SDN & NFV in 5G: Advancements and Challenges

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***Abstract*—The next generation of mobile networks has risen the expectations and has induced a whole new approach in the networking future. This study summarizes solutions, that meet all the existing requirements integrating Software Defined Network (SDN) and Network Function Virtualization (NFV) in mobile networking. The main contribution of this research activity is that it is a tool for literature reference for scientists and engineers, because it presents and compares the most fundamental existing solutions and the future directions. In this paper, the main characteristics of SDN and NFV are summarized as fundamental alternatives contributing to succeed the goals set by 5G. The main demands and challenges faced by these solutions and the most beneficial applications of the combination of SDN with NFV are described. Finally, the main conclusions of this research and suggestions for possible future activity in the field are described.**

Keywords*—*SDN, NFV, 5G, mobile networks

I. INTRODUCTION

The arrival of the next generation of mobile networks has rendered the demands of novel, more evolved and scalable technologies an imperative requirement. Mobile users are highly augmenting not only because of the fact that the number of personal devices is incrementing, but also because of (machine to machine (M2M) communication methods, the Internet of Things (IoT)), that add data overhead, augment the data rate, raise the capacity demands and increase the need for coverage.

Although several types of mobile networks will dominate in the 2020’s, there are also many challenges, such as: extenuating power consumption in devices and base stations, better resource allocation, higher data rates, ensuring lower round trip times, reducing all costs, optimization of mobility management policies, scalability, elasticity and agility.

Though until recently decentralized architectures were considered safe and efficient leading to more and more decentralized models, the augmenting network traffic advocates in favor of adopting a centralized way of control. A central architecture provides important benefits, such as optimal frequency assignment and efficient mobility management policies.

Software Defined Networking (SDN) is not only a means of meeting the 5G demanding goals, but also offers an alternative solution to face the main mobile network problems.

There is not much activity in the field of reviewing the most important studies including SDN and NFV, although there is much research in possible applicable scenarios for implementing the technologies. The survey [16] summarizes the most important facts about SDN and includes several other studies and testings in the field. A framework for cellular SDN is presented thoroughly in [7]. The main objective of this paper is to summarize the main features of SDN and NFV.

The survey [16] summarizes the most important facts about SDN and includes several other studies and testings in the field. Open Network Operating System (ONOS) is the most well-known and important SDN controller. Its latest releases (from Emu and beyond) introduce the Central Office Re-imagined as a Data center (CORD). The next release of NFV is the Brahmaputra, is going to be combined with these releases.

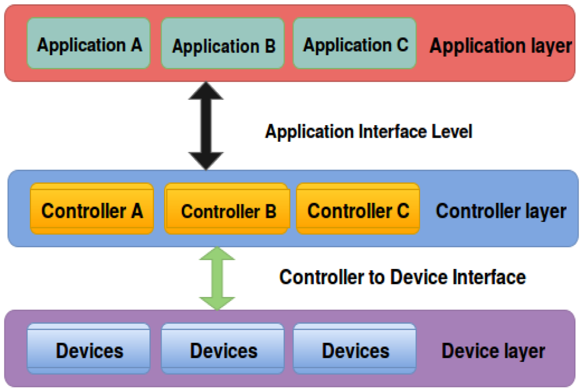

Fig. 1: The general concept of SDN architectural model.

The remaining part of this paper is structured as follows: in Section II the main challenges SDN and NFV should meet are listed. In Section III the SDN mobile and wireless architectures and the uses of NFV in mobile networks are described. In Section IV there is a comparison and contrast of the suggested mobile solutions. In Section V the expected evolution in the domain in the next years is outlined, the paper is concluded and some ideas for future research activity are listed.

II. REQUIREMENTS & CHALLENGES

In this section, the main requirements and obstacles that have been raised are summarized.

Fig. 1 describes the concept in the already presented SDN architectures, such as [12] and [16], which are based on decoupling the data and control layers. The infrastructure layer includes commodity switches. The control layer includes a cluster of controllers. The application layer includes applications and network appliances. Firewalls are virtually deployed reclaiming the NFV and function in the application layer.

The most vital requirements that are linked to the SDN wireless and mobile cases and the demands of NFV presented [6] are summarized in Table I. It is significant to standardize the control and provision future demands of resources and succeed in providing dynamic control not only by statistical development and real-time data. Viewing a large part of the network, contributes in enhancing the assignment and routing capabilities.

It also provides performance degradation control policies, requirements in safety and security issues and alternative applicable scenarios in case the controllers get out of order. 5G and beyond networks are based on ultra-dense deployments.

It is important to succeed in providing denser cellular infrastructures, increasing the available bandwidth, exploring Multiple Input Multiple Output (MIMO) solutions collecting network state, specifying the behavior of the network, updating the network configuration. The OpenFlow protocol and the wireless networking abstractions contribute to this direction, namely the light virtual access point, resource pool, interference map [20]. Finally, the authors end up evaluating the suggested resource management, querying and interference tracking.

TABLE I: The main requirements and challenges linked to the SDN and NFV.

SDN	NFV
CONTROL	
1. Standardization of the control interfaces 2. Protection of commercial business operating schemes 3. Measures to avoid performance degradation 4. Maintenance of information of the controlling network-big data development	1. Seamless control and provisioning 2. Real time and dynamic provisioning 3. Creation of network granularity policies 4. Maintenance of virtualization information-big data development
RELIABILITY	
1. Seamless connectivity and fast connection recovery 2. Security requirements in EPC and RAN 3. Security and reliability of the transport and data network 4. Equilibrium among performance, security and flexibility	1. High complexity of 5G (technologies, devices, IoT) 2. Seamless and high quality connectivity 3. Virtualization of terminal points 4. Security concerns (same physical medium)
SCALABILITY	
1. Support of technology and device heterogeneity 2. Controller messages with performance and survivability (low packet loss levels) 3. Optimization of flow rules-better network slicing	1. Carrier-grade scalability and robustness 2. Acceleration of implementation 3. Openness and interoperability, global reach and cross-administration
COST EFFICIENCY	
1. Capability to support a pay for service commercial model 2. Replacement of hardware with software applications 3. Deployment and acquisition of commodity switches-Replacement of legacy hardware 4. Shorter time to market and less deployment risks	1. Power consumption reduction 2. Operational efficiency improvement 3. Higher capital costs 4. Higher operational costs (short life-cycle of configuration tools)

There is an introduction of some basic terms for IP mobile networks. They analyze the procedure of exchanging IP datagrams. There is also a summary of the main mobile IP challenges, such as security, triangle routing and handover. It describes the OpenFlow implementation based on registration processes, packet processing and the controller application. It concludes that this research activity enforces seamless networking mobility and improves QoE [19].

Review [18] describes a base station and a core network virtualization. The most important motivations of using the NFVs are analyzed. For NFV cases, the virtualized and not virtualized mobile core network should coexist according to [18].

The challenges and performance degradation effects are avoided in the network by the SDN and are specially controlled by the ONOS project in the mobile 5G [5].

III. Proposed solutions of Mobile SDN/NFV

In this section, the main aspects of the existing solutions in the mobile SDN cases are presented.

A. Overview

The EPC in SDN solutions is virtually deployed. The NFV concept will be used for the case of EPC so that the network operates in a virtualized way. The idea takes advantage of all NFV assets including scalability, lower costs etc. According to [12] and [14] EPC provides substantial applications:

- Implementation of virtualized mobile gateways, S-GW, P-GW.
- Creation of mobility management policy.
- Network management & network components management.
- Band splitting in cloud cases & management of cloud nodes.

In Fig. 2 the overall SDN mobile architecture based on the today's LTE networks is summarized. It describes the RAN, the EPC components, the virtualized network parts and how it is possible combining these with mobile SDN solutions, such as mobile or cellular SDN to succeed in the optimization of the mobile networking. Analytically, the Mobility Management Entity (MME), the Serving Gateway (S-GW), the Packet Data Node Gateway (P-GW), the Policy and Charging Rules Function (PCRF), the Home Subscriber Server (HSS), the cloud RAN (OpenRadio, OpenRAN, etc), the Remote Radio Units (RRU), the Virtualized Base Station - Baseband Units (BBU) are presented. The control and the data planes are split. The mobile version of SDN includes all the components existing into the cloud figure. It also manages Quality of Service (QoS) and provides Deep Packet Inspection (DPI). Finally, Policy and Charging Rules Function (PCRF) supports service data flow detection, policy enforcement and flow-based charging.

B. Existing Solutions

*1) **OpenRadio**:* [4] describes the programmable data plane in wireless systems and its possible implementation in today's mobile networks. Firstly, there are several analyses including the cell-based optimization, the coexistence of heterogeneous and alternative types of cells and the application of specific wireless services. It introduces programming abstractions, such as modular declarative interface, information plane, state machine model and deadlines. Finally, it refers to the challenges of the OpenRadio and suggests a designing policy.

*2) **OpenRAN**:* [21] introduces an OpenRAN approach via virtualization. The suggested overall protocol is divided in the SDN controller, in the wireless spectrum resource and the cloud computing resource protocol. It also induces four levels of virtualization: application, cloud, spectrum and cooperation. It concludes that controllers and programmable schemes achieve routing and bandwidth allocation and several flow priorities.

*3) **SoftRAN**:* [9] introduces the dense network management. The authors design the SoftRAN (Software defined RAN) combined with a coupled control plane in dense networks. It introduces the base station abstraction, the SoftRAN, the controller architecture and the refactoring of the control plane. It ends up indicating the feasibility of RAN.

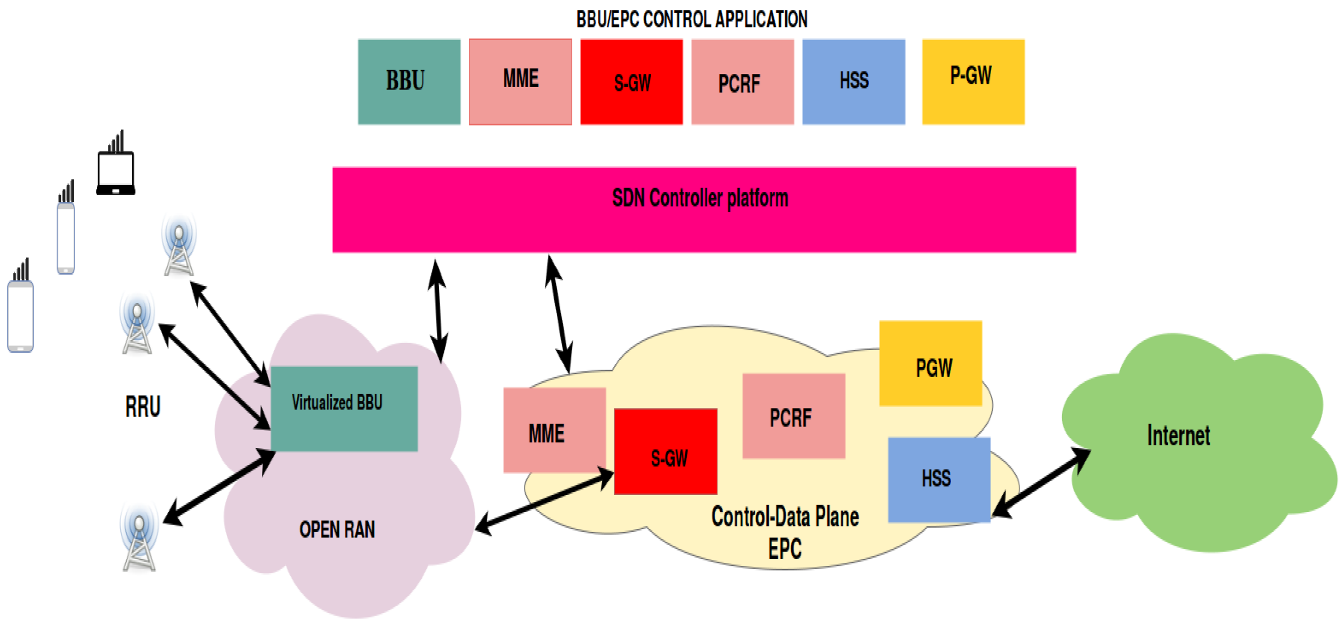

Fig. 2: The overall architectural scheme, including the EPC, RAN, mobile SDN and NFV.

*4) **NetShare**:* [17] operates as manager of shared resources and is introduced as a way of reallocating the existing resources of base stations and multiple entities in an existing network. Netshare isolates entities and highly utilizes the resources of an entity. The resource allocation is based on distribution, strict isolation, network heterogeneity and per base station reservation.

*5) **ONOS**:* [5] analyzes the SDN based on ONOS and the motivation linked to wireless transport networks. MCORD (Mobile CORD) is the mobile ONOS CORD and is available for experimentation since the Emu release of ONOS.

*6) **Software Defined Cellular Network (SDCN)**:* [14] includes fundamental answers in the already augmenting demands, namely flexible policies, scalability, commodity switches, remote control of base stations. Several controller applications are directing traffic throughout middleboxes, monitoring network controlling and billing, providing seamless subscriber mobility and QoS, accessing control policies, offering virtual cellular operators and managing intercell interference. Last but not least, slicing several resources, such as bandwidth, topology, traffic, device CPU and forwarding tables is important for efficient resource allocation.

*7) **Cellular SDN (CSDN)**:* [15] focuses on flexible policies on subscriber attributes, scalability through local agents, flexible switch patterns and actions and network virtualization on subscriber attributes. There are also several CSDN applications such as flexible subscriber policies, scalability for local agents, flexible switch patterns and virtualization of the subscriber attributes.

The SDN architecture induces logical centralized control, programmability and high abstraction levels [10]. The background study is based on inter-cell interference management and mobile traffic management.

SDN and NFV are capable of providing intelligent services and dynamic resource allocation. The virtualized network in SDN architectures includes several functions, designing considerations in the forwarding and control plane [7]. Practical questions are considered when it comes to centralized vs distributed data collection, data processing, decision making and user privacy. Future work is summarized as being a combination of CSDN with Big Data.

*8) **Wireless SDN (WSDN)**:* [6] introduces a wireless SDN architecture. The virtualization of several functions and mechanisms of the network infrastructure are analyzed alongside with other important issues, such as sharing, virtualizing core servers, dynamic energy policies. SDN, OpenFlow, CAPWAP and reconfigurable wireless devices are defined. Virtualization matters, QoE-aware network operations, network access selection and mobility control are raised.

*9) **SDN Mobile Cloud**:* [11] offers important benefits in wireless communications alongside with novel applications, that stem from SDN. There is a consideration of several challenges of combining SDN with adhoc networks and an heterogeneous architecture is proposed.

*10)**Mobile Extension of SDN (MeSDN)**:* [12] summarizes the possible mobile cloud requirements.MeSDN should be used at the enterprises to cover the augmenting demands of the visitors in using the network. The proposed architecture describes the flow manager, the roles of the local and the global controllers. There is also a reference in MeSDN applications, such as App-aware End to End (E2E), QoS, network fault diagnosis, WLAN Virtualization, 4G cellular networks. It introduces pTDMA (pseudo Time Division Multiple Access), a type of pseudo TDMA, analyzing scheduling principles, downlink control, power saving, prototype implementation, such as architecture, threats, evaluation. The most important challenges are presented, among which are: millisecond level synchronization, driver buffering delay and 802.11 beacons.

C. *Ultra-dense deployments based on SDN*

A network model and some control functions are presented, in which the controllers are divided in two possible categories based on optimization approaches. For long term optimization, the technique is deployed in dedicated hardware, while for short term ones only cover some base stations [2]. There is a presentation of some controller applications, such as mitigation LTE, WLAN optimization, LTE access selection, power cycling and offloading.

The main security dangers in 5G, such as interference, backhauling, inconsistent security and high complexity, due to augmenting number of devices, are described thoroughly. The exact applicability of SDN in mobile networks is analyzed alongside with the fact that constant handovers raise security issues in 5G. In order to avoid these problems 5G is suggested to be implemented using SDN capabilities, handover mechanisms and privacy protection [8].

IV. Comparison of SDN & NFV Solutions

In this section, there is a comparison between the two main technological deployments. The most significant studies combine the two achievements and contribute in outlining the future directions in the field.

- **Motivation of deployment:** SDN is deployed in order to decouple the control and the data plane and provides network controlling and programmability. NFV is an abstraction of network functions.
- **Abstraction:** Abstraction levels provided by the NFVs should be standardized.
- **Types of virtualization:** It is possible to virtualize resources or hardware devices, build virtual base stations and manage resources in mobile networking.
- **Mobility Management:** The virtualization methods contribute to better mobility management, creation of policies and deployment of a billing system.It is valuable for controlling traffic classes and forming several flow space partitioning rules.
- **Heterogeneity:** Heterogeneous solutions are supported, supporting combination of different technologies and types of cells.
- **Efficient handover policies:** It is important to standardize innovative radio resource management functionalities.
- **Cost efficiency and software based implementation:** Network Address Translation (NAT), firewalls and mobile core functions should be virtually deployed.
- **Open Source:** Some of the open source solutions are going to be deployed as commercial ones providing extra features in their commercial version.
- **Location:** SDN controllers are located at the data center, whereas NFVs are located in service provider networks.
- **Prototypes:** SDN is prototyped for the wired case and there are several suggestions for the mobile and wireless cases, there is not a prototype for NFV.
- **Technology Readiness Level (TRL):** is a method ranking the maturity levels of a technology. It scales from 1 to 9 and represents the existence of basic technological research in the field and the system launching and operation respectively. In our case, some of the suggestions are close to implementation, while others are in a more immature level.
- **Applicability:** Applicable scenarios will provide scalable and reliable solutions and will cover most of the mobile network demands. It is also vital to prove their applicability through thorough testing and evaluation procedures.

SDN is located at the data center, whereas NFVs are located in service provider networks. SDN applications are linked to cloud orchestration and network management, on the other hand NFVs are mostly linked to particular network components, such as firewalls, gateways, content delivery network (cdn). Although SDN and NFV are two extremely different technological suggestions, their combination offers benefits in favor of succeeding high network efficiency and performance.

As referred to [7] all radio resource management functionalities are included. The corresponding virtual Evolved Packet Core (EPC) functionalities are thoroughly described. In [6] virtualization methods are linked to implementation of different overlay networks. They are responsible for NAT firewalls and implement cellular core functions. On the other hand, the solution helps reducing the CAPEX and OPEX for a provider and the time for implementing a new service.

Table II summarizes the basic comparison of the most fundamental features of different SDN suggestions.

V. Conclusions & Future Directions

In this section, possible future directions in the domain of SDN and the particular suggestion are explained and are formed in future research activity.

The most important requirements of 5G delineate the future directions in the field of mobile SDN, most of which are presented in Table III. The virtualization of networking nodes and the cloud service applications offer high network performance (network speed, data rates, low packet loss, low round-trip times, low power consumption etc) and lead to better Radio Resource Management (RRM). The network is possibly intelligent due to information acquired by the network traffic. It is also fundamental to create particular policies and prototypes for the controllers. The heterogeneous network deployments offer E2E solutions and provide QoE and QoS.

In 5G it will be vital to design switches and controllers, that are compatible with the SDN technology or modify the existing ones with SDN enabled. Scalability is a very important issue as the heterogeneous networks described in 5G are ultra-dense and their exact size is not known yet.

The high speed rates and the low round trip times ensure that the network performance in 5G and beyond will be the best possible. So RRM is important to be investigated and implemented in the future. The issue also raised is how resources are allocated to the applications and the development of a certain policy made in the SDN controller.

The need for supporting QoS also raises the importance of describing and distinguishing its different classes. An important issue is also to reclaim the information from the network in a statistic and dynamic way in order to enhance coverage and other resource demands. Finally, E2E SDN solutions should be suggested and implemented as a way to meet the demands of 5G and beyond.

The combination of SDN and NFV promise a different concept of networking deployments as long as the main challenges presented are faced.

In general this research summarizes the existing SDN and NFV solutions for the mobile case with an insight in 5G networks. This paper is able to inform scientists of the latest trends in the domain and also consists a very strong tool, as it reviews several important studies in this particular domain.

In the future, an architecture combining the SDN and NFV is going to be presented as a new future activity and how based on both a more optimized mobile network architecture will be succeeded and will cover the demands and needs of future mobile users. The primary goal of the authors is to test and evaluate a possible SDN architecture.

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TABLE II: Comparison of mobile SDN/NFV solutions.

Feature \ Solution	MeSDN	CSDN	WSDN	NetShare	SoftRAN	OpenRAN	MCORD
Network as a Service (NaaS)							
NFV abstractions	✓	✓	✓	✓			✓
Heterogeneity	✓		✓		✓	✓	✓
Service provider Network		✓	✓	✓			
Scalability	✓	✓	✓	✓	✓	✓	✓
Reliability				✓			✓
Implementation				✓			✓
Evaluation-Testing		✓	✓	✓	✓	✓	✓
TRL	6	4	4	6	6	6	7
Network part	EPC & RAN	EPC & RAN	EPC & RAN	RAN	RAN	RAN	EPC & RAN

TABLE III: 5G requirements, that should be meet by the mobile SDN combined with NFV.

Direction \ Demand	Capacity	High data rate	Reliability	Energy efficiency	Mobility	High coverage
Virtualization	✓	✓	✓	✓		
Scalability of the network components	✓				✓	✓
High performance	✓	✓	✓	✓		✓
Interface standards			✓			
Cloud services/apps	✓		✓	✓	✓	✓
QoS & QoE	✓	✓	✓	✓	✓	✓
Controller prototyping			✓	✓		
Efficient RRM	✓	✓		✓	✓	✓
E2E solutions					✓	✓
Software defined RAN		✓		✓		✓

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