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Exploring SDN & NFV in 5G Using ONOS & POX Controllers

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ABSTRACT

This article describes how novel functionalities will take advantage of the cloud networking and will gradually replace the existing infrastructure of mobile networks with a virtualized one. Two technologies, namely software defined networking (SDN) and network function virtualization (NFV), offer their important benefits and a combination of them is an answer to the demands raised, such as central office re-architected as a data center (CORD). Open network operating system (ONOS) and POX are SDN controllers and offer an option to combine SDN and NFV addressing many ongoing problems in the field of mobile networks. In this paper, technologies and both controllers are compared and contrasted. Indicative cases of topologies are simulated and help evaluating both controllers. According to the experimental findings, ONOS is one of the most important controllers for practical, theoretical, research and educational purposes, while POX is a useful and simpler controller for other educative applications.

KEYWORDS

Centralized Controllers, NFV, ONOS, POX, SDN

1. INTRODUCTION

Mobile communication networks face several problems, no matter how much progress has been made in the field during the last 20 years. Their transmission medium, namely the air, brings serious problems related to interferences (Inter-cell, Co-channel, Electro-magnetic etc.), handovers, performance, quality, costs etc. The large information load that stems from novel technologies (smart homes/cities, Machine to Machine (M2M) communications, Internet of Things (IoT) etc.) brings a huge onus of data in mobile and wireless networks.

5G networks raise demands such as: lower power consumption, high data rates, reduction of expenses, scalable architectures, optimized management of radio resources, efficient handovers, increased CPU demands, lower delays. Novel networks differ from conventional ones, because they tend to centralize the network structure, e.g. network controllers. Software Defined Networking (SDN) policies enable better routing and more efficient management of network resources.

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5G mobile requirements are addressed using the SDN, which also introduces new ways of addressing alternative control suggestions and faces the basic problems mobile networks induce and are closely related to their transmission medium.

Economic crisis and market laws result in diminishing the overall costs. It is essential to simplify the network devices and lessen the usage and complexity of hardware. Network Functions Virtualization (NFV) contributes in providing programmable network functionalities and several simplistic devices, that function as more complicated hardware.

The most significant advantage of SDN is the split of the network in planes, namely the control and data plane. Planes are orchestrated in a way, that better management and orchestration are succeeded. NFVs define the introduction of devices everywhere and almost immediately. As a result, this leads to scalability, which is vital as nowadays most applications induce large data load in the networks and the need for network expansion raises.

The central policy followed for the controllers existing in SDN networks based on the OpenFlow protocol, induces an amazing fact. For example, the central controller gathers information of all the network traffic and functionality and possibly applies network statistics to imply conclusions and implement policies.

The Open Network Operating System (ONOS) is a controller with many advantages. ONOS is implemented by the Open Networking Lab (ON.LAB). It includes many use cases, which are related to wired and wireless matters. Several different topologies are introduced and tested checking important addressable questions, when it comes to SDN and NFV. The Internet Protocol Radio Access Network (IPRAN) use case is used for testing mobile topologies and mobility from one base station to another alongside with handovers and policies.

There is a lot of debating when it comes to Central Office Re-architected as a Data center (CORD) and how it is going to be more efficient. The Mobile CORD (MCORD) is the corresponding CORD case for mobile networks.

POX is a SDN controller, which also offers several fundamental benefits. As every SDN controller, it enables users to insert and run their own applications into the controller.

Although, the controllers' capabilities have been investigated thoroughly, there are not many studies regarding the advantages of these controllers in education, also there are not known studies comparing these two controllers. In this study, authors gather the most important studies of SDN and NFV, also compare and contrast the usages of ONOS and POX. The vRouter (Virtual Router), IPRAN and MCORD use cases of the ONOS controller are tested. Several important conclusions are drawn when it comes to ONOS functionality and testing capabilities. The same topologies are also introduced into POX. Important conclusions are drawn concerning the POX controller. Both controllers' outcomes are examined, the controllers are compared and contrasted and results when it comes to the applications of each one in education are summarized. This study does not contain experiments regarding other applications of these controllers.

The remaining part of this paper is structured as follows: In Section 2 there is an analysis of the theoretical background regarding the SDN, the NFVs. In Section 3 the most important aspects of both technologies are discussed. In Section 4 the opted parameters for the suggested network topologies are summarized. In Section 5 conclusions and comparison of the two controllers is presented and in Section 6 some ideas for future research activity are listed.

2. LITERATURE REVIEW

In this section, there is a literature background analysis on the most significant studies in the field of SDN, NFV, mobile and wireless SDN. The most important demands and problems that should be faced regarding 5G are summarized. There is also a succinct description of the most important SDN and NFV solutions and combinations.

Many projects exist when it comes to SDN. An open source controller called floodlight is one of these: http://www.projectfloodlight.org/floodlight/. OpenFlow integration into different types of switches is checked by the Indigo project: http://www.projectfloodlight.org/indigo/#sthash.TFXxsT9v.dpuf. An important project testing compatibility with the OpenFlow is the OFTest: http://www.projectfloodlight.org/oftest/#sthash.kPqgLFZy.dpuf. Cloud computations and novel technologies are covered in https://5g-ppp.eu/selfnet/ . MCORD is the mobile CORD of the ONOS project and helps addressing problems related to the CORD and its structure http://opencord.org/ .

Evolved Packet Core (EPC) is virtualized in SDN. Most devices are not implemented in hardware, but are Virtual Machines (VMs). What is more, switches are whitebox, using programmable logic, which could lead to improved networking routing.

(Li et al, 2012) and (Yang et al., 2013) present EPC activities, such as: implementing virtualized mobile gateways, serving Gateway (S-GW), Packet Data Node Gateway (P-GW), creating mobility management policies, manage the subscribers, managing the network and the frequency division efficiently.

The network parts of the EPC are virtualized and they include several important networking functionalities, such as:

Mobility Management Entity (MME), S-GW, 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), the control and data plane, the Deep Packet Inspection (DPI).

The most common SDN concepts are presented in (Liu et al., 2013), and (Yang et al., 2013). The architectural schemes presented consist of split data and control planes. The included hardware only consists of white-box switches, that are devices with intelligence, which are programmable and integrate logic derived from software. One or more controllers perform the network management and orchestration, which enables optimized network orchestration and implies reliability. Several applications run at the top. Functionalities are replaced by software exploiting NFV techniques.

2.1. Solutions

In this subsection, the most important studies in the field of SDN and NFV are overviewed. When it comes to the Open RAN: (Bansal et al., 2012), (Gudipati et al. 2013), (Yang et al, 2013) describe the approach of the RAN taking advantage of the SDN profits. Several important issues are introduced concerning the suggested architectures, the approach of the SDN controllers, the strategies and the measures of how RAN will be virtualized in SDN. Finally, with the development of SDN techniques, base stations become abstract and more efficient. Scheduling is enhanced in favor of (Mahindra et al., 2013), which also introduces ways to redistribute the available existing resources.

SNMP visor (Yap et al., 2010) deals with the basic problems mobile networks induce, such as hand-offs, packet losses, etc. FlowSense is the answer to the traffic management in mobile networks. The OpenRoads enables heterogeneity and creates policies for better resource allocation.

Software Defined Cellular Network (SDCN) is described in (Jin et al.), (Bernardos et al., 2014), (Bradai et al., 2015), (Ku et al., 2014), (Li et al, 2012), (Kabir et al., 2014), and (Yang et al., 2013). Several important issues are presented, such as scalable, flexible policies and architectures, Quality of Service (QoS), transmission control, policies, alternative ways of virtualizing simple switches.

Ultra-density is analyzed in (Duan et al., 2015) and (Ali-Ahmad et al., 2013). In these papers, issues are highlighted when it comes to the problems faced by mobile networks alongside with issues regarding security and heterogeneity. Several policies when it comes to optimization, handovers, backhauling and Long-Term Evolution (LTE) are presented.

The Ultra-dense deployments alongside with the ways they configure the network, augment bandwidth resources, induce new technologies in the next mobile network generations are examined in (Riggio et al., 2013). Several issues concerning terminals, mobile controllers, software configuration, enhancement of the mobile network performance, of routing and handoff challenges, network mobility and the providing of Quality of Experience (QoE) for users are analyzed in (Pupatwibul et al., 2013). The policies proposed for the base stations are analyzed.

(Bercovich et al.) presents the ONOS project, which enables avoiding the better network behavior and solves many issues raised in the telecommunications' domain. Several important analyses of the ONOS controller are presented in (Muqaddas et al., 2016), (Kim et al., 2016), (Berde et al., 2014), (Jin et al., 2013), (Li et al, 2012) and (Yang et al., 2013). The core network is virtualized. Several actions should be considered so that virtualized and no virtualized technologies are followed.

ONOS includes many fundamental advantages: modular and abstracted architectures, high coherent architectures, easy testing, maintenance and management of the network, scalable, reliable and easily managed controllers, distributed core, northbound and southbound abstraction, software modularity, easy addition and maintenance of servers. CORD offers many substantial activities, such as: Access as a Service (AaaS), Subscriber as a Service (SaaS), Internet as a Service (IaaS), Content Distributed Networking (CDN), Monitoring as a Service (MaaS).

MCORD is going to be the main answer in the increased data traffic, resulting in the augmentation of demands for alternative access points. There is also a huge investment when it comes to spectrum, alongside with LTE infrastructures, that ensure benefits and augment revenue growth for the operators. ONOS and MCORD are going to satisfy technical demands, such as the suboptimal use of radio resources, the customization of various customers, the rapid creation of innovative services and industrial specifications (IoT).

MCORD will help with the enhancement of the spectrum utilization. It is enabling QoE for users as it reduces latencies and round-trip delays.

It consists a tool for developing personal provider services, such as billing. Agility and cost-efficiency are offered by MCORD. The architectural scheme of the MCORD constitutes of a virtual BBU, a virtual MME, a virtual S-GW, a virtual P-GW, OpenStack, ONOS and a virtual CDN.

2.2. Demands and Obstacles

In this section, the most important advantages of the SDN and NFV and their most controversial issues are presented below. SDN offers many useful advantages and is able to:

- Standardize the controllers and policies, restore the controller in real-time,
- Offer profitable networks, benefits from commercial editions of SDN, result in market products based on open source,
- Help exploiting data from the controller for enhanced operation, enable uninterrupted network accessibility,
- Pose security rules in EPC and RAN,
- Implement strategies to support heterogeneous technologies & architectures,
- Develop network slices, exploit NFVs to avoid hardware,
- Replace the hardware with software and white-boxes resulting to fast novelties invasion into market.

NFV approaches offer hardware alternatives and are able to:

- Allow uninterrupted network orchestration, real time resource allocation, exploit network utilization data,
- Help designing network's distributed and central logic parts, alternatives for uninterrupted communication,
- Offer scalable & robust architectures, hardware avoidance, open network architectures,
- Include security policies unalike technologies of the physical layer,
- Reduce costs, limit the electricity costs, lower the capita& operational expenditures.

In 5G controllers will be the network orchestrators and managers. The resources should not only be efficiently allocated, but several policies should be developed in this direction. Data driven from network utilization could also improve the real-time resource allocation. Controllers are able to view a big network part and maybe result to more efficient routing algorithms. Network reliability is an indisputable fact. In this direction, several issues regarding safety, controlling, avoidance of network degradation should be covered. Plan Bs should be ready for application if the network or a part of it is damaged. Using several instances of controllers enable safety all over the network.

Scalable architectures are also a fundamental requirement, which is provided by heterogeneous schemes. All networks will be large, because new types of devices will be accessible through the Internet. The need for investigating in efficient and low-cost technologies leads to lower Capital and Operational Expenditures, raises the demands of reducing the times for the invasion into the market.

3. COMPARING & CONTRASTING SDN & NFV SOLUTIONS

These two technologies are supplementary as the one interacts with the other. As a result, the most fundamental controversies are:

- **Introduction of the technologies:** The split between control and data layers is based on the SDN architectures. NFV implements network functionalities replacing hardware with software.
- **Prototyping:** NFVs are not standardized, while SDN is prototyped.
- **Virtual architectures:** It is possible to create virtualized architectures. Most networking parts are virtually deployed using the NFVs. SDN controllers are software-based.
- **Mobile networking:** Virtualization and SDN controllers contribute to better mobility management policies and enhancement of routing and handovers (Bradai et al., 2015).
- **Heterogeneous Architectures:** Different technologies should be addressed so that all technological advancements coordinate and keep performance in high levels (Bernardos et al., 2015), (Bansal et al., 2012).
- **Enhanced handoffs:** Using these technologies better routing and handover policies could be adopted so that handovers are more efficient.
- **Low cost solutions:** Virtualized devices result in lowering the capital and operational expenditures. Most solutions are based on open source software. Statistical data from SDN controllers could lead to better resource allocation. They offer important benefits of open-source software and also provide the opportunity to gain larger profits by a market edition of the SDN controllers.
- Applicable scenarios: Most of the mentioned scenarios are applicable solutions. NFVs provide applicable networking functionalities. SDN controllers are applicable solutions.

4. EXPERIMENTAL FRAMEWORK

In this section, the main experimental framework, the architecture examined, the simulation parameters and the experiments conducted are described analytically. VRouter includes the replacement of the router with a simple switch by adding programmable logic into it. For the IPRAN use case two different scenarios are tested. A scheme following a mobile architecture only and another one that includes a combination of a heterogeneous architecture are presented.

For the experimental procedure of the vRouter use case, ONOS, POX and Mininet are needed. Mininet is a very famous network emulator, which contains all types of network devices, that could be introduced into a topology, such as: switches, routers, hosts, etc. For MCORD and IPRAN, the Mininet-wifi is used. It is the extension of Mininet for wireless and mobile networks. Mininet wi-fi also enables the introduction of all components of the wireless and mobile topologies, such as: base stations, access points, antennas, mobile hosts etc.

The topologies are introduced in the controllers via the Linux terminal executing the basic commands in Mininet. The configuration of the topologies is created using a file with the topology and the configuration, while enable the corresponding ONOS app for the case of ONOS. In the POX, the topology file runs via the Mininet terminal. The goal is to run the same experiments in both controllers to show which one is the most suitable for different usages.

Table 1 presents the schemes that are used in the experimental procedure, analyzing the network components per scenario. All the performance tests of the topologies are conducted in a time window of 15 seconds. The controllers in all cases are ONOS and POX. The communication between the network and the ONOS occurs via the BGP protocol. Several switches and hosts are introduced in the vRouter and the heterogeneous cases. Several base stations and access points are introduced for both IPRAN scenarios.

Analytically, the topologies (Figure 1), the parameters and the experiments conducted for each case are presented below:

4.1. vRouter

The vRouter implements a virtual router avoiding the usage of hardware, adding its functionality via programmable logic to a white-box switch. The ONOS controller communicates with the switch and performs the routing. It includes one switch and two hosts connected to it. The ONOS controller monitors the whole network.

The vRouter topology contains 2 hosts connected to the switch, which communicate with the ONOS SDN controller via the Border Gateway Protocol (BGP). ONOS has a catholic view of the topology.

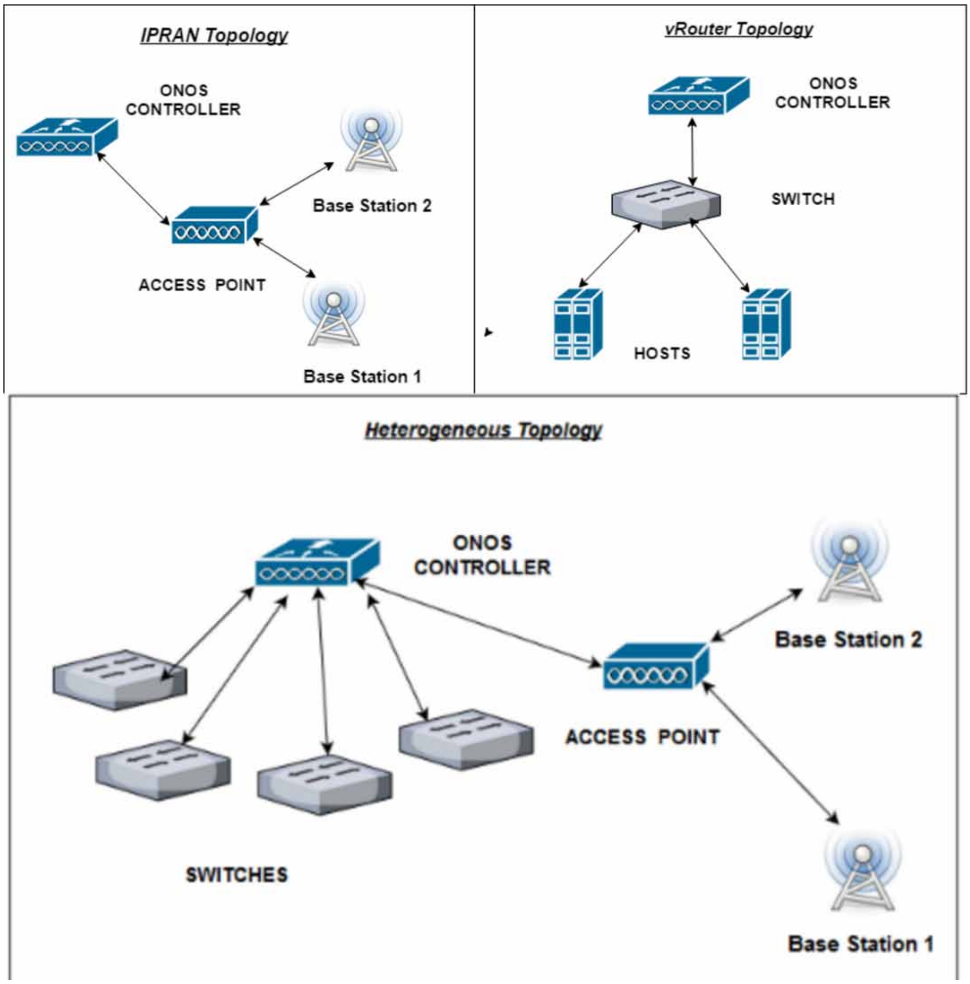
The experimental procedure followed is presented in Figure 2. The sequence of the steps followed is also described. The ONOS controller is depicting all these changes into its interface. Every change into the topology or the components is described into ONOS. These possibilities are not offered by POX. POX only displays messages about its connection state, namely about being connected to the topology or not. In the case of POX, Mininet indicates all the differences in the network. On the other hand, the interface of the ONOS controller is very thorough and indicates messages about any change made in the network, for example, about the connected devices and the traffic exchanged.

Figure 3 describes the efficiency of the vRouter use case depicting the transfer rate and the bandwidth in the selected time window. In the testing scenario, vRouter topology was executed in a time window of 15 seconds. In this period of time 42.2 Gbytes were transferred in 24.1 Gbps bandwidth. Both controllers had the same results and therefore, there is only one graph for the performance of the controllers in the vRouter case. This device is a simple switch and the introduced programmable logic into it rends it to function as a router. Such ideas could be applied to larger networks. What is more, it is obvious that simple devices with applied programmable logic integrated in them function

Table 1. Data summary for the experimentation topologies

Network Component	vRouter	IPRAN	HetNet
Controller	ONOS/POX	ONOS/POX	ONOS/POX
Switches	4	-	1
Router	Virtual Router	+	+
Hosts	2	-	16
Base stations	-	2	2
Access Points	-	1	1
BGP communication	+	+	+

Figure 1. The architectures of the topologies used in the experimental procedure (vRouter, IPRAN and IPRAN heterogeneous)



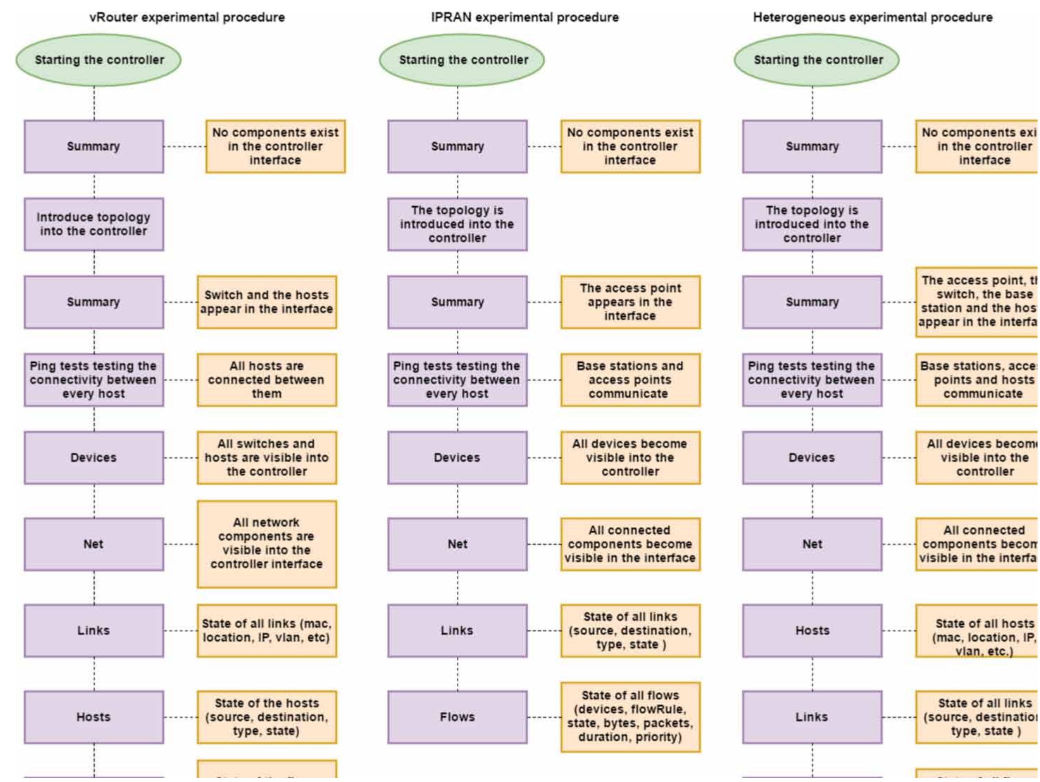
as complex devices. The controller has a catholic network view and depicts all possible changes immediately. This rends the network low-cost, efficient, scalable, secure.

4.2. IPRAN

The IPRAN use case of ONOS is a use case of mobile networking and thus, it enables experimenting with mobile topologies. For this use case Mininet-wifi is used, because base stations and access points are needed for this type of networks and offered by this extension. In the first scenario, only experiments with mobile network components are included. For the POX controller, the same topology is introduced and connected to the remote controller.

The topology presented in Figure 2 contains one access point and two base stations communicating with the access point. The ONOS controller is the device that performs all transportation activities and orchestrates the communication between the access point and all mobile network components. So, does POX. Table 2 describes the configuration of the mobile network components (access points, base stations) including their names, channel, position, Media Access Control addresses (MAC) and Internet Protocol (IP) addresses.

Figure 2. The experimental procedure followed for vRouter, IPRAN mobile components only and IPRAN heterogeneous topologies in the ONOS controller



The experimental procedure as well as the sequence of experiments followed are presented in Figure 2. Figure 4 describes the efficiency of the IPRAN use case for the mobile case scenario. In a time interval of 15 seconds, 19.2Mbytes are transferred and 10.3 Mbps are used. The network remains efficient. Both controllers had the same results and therefore, there is only one graph for the performance of the controllers in the IPRAN case.

Another possible scenario of the IPRAN use case is the combination of the mobile network components with wired ones creating a heterogeneous model. Figure 2 describes the IPRAN heterogeneous model. It includes 2 base stations communicating with an access point, 1 switch and 4 hosts connected to the switch.

Table 2 presents the configuration parameters opted for this scenario and the configuration for the mobile network. The experimental procedure followed is presented in Figure 2. The sequence of the steps followed is also described. The experimental procedure for the IP mobile cases followed are presented in Figure 2. The one topology is testing a mobile-components only scenario, while the other topology tests a heterogeneous scenario. The sequence of the steps followed is also described. The ONOS controller is depicting all these changes into its interface. Every change into the topology or the components is described into ONOS. These possibilities are not offered by POX. POX only displays messages about its connection state, namely about being connected to the topology or not. In the case of POX Mininet is indicating all the differences in the network. On the other hand, the interface of the ONOS controller is very thorough and indicates messages about any change made in the network, for example, about the connected devices and the traffic exchanged. Figure 5 describes the efficiency of the IPRAN use case for the heterogeneous scenario.

Figure 3. The performance (Transfer rate, Bandwidth) of the vRouter case scenario in a time window of 15 seconds

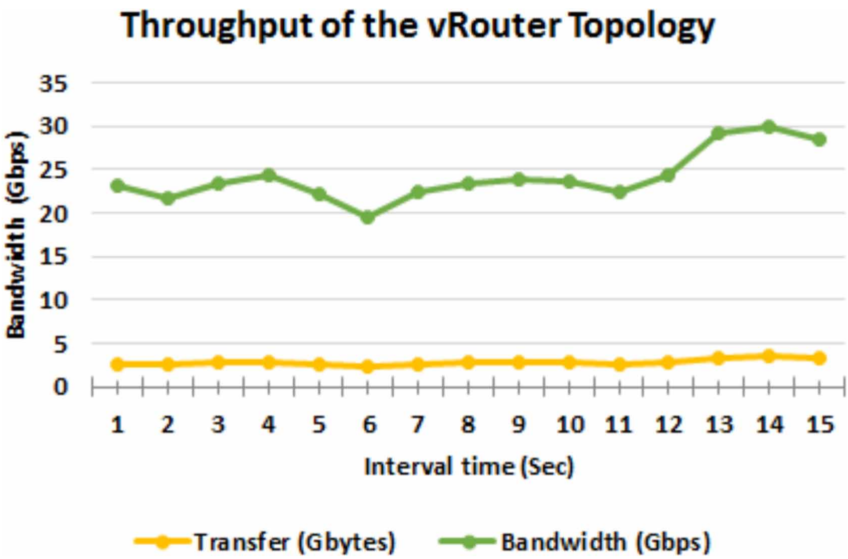


Table 2. The configuration of the IPRAN topology's Access Points and Base Stations

Component	Channel	Position	
Access Point	g	10,30,0	
Component	**MAC**	**IP**	**Position**
BS-sta1	00:00:00:00:00:01	10.0.0.1/8	10.20.1
BS-sta2	00:00:00:00:00:02	10.0.0.2/8	50.20.1

Figure 4. The performance of the IPRAN case (mobile components only scenario) in a time window of 15 seconds

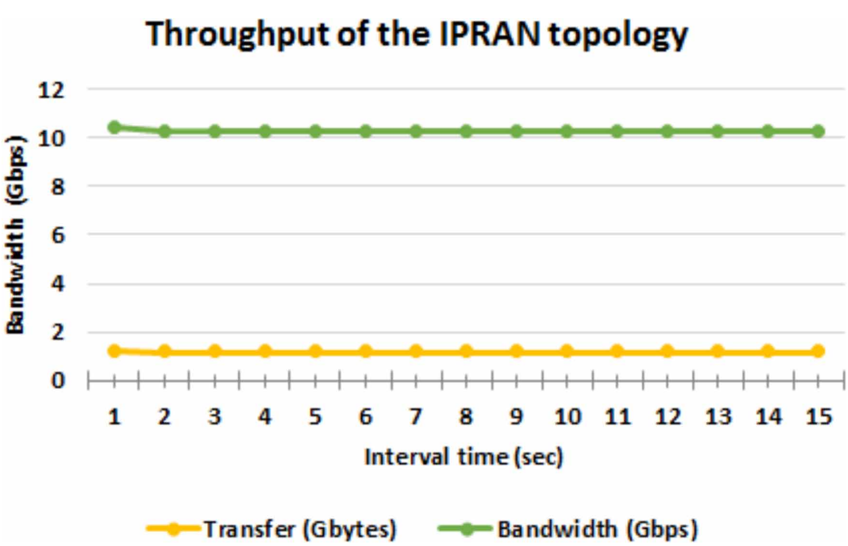
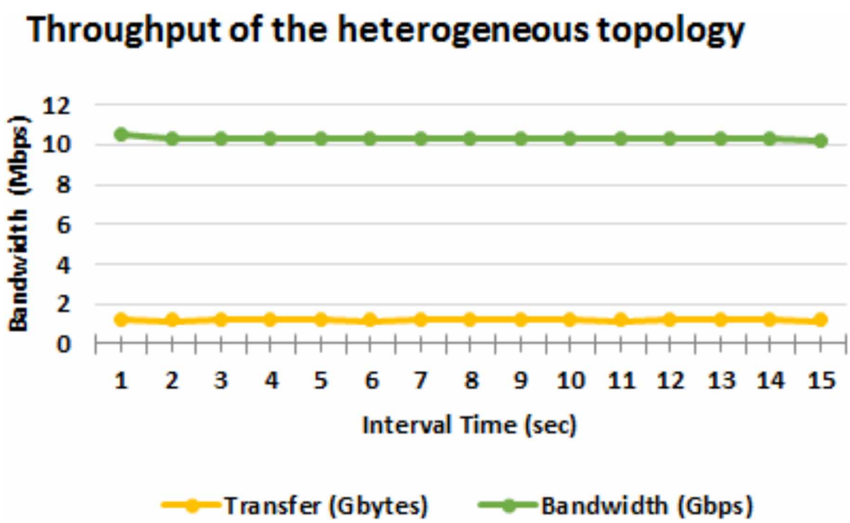


Figure 5. The performance of the IPRAN (heterogeneous scenario) in a time window of 15 seconds



In the IPRAN heterogeneous topology, in a time interval of 15 seconds, 19.2 Mbytes are transferred and 10.3 Mbps are used. The network remains efficient. Both controllers had the same results and therefore, there is only one graph for the performance of the controllers in the heterogeneous case.

These possibilities are not offered by POX. POX only displays messages about its connection state, namely about being connected to the switch or not. In the case of POX Mininet is indicating all the differences in the network. On the other hand, the interface of the ONOS controller is very thorough and indicates messages about any change made in the network, for example, about the connected devices and the traffic exchanged.

The IPRAN use case of ONOS is used to perform several tests and experiments developing mobile only or combinations of mobile and wired scenarios. Several important issues could be tested, such as mobility, handovers etc. The ONOS controller has a catholic view of the network's state. More complex topologies could be tested and result to more important conclusions. For example, handover and routing policies could be tested. For example, if the network has a catholic view of the network and checks the mobility it could be vital to create algorithms with different approach than nowadays.

4.3. MCORD

MCORD is built adopting the CORD-in-a-Box or single Node POD according to the ON.LAB documentation. It offers the possibility that several VM copies coexist. Open software is used to build the experimental environment, the most important of which are: OpenStack, XOS, ONOS, vOLT, vSG, vRouter, Virtual Terminal Network (VTN).

MCORD requires Ubuntu LTS 14.04. Two possible methods of creating the experimental environment are via Vagrant or via a script. A CloudLab account is needed to access VMs. ListView depicts all possible ssh commands. The MCORD environment is easily manageable. The previously mentioned ssh commands enable reset actions into the server. Restarting the server further applications are investigated.

BBU and P-GW are existing as use cases of MCORD, but are virtualized. The VTN is possible to be loaded in the ONOS. The administration panel is accessible and managed by a browser. The VTN is configurable using the browser. Several network slices are added using a particular instance of MCORD. There are many different services included in the MCORD use cases. The most fundamental of which are: RAN: virtual Business Connection Network (vBCN), vBBU and the BBU, Firewall, Cache and Video Optimization, vEPC: vP-GW and MME.

The vBBU runs on VM. All networking components, such as firewalls and caches are easily monitored using the basic platform. Video optimization is one of the services included in the platform. All the provided services are easily connected and disconnected. The possibility of introducing several network slices enables tests concerning 5G, leading to more efficient network slicing.

MCORD is not offered as a use case by the POX controller, so there is not a special interface that one could build in order to experiment with CORD and MCORD. As a result, if one wants to investigate what are the effects of POX to the CORD, he has to make a MCORD application and run experiments into it.

5. CONCLUSION

In this section, the most significant conclusions are analyzed. In the presented scheme, the data centers communicate with the cloud via the transport layer. The controllers perform orchestration between components and allocate resources for the network applications demanding space, bandwidth, etc. The EPC and RAN coordinate with the SDN controller and induce a whole new approach in the future of mobile networks.

In 5G it will be vital to design switches and controllers, that are compatible with SDN or modify the existing ones to enable SDN. The high-speed rates and the low round trip times promised by the next generation ensure that the network performance in 5G and beyond will be the best possible. The issue also raised is how resources are allocated to applications and the development of policies in the SDN controller. The interface between the applications and the controller should also be designed in an effective and compatible way.

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. So, in the future there is a need in finding a way to incorporate intelligence in the network. Finally, E2E SDN solutions should be suggested and implemented as a way to meet the demands of 5G and beyond.

The existing solutions of the issues raised are vital, because they not only provide measurements and ideas for solving the most important problems, but also, they consist a trigger to come up with other possible deployments that solve the existing obstacles.

In this research, we summarize the existing SDN and NFV solutions for the mobile case with an insight in 5G networks. This paper informs scientists of the latest trends in the domain and consists a very strong tool, as it reviews several important studies in the domain.

A combination of SDN and NFV is the answer to the demands raised by the next generation of mobile networks. In this paper, several networking topologies were tested using the ONOS and POX controllers, showing that combining SDN and NFV is a feasible solution, that helps meeting the excessively high demands of 5G and beyond networks. There is an introduction to the design of the architectural scheme, on which the analysis is based. The experimentation parameters are chosen, the network topologies are formed and several scenarios are tested. There are also simulations for the network using the use cases vRouter, MCORD and IPRAN of the ONOS controller and the corresponding topologies tested into the POX controller. The experimentation results are evaluated.

The installation procedure of POX is very simple. It only requires running a python script. This makes the procedure easy and not demanding at all. Installing ONOS is more complicated as a procedure, but there is a lot of documentation and an active community offering all the necessary information.

The topologies created and tested, namely the vRouter, the IPRAN, the heterogeneous are several simple topologies that are inserted and interact with ONOS and POX. By the experimentation procedure was showed that it is easy to insert topologies in both controllers, configuring several components, such as base stations and access points to a mobile topology, monitor traffic and mobility via ONOS. POX does not offer such a descriptive interface and this is its main drawback. Furthermore, it does not include so many use cases-ready to use and to experiment.

The possibility of several instances of the controller means that if the controller is disabled for some reasons (attacks, failures), another controller easily takes its place and functions on its behalf instead. The topologies are indicative cases, that could be extended for bigger networks and topologies.

When it comes to CORD and as a result to MCORD, several slices for different purposes are introduced. The control of the slices is easier, because of slice management mechanisms introduced into MCORD, slice elasticity options and common analytics control APIs. For example, a proposal for the slices that could be included is: CDN QoE, Video streaming, Virtual reality, IoT applications (M2M communications, e-Health, etc.), public safety, Service, User/Devices/Data type, Application, QoS & QoE, Enterprise, Location. To use MCORD with POX, an application should be made to run experiments.

The monitoring of the network is held onto the controller and as a result, the providers/operators/engineers have a more catholic view of the network. This ameliorates the state of the network by enhancing the resource management in mobile networks and is also a way for scientists to acquire and reclaim empirical data by the network usage, and creates better traffic and routing algorithms for mobile networks. Especially for ONOS, which indicates thorough information about the state of the controller.

ONOS is essential for educational purposes. It is an open source controller, which contributes to education, because there is no need for commercial licensing, has many use cases, has a very descriptive interface. On the other hand, POX is also essential for education. It is also open source, but it is suitable if the goal is to train in the making of new applications and network software development. Therefore, for different educational purposes both controllers may be useful.

6. FUTURE ACTIVITY

In this section, we suggest possible future directions in the domain of SDN. There is a lot of effort that should be made in order to convince market to adopt SDN & NFV. It is therefore fundamental to experiment with significant issues and SDN's main drawbacks, which are mainly security issues.

It is fundamental to show how the OpenFlow protocol could be further secured and enhanced, in order to ameliorate switches' intelligence using programmable logic techniques of other NFVs in order to avoid attacks in switches, such as identity spoofing or Man-In-The-Middle attacks etc. SDN networks suffer from Denial of Service (DOS) and distributed DOS attacks, as the SDN controllers are centralized. Thus, several measures and procedures should be made on how to avoid these types of attacks that could set the network to a no-working state.

Specific policies and prototypes should be deployed. Software problems should be settled, such as bugs, software security, etc. Investigation procedures should be analyzed on how to introduce ONOS for educational procedures and methods alongside with comparing with other educational SDN controllers, such as NOX.

New services should be created using the MCORD to address 5G requirements and also provide solutions network flow partition, billing systems and enhance simple searches inside large servers.

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