 3GPP RAN and non3GPP RAN networks should provide gateways for WSNs. In addition, the flows generated by each WSN are also attached VLAN tag to differentiate from other WSNs.

V-MultiRAT application will be deployed based on the diversity of physical cells such as macro-cell, picocell, femtocell, 5G-RAN, or new air interface.

## IV. CHALLENGES OF APPLYING SDN/NFV FOR FULL-SDMN ARCHITECTURE

### A. Challenging in Network Virtualization

Requirements for resource abstraction, inter-slice isolation, customizable inter-slice resource allocation, programmability, and authentication are always required in the Full-SDMN network. Firstly, the core mobile network and RAN resources must be abstracted and virtualized; and then, it is necessary to build applications and algorithms for resources scheduling and allocation to tackle slicing problems. Finally, each slice in the network must satisfy all requirements to ensure isolation among slices. Under those circumstances, the slicing network owner can configure and deploy his/her own software functions independently.

### B. Orchestrating Smoothly overall Network

The same physical mobile network resources can be abstracted and shared by several VMNs, and each VMN consist of VCN and VRAN to provide services seamlessly through the whole VMN.

Obviously, many RANs and core mobile networks are inter-connected and controlled under the orchestration of a logically centralized controller based on physically distributed controllers. To deal with this challenge, ONOS [13], a distributed control architecture, can be installed into the physically distributed controllers and operate as an unified entity. In the same way, OpenDayLight (ODL) [14] is also an SDN controller, which can be deployed in multiple clusters of controllers. Both ONOS and ODL can be utilized to guarantee scalability, performance and availability in multiple network domains.

### C. Independent Network Protocol

Independent network protocol among slices is a key feature for motivating innovation, encourage deployment of network programmability in applications, controls, and data planes. By the way, the nodes of Full-SDMN architecture including Home GW, AGW, and Full-SDMN nodes are equipped general-purpose servers, network processors, and OFS. As the result, they can be characterized into two key features. The former feature enables virtualizing the computing resources at each node while the latter feature enables virtualizing the link resources among nodes. Hence, each slice can be deployed its own network protocol independently such as OpenFlow, P4, or even conventional Ethernet. Moreover, each server can provide multiple VMs that work as processing components in which we can implement various software functions to enhance service functionalities.

### D. Meeting the Explosion of IoT Traffic

The 5G network will have to fulfill the diversity of IoT applications, and in this situation, the virtualizing mobile network expanding from core to RAN with independent protocols and deeply programmable data plane will be actualized. Furthermore, we believe that the access mobile network from the idea of MEC (Mobile Edge Computing) will be selected for processing a huge amount of data generated by IoT applications because this architecture can integrate both network and computing functions, which are available any place on the network.

Moreover, using CORD edge carrier network brings benefit from "*the customer LAN*". That means a remote VM residing in the telco CO (telecommunication central office), provides every subscriber a direct ingress into the telco's cloud. In other words, a huge amount of data generated by IoT devices is directly aggregated, computed, and stored at edge networks so that the network can address the explosion of traffic in 5G. Furthermore, using CORD for communicating on the edge in mobile networks is a good choice for real-time big data analysis.

### E. QoS and QoE on Demand

Full-SDMN architecture must satisfy the distinct QoS (Quality of Service) requirements in terms of reliability, latency, jitter, and throughput. For example, WSNs usually require minimal packet loss while mobile surveillance applications usually tolerate a modest bit error rate and latency but require much higher bandwidth than in the former case.

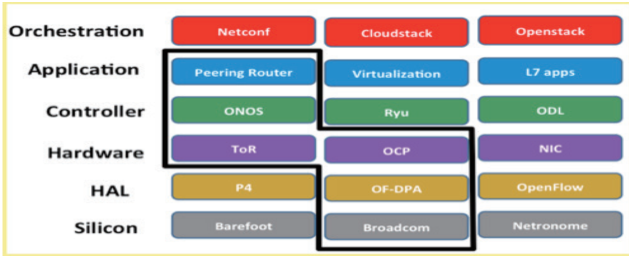


Fig. 4. Vertically Integrated Stack as SDN Distribution [15]

Similarly, different QoE (Quality of Experience) of each service is determined by following components: the service architecture (e.g. server capabilities, caches, and their location); core mobile network performance; and RANs. These components should be addressed in Full-SDMN architecture via routing, scheduling and slicing on the application, control, and even data plane.

### *F. Issues of Integration of SDN and NFV*

The integration of SDN and NFV presents many issues with their incompatibility such as creating a vertically-integrated open source stack, transforming such a diverse collection of devices into software running on commodity servers, and virtualizing network elements defined in NFV. These functions always change while operating such as the continual revision of the open source software and tools of SDN. In this case, the authors proposed a vertically integrated stack as SDN distribution solutions shown in Fig. 4 as an effective solution.

### *G. Scalability and Compatibility Issues*

The Full-SDMN network must be able to provide a wide set of controller applications that are simultaneously deployed on physical network devices, which may raise several scalabilities and compatibility issues. For example, an application may be working and requiring fast reaction upon changes in the underlying physical infrastructure. Otherwise, the deployment of multiple applications will be complicated to allocate and schedule the physical resources that reducing the network capability. Thus, the orchestration mechanism should be called for coordinating among NFV, SDN controller, and data plane operation.

### *H. Throughput and Latency Issues*

In the Full-SDMN network, throughput and latency features, which are significant in the context of 5G networks, may be affected. To deal with this issue, the adopted optical technologies for edge and core mobile network can be considered as an effective approach for not only reducing the transmission latency, but also satisfying the bandwidth requirements. However, the latency due to the processing of SDN controller and orchestration functions will become major concerns. Especially, the latency for establishing end-to-end channel is a major factor that may affect the whole system.

## V. CONCLUSION

The Full-SDMN architecture was proposed to solve the current mobile network based on 5G trends. It equips with the intrinsic capabilities of independent network slices across from access to core network. Each slice can run different network protocol in which SDN and NFV are associated to build on-demand network services. Moreover, the architecture can also adopt CORD for edge network, FLARE as Home-GWs, and other technologies such as MEC to bring benefit for data computing, data storages and other IoT applications. The paper also explores the challenges and solutions when applying SDN and NFV for the context of deeply programmable networks. Furthermore, the paper also mentioned that the latency of establishing an end-to-end channel in the Full-SDMN architecture can be satisfied for 5G in the context of heterogeneous RAN including 3GPP RAN, non3GPP RAN, and Multi-RAT.

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