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Research Article

Virtualization of a 4G Evolved Packet Core Network Using Network Function Virtualization (NFV) Technology with NS3 for Enterprise and Educational Purpose

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Abstract

The current networks of many operators dispose an increasing variety of purpose built, vertically integrated, and vendor-locked hardware equipment. This makes it difficult to easily scale their radio access and core networks as it requires yet another variety of equipment, leading to increased Time-to-Market and inefficient resource utilization. Furthermore, network equipment are expensive to procure and upgrade (increased CAPEX), and are difficult to adapt and program for new services (increased OPEX). These trends have recently spurred several efforts to redesign various components of mobile networks, notably the 4G Evolved Packet Core (EPC). With regards to this, the present work proposes a solution based on Network Function Virtualization (NFV), which can be deployed for educational or enterprises purpose like in Data Centers, or network nodes with a fine-grained QoS, while maintaining the scalability of the virtualized network function entities, and optimum resource utilization. The actual work develops a mobile network simulation module centered on the 4G Core network comprising its major components; MME, SGW, and PGW (vEPC), as well as the networking amongst these entities, core network related aspects such as its interaction with the Enhanced Radio Access Network (E-UTRAN) and the Packet Data Network Services (Internet). This solution gives to core network engineers and EPC network agents the possibility to design, analyze and test variable types of network scenarios. The solution can be also integrated in engineering schools and college for labs' practical work or to any e-laboratory initiative to allow students in virtual environment to analyze signaling, modify the network configuration and better understand some theoretical concepts taught during the courses. The results obtained from the present work can be of great help during the final deployment phase of the network for full production for engineers of carriers' network or improve the engineering understanding of core network in academic domain. In this light, the network can easily be scaled, adjust virtually for the time to commercialize a service reduced for carrier or enterprises' solutions or for testing in e-laboratories.

Keywords

Virtualization, vEPC, NFV, Scalability, Network Simulation

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1. Introduction

The mobile network is constantly changing the way people communicate, stay informed, and are entertained. With more compelling services and mobile multimedia computing devices, users are increasingly entering the network and creating an enormous surge in mobile traffic, saturating the networks. According to Cisco's predictions mobile data traffic will increase eightfold between 2015 and 2025. Current Telecom network architectures are expected to face difficulties scaling to this load, causing mobile operators to look for new alternatives to overcome this challenge and putting them on pressure of maintaining appreciable user experiences. The table below gives a brief summary of mobile network changing dynamics.

Table 1. *Mobile network changing dynamics [1].*

Network/observation	Old normal	New normal
Users	People	People and things
Access	Homogeneous	Heterogeneous
Services	Voice and data	Experiences
Usage	Predictable	Unpredictable
Architecture	Static	Elastic

In Cameroon, many operators, in partnership with Huawei, her main equipment vendor, since 2005 and 2006 launched projects by purchasing Huawei Core network. With the deployment already completed all these companies aim to guarantee better customer experiences to her vast and growing clients especially for data service.

In the quest to meet up with this "new normal", mobile network operators are greatly faced with a situation where, they tend to have increased variety of vertically integrated hardware equipment, requiring much of the procure design-integrate-deploy cycle to be repeated, whereby the deployment of a new network service often requires yet another variety of hardware, space and power to accommodate and this is becoming increasingly difficult; considering the increasing costs of energy, capital investment challenges and the rarity of skills necessary to design, integrate and operate increasingly complex hardware-based equipment which also rapidly reach end of life with shorter lifecycles as technology and service innovations accelerates, constraining innovation in an increasingly network-centric connected world [2].

NFV is an emerging key technology to overcome the major challenges facing the mobile network operators such as reducing CAPEX (Capital expenditure) and OPEX (Operational expenditure), and satisfying the growing demand for mobile services (scalability). It stands as a promising solution to transfer IT virtualization technology advantages to the telecommunication industry by leveraging standard IT virtualization technology to consolidate many network equipment types onto industry standard high-volume servers, switches and storage [2]. NFV is applicable to any data plane packet processing and control plane function in fixed and mobile network infrastructures, and also paves a way to 5G.

The present work titled "Virtualization of a 4G Evolved Packet Core Network Using Network Function Virtualization (NFV) Technology for Enterprise and Educational Purpose" in regards to the above observation, therefore stands as a square peg in a square hole, as operators need to deploy a core network that combines performance with intelligence to meet different traffic demands with an elastic architecture, to create a robust multimedia environment, enhance and manage the subscriber experience, and monetize network traffic. The virtualization of the EPC as it can be used for enterprise purposes, it can also be used for teaching purposes which will allow the teacher to present the way of designing a 4G core network, the way signaling is carried in an EPC, the way nodes will exchanged information. In this way, some remote access to laboratories can be designed allowing students from one university to use remotely the resources of another university, so in this work we will regard the use of virtualization for both enterprise and educational purposes. For an easy walk through this work, we adopted the following partition of three major parts: The first one will be related to the context and problem statement; this will be followed by the method used, after that we will present the results obtained through simulations and we shall end with a conclusion.

2. Context and Problem

vEPC existing solutions

Though no standard reference solution currently exists, there is a variable number of virtualized EPC solutions already in market, on test, as well as on development. As new MNOs (Mobile Network operators) worldwide tend to embrace the current breeze of virtualization, so does the number of vEPC solutions keeps increasing. Some of these solutions include:

1. *Huawei CloudEPC,*
2. *Affirmed Networks Mobile Content Cloud,*
3. *Cisco Virtual Packet Core, Ericsson Cloud Packet Core,*
4. *Mavenir vEPC,*
5. *Nokia Cloud Packet Core,*
6. *ZTE vEPC,*
7. *Brocade vEPC etc.*

A walk through 02 of the solutions above, with a brief description is presented below

Huawei CloudEPC

The Huawei CloudEPC solution uses the network functions virtualization (NFV) technology to virtualize the EPC system. This solution accelerates service launch, builds a more open ecosystem, continuously improves service innovation capabilities, and reduces device purchase and maintenance costs.

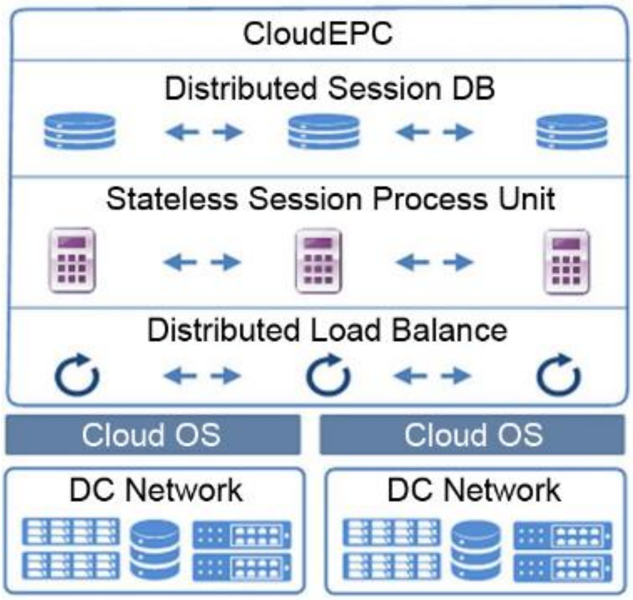

Figure 1. Huawei CloudEPC [3].

The CloudEPC is an important part of the Huawei Cloud-Edge solution and consists of the following network elements (NEs):

1. CloudUSN: supports serving GPRS support node (SGSN) and mobility management entity (MME) functions.
2. CloudUGW: supports serving gateway (S-GW), PDN gateway (P-GW), gateway GPRS support node (GGSN), evolved packet data gateway (ePDG), and trusted gateway (TGW) functions.
3. CloudCG: supports charging gateway (CG) functions.
4. CloudDNS: supports Domain Name server (DNS) functions.

Key Features

1. Efficient Resource Usage
2. Flexible Scaling
3. Flexibility and Openness Based on the NFV Architecture
4. Standard interfaces
5. Flexible hardware selection
6. Fast Service Deployment

Cisco Virtual Packet Core

Cisco Virtual Packet Core (VPC) changes the paradigm of agility for service providers. It’s the industry's most complete, fully virtualized, evolved packet core platform and hypervisor-independent solution that combines network functions virtualization (NFV) and software-defined networking (SDN). It captures untapped revenue opportunities, particularly with Internet of Things and machine-to-machine connections. It supports configuration models such as: Single Instance (left) and Distributed Instance (right).

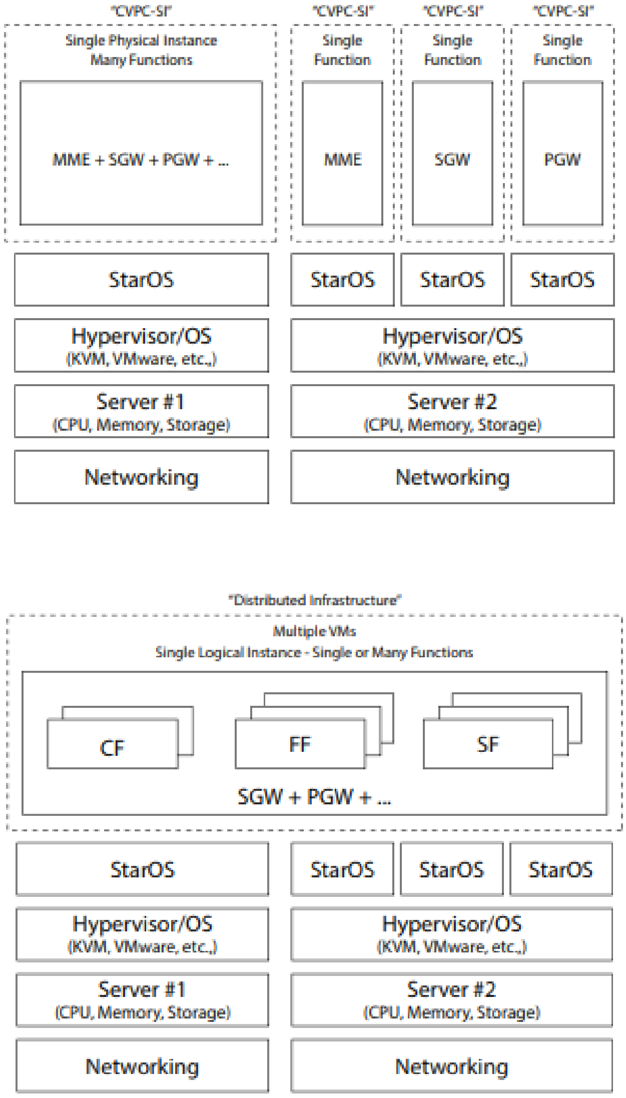

Figure 2. Cisco Virtual Packet Core [4].

Cisco’s VPC combines all packet core services for 4G, 3G, 2G, Wi-Fi, and small cell networks into a single solution. It provides those network functions as virtualized services, so you can scale capacity and introduce new services much faster and more cost-effectively.

The solution is based on the same proven StarOS software used in Cisco ASR 5000 Series platforms. It is designed to distribute and orchestrate packet core functions across physical and virtual resources so you can easily transition from physical to virtualized packet” core services, or use both simultaneously.

Features

1. Expandable
2. Cost effective

3. Flexible
4. Simple
5. Simplify migration through a software upgrade

Problem statement

Although EPC has been deployed over the last few years as an upgrade from the packet core network of 2G/3G SGSN/GGSN with some advantages including: Higher throughput, Lower latency, Simplified mobility between 3GPP and non-3GPP networks, Enhanced service control and provisioning, Efficient use of network resources, the next section focuses on some of its limitations, which constitutes our problem statement.

Disadvantages

Despite the advantages, and with regards to the rapid evolution in communication trends and network technologies, the current EPC tends to be less dynamic (flexible) to effectively support communications as a result of some functional limitations such as:

1. Poor scalability as EPC is mostly dedicated or purpose-built vendor locking hardware implementation in which to deploy a new network service often requires yet another variety of equipment, space and power to accommodate and this becomes increasingly difficult due to increasing costs of energy, capital investment challenges and the rarity of skills necessary to design, integrate and operate increasingly complex hardware-based digital equipment;
2. Hardware-based equipment rapidly reach end of life without any recycling options, requiring much of the procure-design-integrate-deploy cycle to be repeated with minimal revenue benefits;
3. Inefficient resource optimization, provisioning and allocation due to manual and static network configurations;
4. Slowed down time-to-market for new services and innovations, with high deployment and dimensioning costs;
5. In an increasingly network-centric connected world, hardware lifecycles are becoming shorter as technology and services innovation accelerates;
6. The supervision platform; the U2000 MBB server application does not offer a graphical analysis of the performance of the network nodes while having their major resources been utilized e.g. the CPU and Memory stress levels;
7. It is not possible through the monitoring platform, to re-plan the network in order to bring to existence a new node(s) without having the latter already deployed and hence makes it difficult to adapt to an evolving network topology.

Specifications

The problem of increased CAPEX and OPEX greatly impacts a MNO's revenue and eventual growth. Hence the need for more efficient and cost-effective solutions. Our proposed solution will strive to realize the following:

1. Study an NFV based solution for mobile core networks;
2. Design and deployment a simple virtual 4G mobile network core (vEPC);
3. Simulate our design on Linux (Ubuntu), using NS-3 to visualize how the proposed solution works.

3. Method

3.1. State of the Art

Andreas G. Papidas, in a study [5] for his Master Thesis in Information Systems from the Athens University of Economics and Business, June 2016, studied the "Network Functions Virtualization for Mobile Networks". His studies covered the implementation of NFV in the mobile core network (EPC) and the radio access network (C-RAN) as well as its correlation with SDN. As a limitation, the author focused only on the theoretical study and did not show any practical implementation. The present work will go further to present a simulation module. By using virtualization, it is also possible as explain before to build a virtual laboratories environment which can be share remotely by many universities for testing, simulation and teaching purpose, this have been proposed by authors for the usage of Huawei eNSP software [6] and a self-developed software [7] for network optimization.

NFV-based EPC implementations have seen significant interest from academia and industry. Some Authors (A. Jain et al, 2016) showed that an NFV-based implementation of EPC is better suited for networks with high signaling traffic while an SDN-based design of the EPC is better suited for networks with high data plane traffic [8].

To test and simulate problem using NS3, Lyeb, Deussom and Tonye proposed the used of NS3 in virtual environment to do the simulation of an offloading algorithm between LTE and WiFi network [9]. Similarly, Deussom, Ndje and Tonye have proposed the usage of NS3 to simulate and test the usage of artificial bee colony algorithm for the Cloud RAN [10] to allow to increase the network capacity by the virtualization of the base station and the sharing of cloud resources.

Other writers like B. Hirschman et al, 2015 evaluated a commercial NFV-based EPC, and demonstrate that its performance can match that of a hardware-based appliance [11].

Other research proposals showed how the MME (Mobility Management Entity) component of a virtualized EPC, can be scaled horizontally in order to build a high-performance scalable distributed EPC.

A. Banerjee et al, 2015 [12] proposed that the MME element can be divided into a load balancer and packet processor components, and a consistent use of hashing at the load balancer to distribute incoming connections.

According to X. An et al, 2012 [13], the central MME core node can be distributed into multiple replicas and pushed closer to the access edge, resulting in reduced latency and better handover performance.

A. Takano et al, 2014 [14] present an MME architecture based on a stateless worker-thread and centralized state storage model. However, with the exception of A. Takano et al [14], none of the prior works mentioned above in this area made their code open for researchers.

3.2. System Analysis

The Evolved Packet Core (EPC) as described earlier, stands as the central point of a whole 4G network, working in collaboration with other sections of the network such the access and transport networks, to process and channel information to required destinations. Hence it has to be well planned, designed, deployed, and maintained in order to attain optimum performance. Therefore, a poorly designed EPC will generally give rise to slow and dormant network. This section details some key tasks of an EPC, the Constraints it encounters and views the feasibility of these constraints.

Problems Encountered

In the case of an increase in the number of subscribers or network expansion, new licenses (equipment) have to be purchased for eventual deployment. This of course will entail new capital and operational costs as well as energy and space which in turn is not an efficient way of scaling up a network. Hence, a virtualized and automated Network will go a long way to remedy the latter short comings by providing a more flexible network that can respond to instant demands.

In the case of a network using Huawei solution, the iManager U2000 MBB server application is the corresponding management platform used for supervision, though this application is of great help in this key role, it can be found to be limited in following aspects:

1. It does not offer a graphical analysis of the performance of the network nodes while utilizing the major resources, e.g. the CPU and Memory stress levels.
2. It does not permit a re-planning of a network to bring into existence a new node(s) without having the latter already deployed and hence difficulties in adjusting to an evolving network topology.

Therefore, a virtualized core with its management and orchestration component through which we can perform dynamic configurations, generate, maintain and tear down network services will greatly improve performance in terms of the core network monitoring and management for a corporate context. Also for academic context, a virtualized core be used for teaching purpose and can be reachable through internet for remote lab. Then engineering schools for the same university or even different university can share the same virtual infrastructure for remote lab and teaching. So this solution of core network virtualization is suitable for both corporate and academic purposes.

System Inputs

As mentioned above, a vEPC is not a standalone solution and processes data received from the following sources and channels the resulting responses to targeted points or destinations:

1. Access Network (UE, eNodeB, IPRAN) attachment, authentication, and connection procedures.
2. External networks (GiLAN) connection procedures.
3. System's Administrator (s) registration and configuration commands.

Some of these procedures are been described in the flow diagrams below.

Protocol stack in control and user planes

Components in the LTE network have unique protocol stacks that permit them to function. The protocol stacks for the user and control planes in each entity are both different.

The control plane handles radio-specific functionality which depends on the state of the user equipment (idle or connected). The protocol structure for the control plane (UE, eNodeB, MME) is shown below.

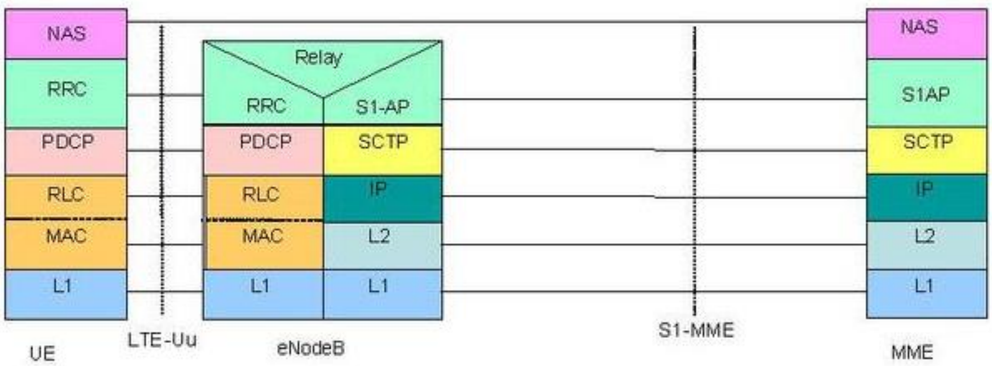

Figure 3. *LTE Control Plane Protocol Stack.*

For the Data plane protocol structure, packets in the core network (EPC) are encapsulated in an EPC specific protocol and tunneled between the P-GW and the eNodeB. Different tunneling protocols are used depending on the interface.

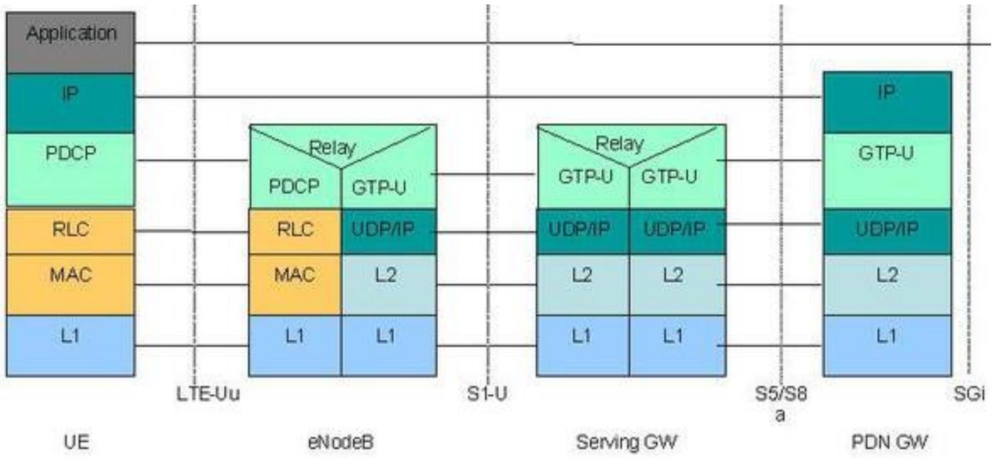

Figure 4. *LTE Data Plane Protocol Stack.*

End-to-end IP flows are realized by EPS bearers, which is a combination of Radio, S1, and S5/S8 bearers. Hence an EPS bearer is a virtual connection between a UE and PGW. An EPS bearer identity uniquely identifies an EPS bearer for one UE accessing via E-UTRAN. The EPS Bearer Identity is allocated by the MME and is the one that carries the user data.

UE requests are generally channeled into the core network for processing through what is known EPS Bearer activation. Some of these requests called procedures are presented flow diagrams below.

Attach procedure

To get NAS-level services e.g. internet connectivity from a network, NAS nodes in the network have to know about the UE. The latter has to initiate the Attach Procedure, which is mandatory at power on and also during the initial access of the network. Once the attach procedure succeeds, a context is established for the UE in the MME, and a default bearer is established between the UE and the PGW and an IP address is allocated to it. With an IP connectivity, the UE can start using IP-based internet services or IMS services [14].

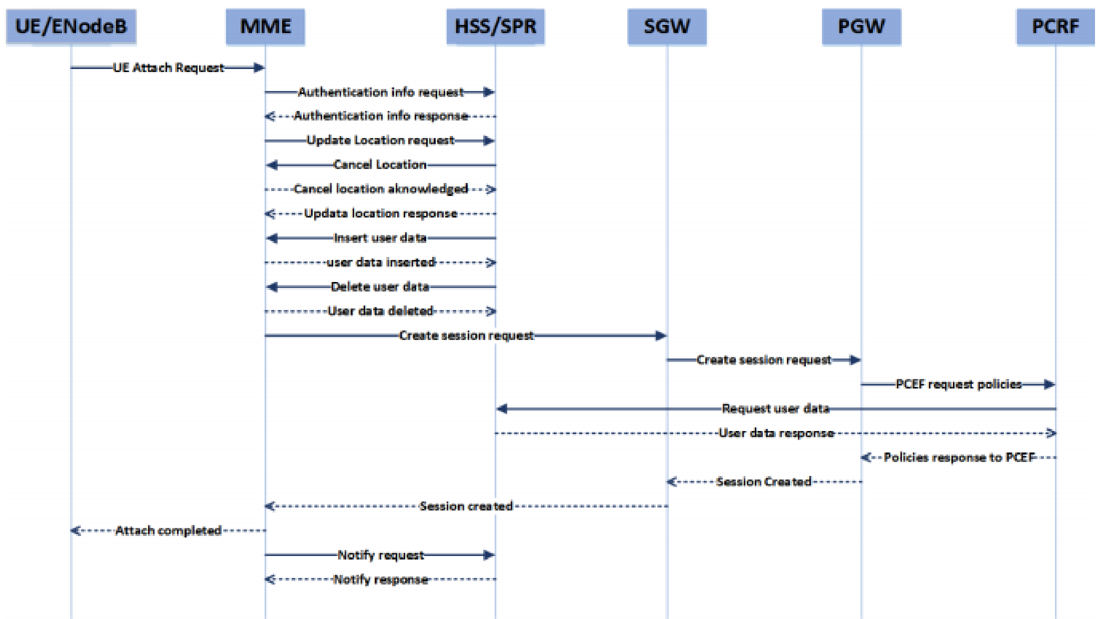

Figure 5. *UE Attach Procedure [15].*

Paging

Paging is typically used when the UE is in an idle state, which means that it is not currently communicating with the network. When the network has data to send to a particular UE, it will initiate a paging procedure by sending a paging message to all cells that the UE is registered with. The UE monitors the paging channel of the cell it is currently camped on and will respond to the paging message if it recognizes its identity. If the UE does not respond within a certain time frame, the network will assume that the UE is not available and will retry the paging procedure in other cells where the UE is registered.

Mobile Data call

After successfully attaching to the network, the UE can request the services from the Network using the service request procedure. One example scenario is when the UE requests resources from the Network to initiate a data call.

Functional Need

Here, we be examining how Operations are been carried out by our solution and the key block in the NFV architecture in charge of this, is the NFV MANO whose functions detailed next.

Management and Orchestration in NFV (NFV MANO)

It is worth taking a more detail view of an NFV MANO, since it acts as the brain behind the NFV solution and understanding it will clarify the complete picture of such a solution. It will also help in the understanding and benchmarking of different vendor's NFV solution with reference to the ETSI model. ETSI is the pioneer and the only standards body that has done considerable work on defining the architecture and frame work of NFV.

The diagram below shows the MANO block in the NFV architecture comprising three principal Managers, numbered 1, 2 3, and repositories labelled 4 namely:

1. NFV Orchestrator (VNFO);
2. VNF Manager (VNFM);
3. Virtualized Infrastructure Manager (VIM).

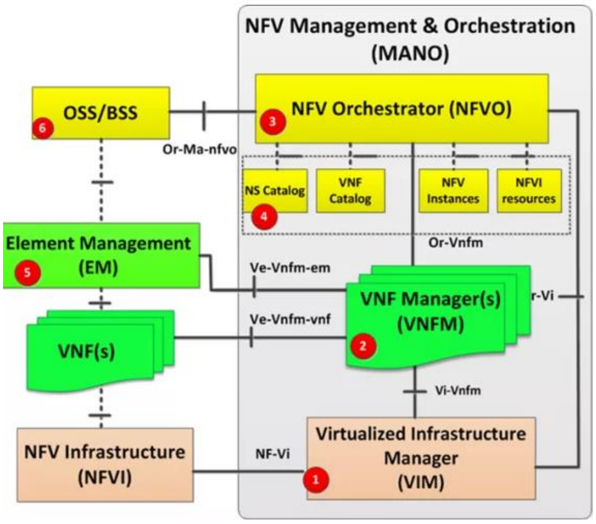

Figure 6. *NFV MANO.*

As from the figure above, two other blocks outside of the MANO are included namely: The Element Management (EM) and OSS / BSS, labelled 5, and 6 respectively. Though not directly part of the MANO, they do exchange information with the MANO block, for a smooth functioning of the whole system. A description of the role or tasks to be performed by each of the labelled blocks above is presented next.

Virtualized Infrastructure Manager (VIM)

VIM manages NFVI resources in a single domain. The emphasis of a single domain is made here because there may be multiple VIMs in an NFV architecture, with each managing a specific NFVI domain. It is in charge of the following:

1. Manages the life cycle of virtual resources in an NFVI domain, by creating, maintaining; and tearing down virtual machines (VMs) from physical resources in an NFVI domain;
2. Keeps inventory of virtual machines (VMs) associated with physical resources;
3. Does performance and fault management of hardware, software and virtual resources;
4. Contains north bound APIs, which exposes physical and virtual resources to other management systems.

Virtual Network Function Manager (VNFM)

Briefly, VNFM is to VNFs, what VIM is to NFVI. That is, in a similar way, it manages virtual Network Functions (VNFs). Some of its tasks include:

1. Manages the life cycle of VNFs. It creates, maintains and terminates VNF instances, which were installed on the Virtual Machines (VMs) that are created and managed by the VIM;
2. Responsible for the FCAPs (Fault, Configuration, Accounting, Performance and Security) Management of VNFs;
3. Scales up / down VNFs which results in the scaling up and scaling down of CPU usage.

Multiple VNFMs can exist, managing separate VNFs, as well as there can be a unique VNFM managing multiple VNFs.

3.3. System Modelling

vEPC is an architectural framework for virtualizing the core network nodes or components (functions) required to converge voice and data on 4G LTE networks [16]. vEPC [17] moves the core network's individual components that traditionally run on purpose-built hardware to software that operates on low-cost Commercial Off-The-Shelf (COTS) servers.

It provides a centralized control, management, security and intelligence to connect a large number of mobile edge elements [18], such as base stations and base station controllers as well as trusted (WiMAX) and untrusted (WIFI) non 3GPP access network technologies.

Figure 7 below gives a view of a virtualized EPC based on network function virtualization, according to NFV Use Case 5.

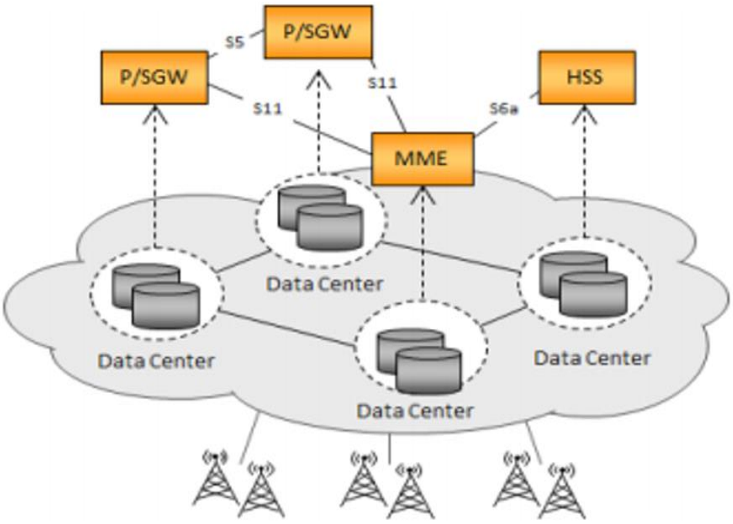

Figure 7. *vEPC Functional Architecture.*

Benefits of vEPC

Some of the advantages of a virtualized EPC include:

1. Lower acquisition (CAPEX) costs: A vEPC can cost significantly less than a traditional EPC, often resulting in savings of 30% to 40% or more;
2. Lower operating costs (OPEX): A virtual EPC can lower power consumption, require less space and be easier to operate and maintain;
3. Flexibility: vEPC enables rapid service delivery, and the introduction of new innovative services and the targeting of specific services by geography or customer type;
4. Agility: Virtual EPC allows providers to elastically scale services up or down based on network traffic and customer demand;
5. Higher service availability and resiliency provided to end users by dynamic network reconfiguration inherent to virtualization technology;
6. Elasticity: Capacity dedicated to each network function can be dynamically modified according to actual load on the network, thus increasing scalability;
7. Topology reconfiguration: Network topology can be dynamically reconfigured to optimize performances;
8. Improved network usage efficiency due to flexible allocation of different network functions on a hardware resource pool.

Modeling Method

In this work, an Object-Oriented Modelling approach (OOM) was adopted. This is an approach commonly used to modeling applications, systems, and business domains by using the object-oriented paradigm throughout an entire development life cycle, which integrates both data and functions.

In simple terms "object-oriented" can be considered to refer to the organization of software as a collection of discrete objects that incorporate both data structure and behavior (as a set of associating objects).

This approach involves the implementation of a conceptual model produced during object-oriented analysis. Here, concepts from an analysis, which are technology−independent, are mapped onto implementing classes, constraints are identified and interfaces are designed, resulting in a solution model.

Modeling Tool

To realize our solution model, we used a discrete-event simulation software called Network Simulator 3 (NS-3). Discrete-event simulation is a widely used method for modeling complex environments, which have a lot of interactions between the modeled objects.

Our solution was developed from a software tool called LENA, which is an open source product-oriented LTE/EPC Network Simulator that allows LTE small/macro cell vendors to design and test Self Organized Network (SON) algorithms and solutions.

LENA is based on the popular NS-3 simulator for internet systems. Its development is open to the community in order to foster early adoption and contributions by industrial and academic partners.

Use cases

vEPC is aimed to enable significant new business opportunities for mobile operators. The largest opportunity is to participate in the growth of the IoT market. IoT applications have very different network requirements and price points than the smartphone and tablets that predominate in the current networks [19]. Some Providers have started to leverage NFV to build IoT-specific sections of their mobile networks with new virtual EPCs.

EPCs are composed of many sub-elements, which will be used in different combinations for specific IoT applications. Virtual EPCs gives mobile operators the ability to cost effectively customize their networks for individual customers, industries and applications which is critical in the diverse world of IoT.

Other interesting market applications enabled by vEPC include:

1. Enterprise-specific mobile networks
2. High-speed mobile data
3. Mobile virtual network operators (MVNOs).
4. VoLTE
5. VoWIFI
6. Broadband Wireless Access (BWA)
7. M2M communication.

Most large Mobile Operators have already built new, high-capacity Mobile Cores for their 4G LTE deployments. As a result, most vEPC deployments may be for either Greenfield mobile networks or new applications (e.g., IoT) distinct from the traditional mobile network, which is optimized for smartphone traffic.

Dozens of mobile operators are testing vEPC for various applications. Several Mobile Operators have deployed vEPC, including Saudi Telecom (IoT), AT&T (connected cars), TELUS (IoT), NTT (Mobile Data) and SK Telecom (IoT).

Tool Design

This subsection will take us through the actual design of our solution. Here we are going to present the steps (flow chart) we adopted in setting up this solution (simulation module), the challenge(s) involved when realizing such a solution, the technological tools used in the process, and the resulting architecture of the solution after design will also be presented.

Simulation Flow Chart

Figure 8 below presents the steps we used in realizing this simulation module.

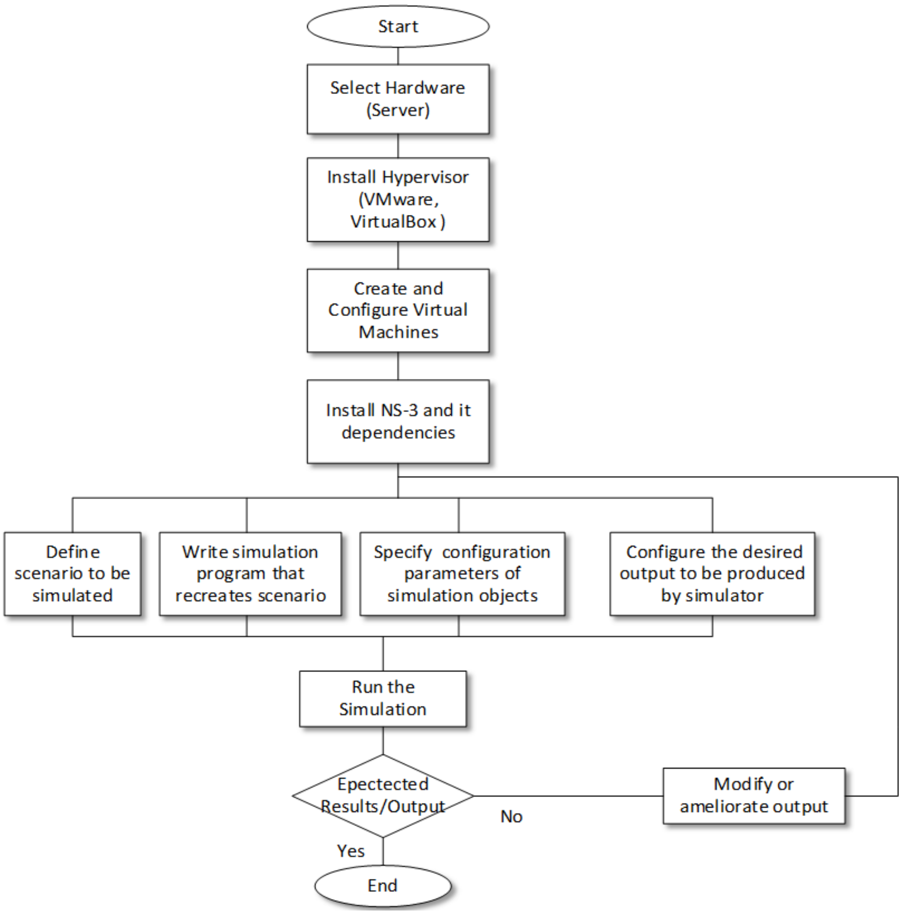

Figure 8. *Simulation Procedure.*

Challenges

Like many new complex technologies, vEPC creates some challenges. According to the NFV ISG, these challenges can easily be solved should service providers and equipment vendors work closely together (See table 1). Our major challenge here will be to design, program and then simulate a simple NFV based mobile core network solution as an NFV Proof of Concept (PoC). In general, in order to leverage the huge benefits of NFV, a number of technical challenges ought to taken into consideration.

Performance trade-off, portability and interoperability

Achieving high performance virtualized network appliances which are portable between different hardware vendors, and with different hypervisors.

Migration, co-existence, and compatibility

Achieving co-existence with bespoke hardware-based network platforms while enabling an efficient migration path to fully virtualized network platforms which re-use network operator OSS/BSS. OSS/BSS development needs to move to a model in-line with Network Functions Virtualization and this is where SDN can play a role.

Management and Orchestration

Managing and orchestrating many virtual network appliances (particularly alongside legacy management systems) while ensuring security from attack and misconfiguration.

Automation

Network Functions Virtualization will only scale easily if all of the functions can be automated.

Security and Resilience

Ensuring the appropriate level of resilience to hardware and software failures.

Network Stability

Integrating multiple virtual appliances from different vendors. Network operators need to be able to "mix & match" hardware from different vendors, hypervisors from different vendors and virtual appliances from different vendors without incurring significant integration costs and avoiding lock-in.

Technological Choices

In the course of this work, the following Applications, software, and programming languages were used either directly or indirectly to realize our solution:

VirtualBox 6.0.10

In our solution design, made use of a type two hypervisor, precisely the Oracle VirtualBox. VirtualBox is a powerful x86 and AMD64/Intel64 virtualization product for enterprise as well as home use. Not only is VirtualBox an extremely feature rich, high performance product for enterprise customers, it is also the only professional solution that is freely available as Open Source Software under the terms of the GNU General Public License (GPL) version 2.

NS3 3.29

NS-3 is a discrete-event network simulator for Internet systems, targeted primarily for research and educational use. NS-3 is free software, licensed under the GNU GPLv2 license, and is publicly available for research, development, and use.

Ubuntu 16.04 LTS

Ubuntu is a free and open source GNU / Linux operating system based on the Debian Linux distribution. It is developed, marketed and maintained for individual computers by the company Canonical.

C++

C ++ is a compiled programming language for programming under multiple paradigms (such as procedural, object-oriented or generic programming). Its good performance, and compatibility with the C make it one of the most used programming languages in applications where performance is critical. It is one of the main programming languages used in NS3.

Python 3.7

Python is an interpreted programming language, multi-paradigm and cross-platform. It promotes structured, functional and object-oriented imperative programming. It has a strong dynamic typing, automatic memory management with garbage collection and an exception management system.

NetAnim 3.108

NetAnim (Network Animation) is an offline animator based on the Qt toolkit. It currently animates a simulation using an XML trace file collected during simulation.

Edraw

Edraw is a professional 2D business technical diagramming software which helps to simplify the creation of flowcharts, organizational charts, mind map, network diagrams, floor plans, workflow diagrams, business charts, and engineering diagrams.

Visio

Microsoft Visio is a diagram and synoptic software for Windows that is part of the Microsoft Office suite.

Functional architecture

Our solution was design based on the standard NFV architecture. With respect to our available resources the latter could be modified and tailored to suit our context and the following was obtained as seen in Figure 8.

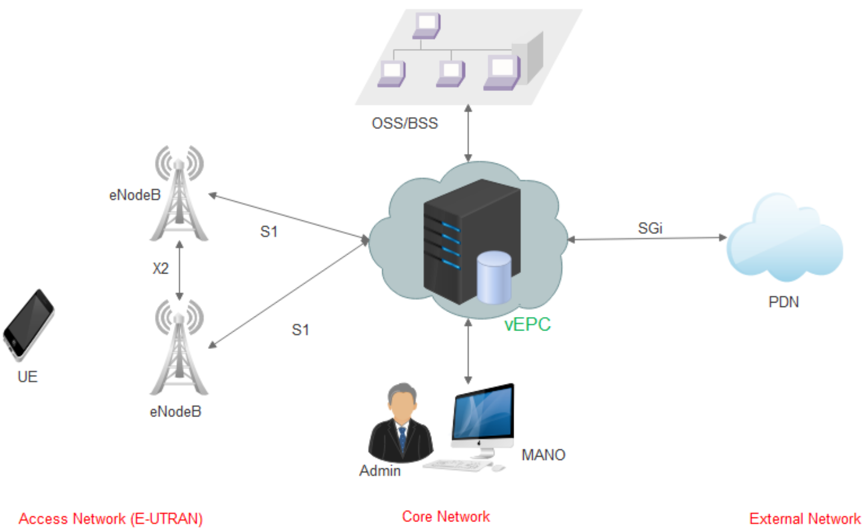

Figure 9. *Functional Architecture of Solution.*

The Table 2 below summaries the tools used to design our solution.

Table 2. *NFV Blocks with corresponding solution.*

NFV Block	Tool Used
NFVI	PC storage, compute, and network (HP 2000)
Hypervisor	Oracle VirtualBox 6.0.10
Programming language	C++
Visualization	NetAnim, PyViz (Python based module)
OS	Ubuntu 16.04
MANO	PC (HP 2000)
VM	Ubuntu VMs
Simulation Software	NS 3.25

The following diagram (figure 10) shows the position of (or to situate) our solution in the whole Network.

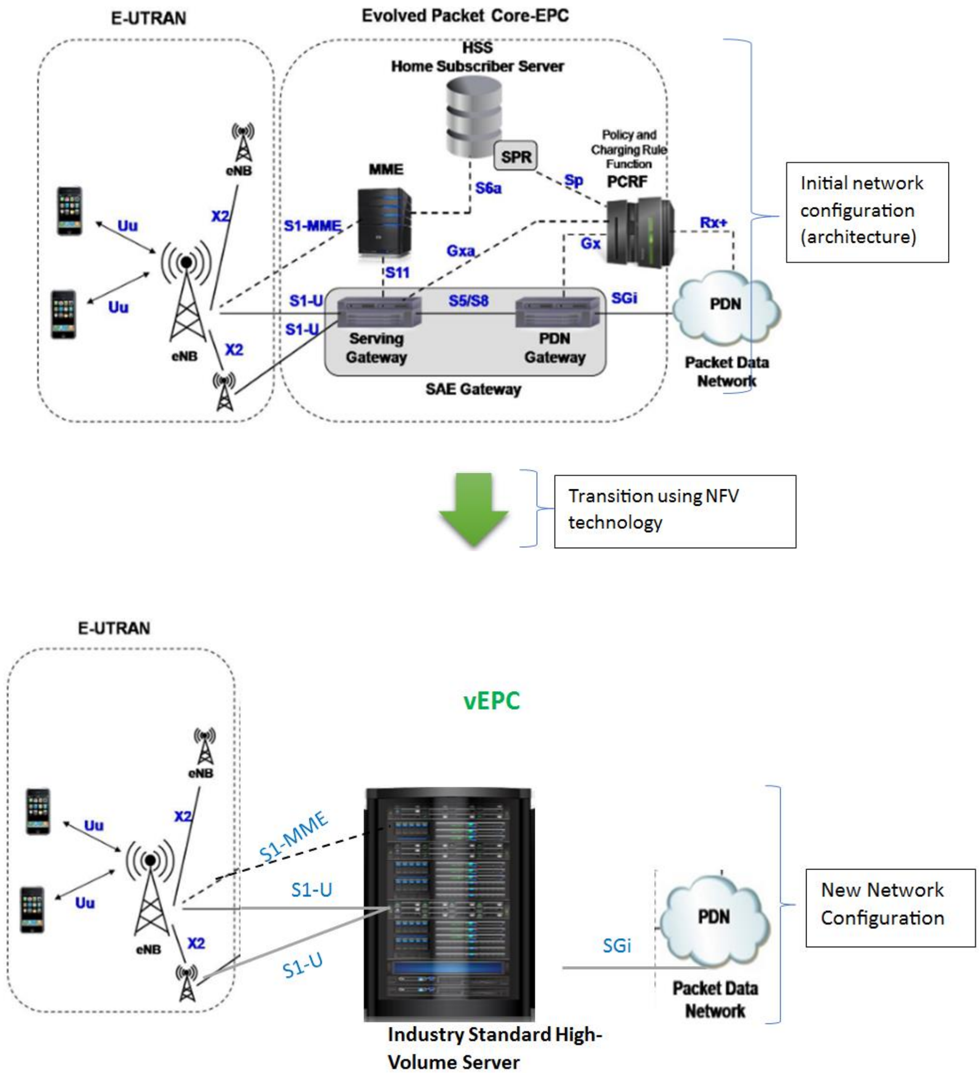

Figure 10. *New view of the whole network.*

4. Results

We had as main objective to design and deployment a simple virtual 4G LTE mobile network core (vEPC) through a simulation on Linux (Ubuntu), using NS-3 to visualize how the proposed solution works. In figure 11 we present the hypervisor installation with virtual machine and the following results which were obtained.

Hypervisor installation with Virtual Machine

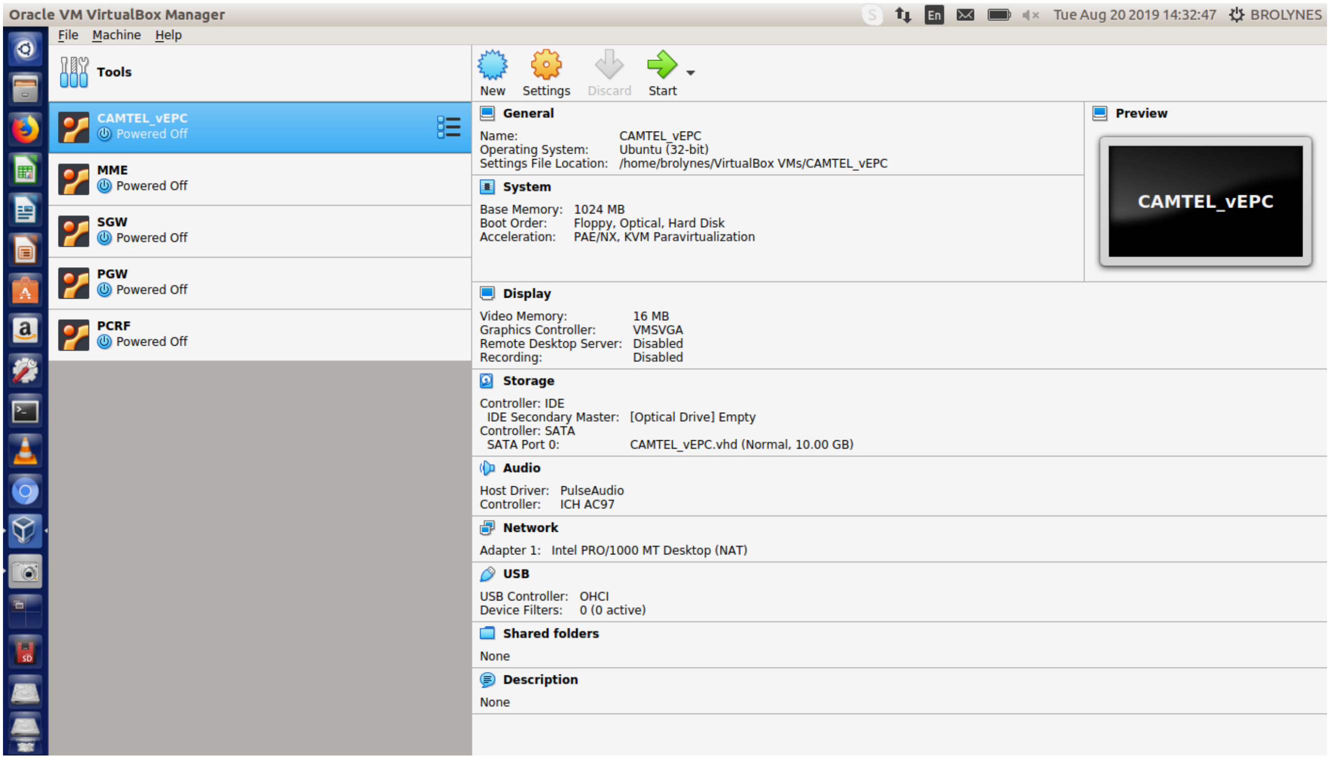

Figure 11*. Installed Hypervisor and Virtual Machines.*

1. With respect to the choice of the hardware on which our solution will be implemented, we made use of a laptop. A VirtualBox hypervisor was chosen because it is free and installed as shown on the figure above.
2. We opted to use an all-in-one solution, by simulating all of the core elements in a single virtual machine (highlighted blue on the figure above) using NS-3 due to the limited resources of our hardware (storage, compute and network).
3. In order to view how the virtualized core works, we simulated alongside the core network; an access network (E-TRAN) comprising UEs and eNodeBs and an external network (PDN). Table 3 presents the nodes quantity.

Simulation Scenario

Once NS-3 was installed and configure, we defined the following scenario for the simulation and the simulation scenario as presented in figure 12, figure 13 and figure 14:

Table 3*. Design of simulation scenario.*

Node Type	Number of Nodes
UE	09
eNodeBs	03
EPC	01
Packet data Network	01

The simulation was done using an NS-3 python module known as PyViz (Python Visualizer).

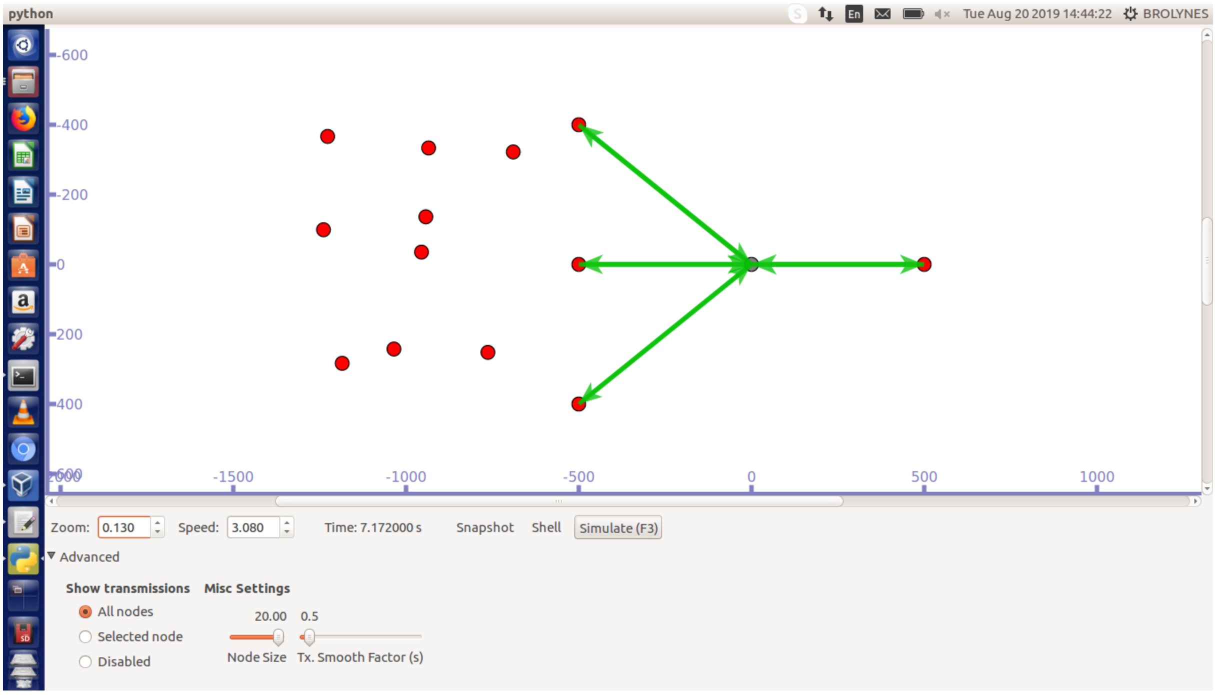

***Figure 12**. Simulation Scenario.*

Instant Link Speed

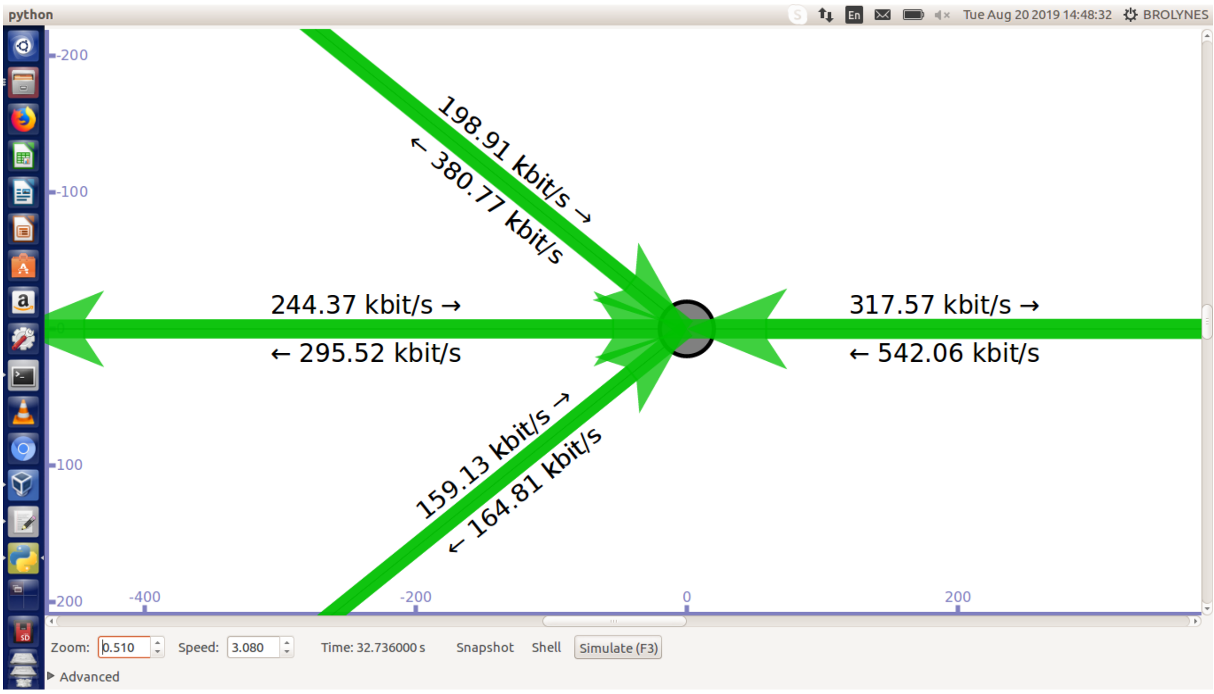

***Figure 13**. Link Speed.*

Animation of simulation module

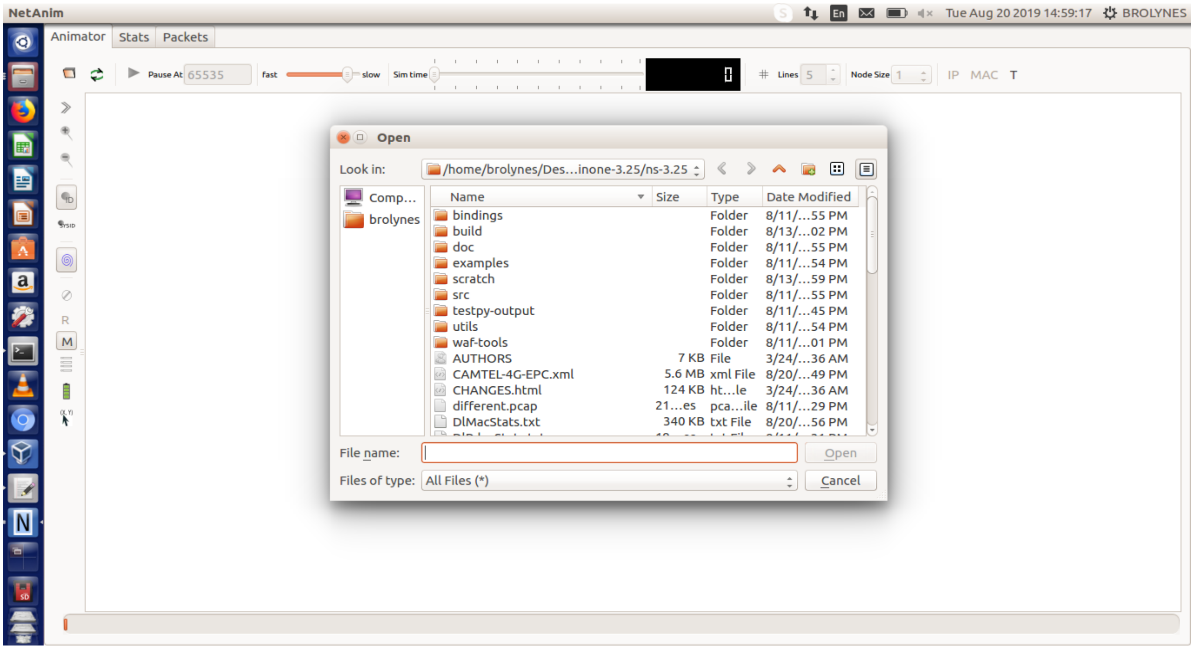

Figure 14. Load NetAnim XML trace file.

1. Once a simulation is successful, the instantaneous speed on each link for a given network scenario can be observed as seen in Figure 13 above.
2. The animation of the simulated module was done an NS-3 based module called NetAnim (Network Animator).
3. At the end of the simulation using the PyViz module, an xml trace file (CAMTEL-4G-EPC.xml) is generated to be used by NetAnim. As shown in the figure 14 above, the trace file has to be loaded once NetAnim has been launched.
4. After loading the trace file, the simulated scenario is reproduced for animation as shown below in figure 15:

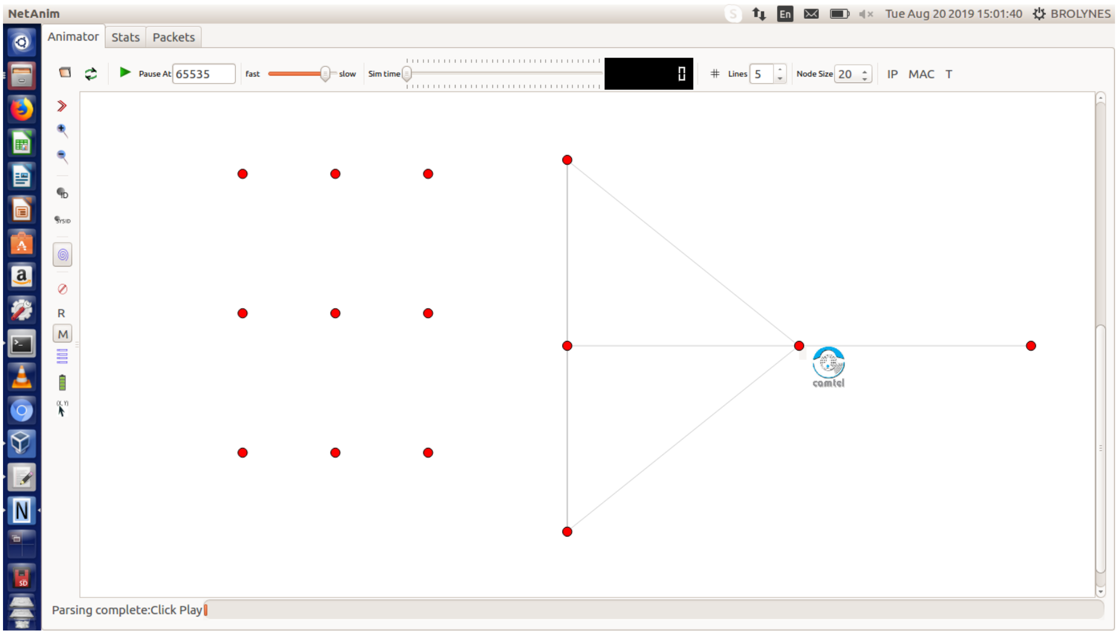

Figure 15. Loaded XML file for animation in NetAnim.

Animation Modules

In the Figure 16 and figure 17 below, the nodes are been replaced by their corresponding equipment icons during the animation for a better perception of a real-world instance.

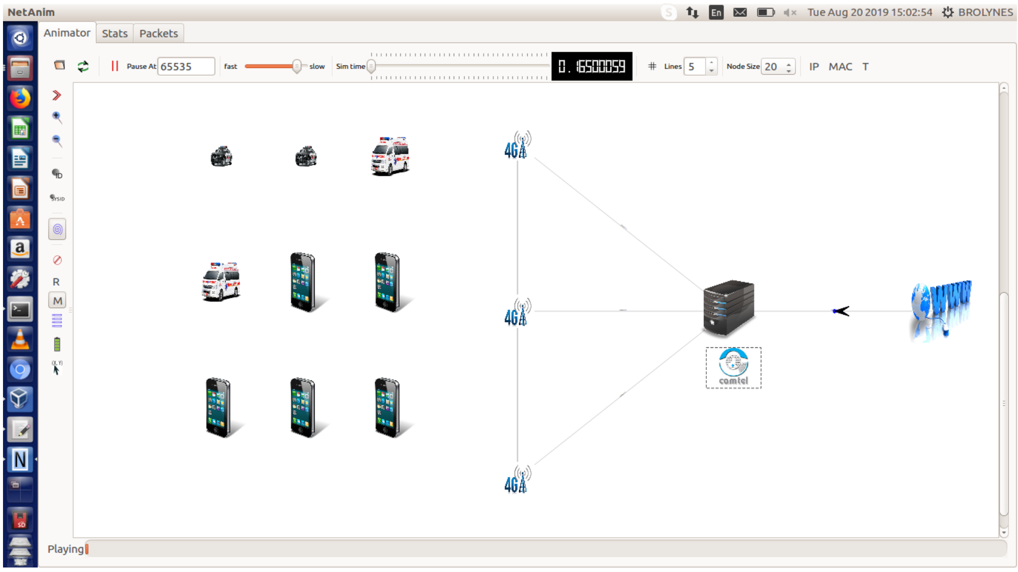

Figure 16. Start of Animation.

1. The nine access points or devices we used includes: 5 smart phones, 2 ambulances, and 2 police cars.
2. These groups of access points all have different degrees of mobility, with the ambulance being the fastest.
3. The virtualized core is then expected to efficiently process the traffic generated by these devices at different velocities.
4. eNodeBs have been configured to communicate or link to each other through an x2 interface.

Sample of the Animation Process

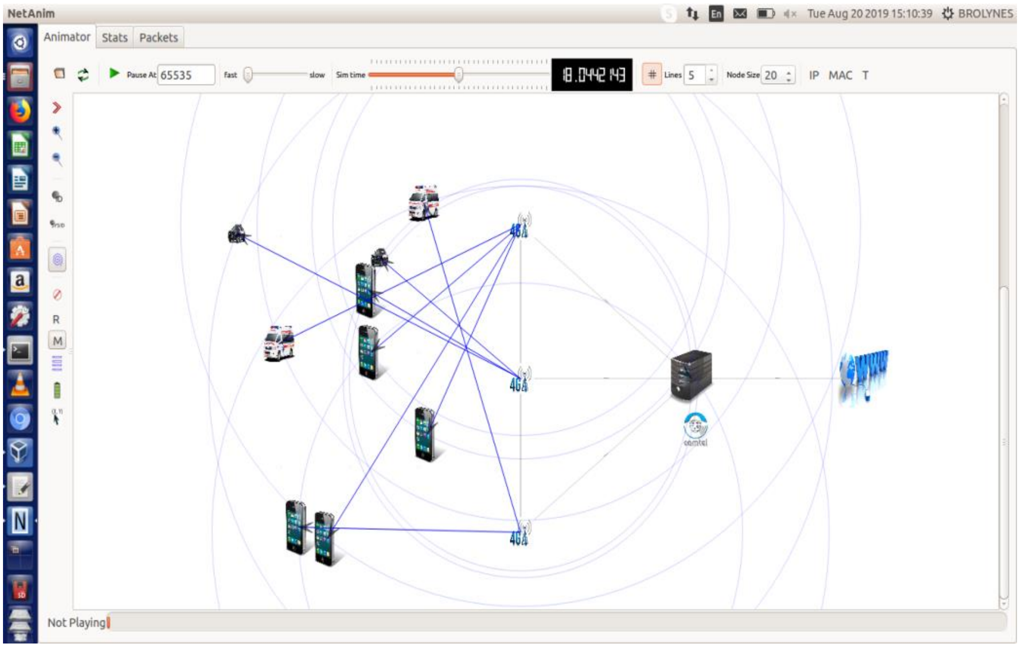

Figure 17. Animation Process.

1. During the animation, the PDN node, vEPC node, and the eNodeBs are stationary just like in a real network.
2. The UEs were configured to be mobile (can also be configured to be stationary), and can auto displace themselves around in a random manner.
3. Circular Paging curves (coverage zones) are generated.
4. X2 handover has been programmed to link a device from a saturated eNodeB to an accessible one, to avoid losing track or connection with devices as they randomly move around;
5. The attached UEs and packet forwarding actually shows that the core network is performing the functions of the

MME, SGW, and PGW (virtualized).

As shown on the figures below, other operations such as statistics of nodes (IP address etc.), Packet transfer flow diagram, nodes parameter modifications etc. can be performed and the results obtained presented in files that can be exported for further study.

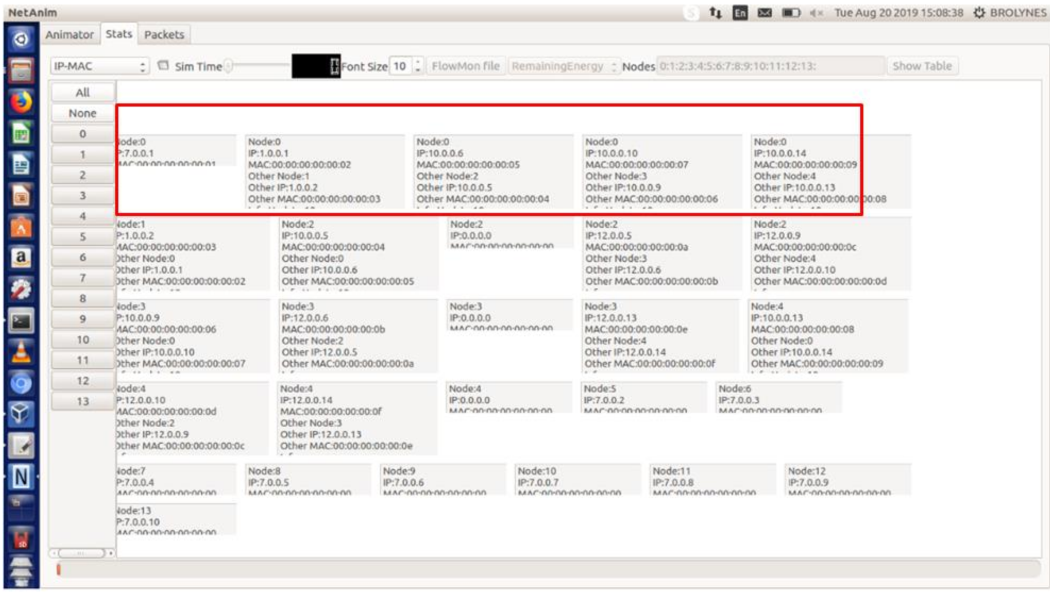

Figure 18. *Nodes Statistics.*

At this statistics interfaces of the Network animator as presented in figure 18, all active devices and equipment can be viewed as simple nodes.

The statistics (information) about each node is briefly represented in a separate box in a chronological manner.

Some of data that can be found in the boxes include; the node's name at the top, the IP and MAC addresses.

Another interesting aspect is that, at a glance, we can get the details about the connections between a particular node with other nodes. These details are also briefly represented in boxes next to that of the particular node in question. For example, as highlighted in the figure 18 above, we can view details about the connection between node 0 with nodes 1, 2, 3, and 4 respectively in boxes next to that of node 0. This renders the supervision and troubleshooting of a network easier.

From the "Packets" interface on the network animator, the following can be obtained as presented in figure 19:

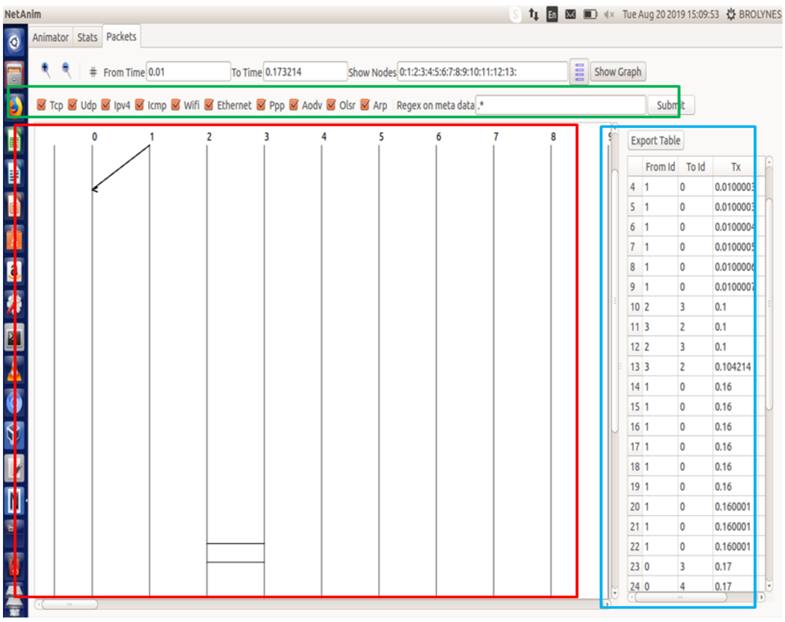

Figure 19. *Data Packet flow.*

The exchange of packets between the configured network nodes, can be observed graphically through a packet transfer and signaling flow diagram (red box).

The data or exchanges represented in the flow diagram is also can also be found in a tabular form that can be exported for further examination or later usage (blue box).

Different graphs can be generated by checking and submitting the desired type of data or information exchanged between node (green).

Dynamic Network Supervision

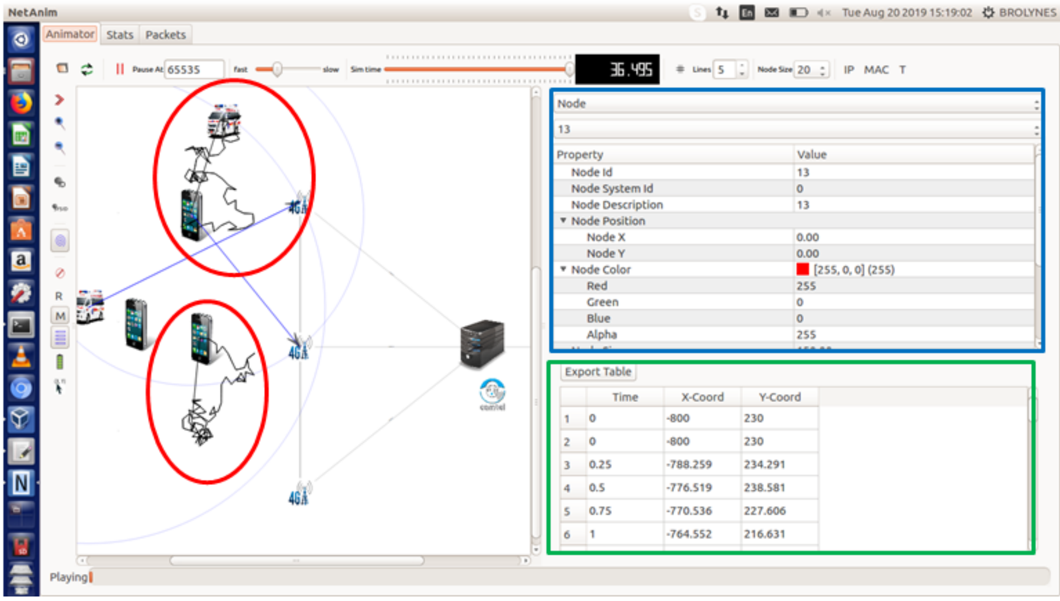

Figure 20. *Performing a modification and a cross-check of some node parameters.*

1. As the simulated access nodes get displaced randomly, the trajectory or path taken by a desired node can be viewed (red), see figure 20.
2. The properties of a desired node e.g. node Id, position etc. can also be verified or modified (blue)
3. Information about the position of desired node at different times is represented in an exportable tabular form (green).

Limitations

Our work is far from being perfect just as any human work. Some of our limitations include:

1. Our solution is not an industry standard, accounting to this is the fact that NFV as a new technology permitting Telecoms operators to leverage the benefits of IT virtualization, many testbeds, researches and commercial tests works are still in progress and others keep emerging to provide a sustainable solution. To the best of our knowledge, till date, there is no industry standard or reference NFV solution;
2. As a new technology, there are few existing and accessible works and literature reviews in this domain;
3. The lack of resources at our local level in terms of test environments, labs etc. is also a great hindrance;
4. Little or no accessibility to some few projects, labs or testbeds existing elsewhere;
5. Resources of better quality or performance in terms of software, membership to projects and labs that have been developed and can serve this purpose are licensed and hence not free.

5. Conclusion

Arriving at the end of this work which consisted in virtualizing the principal elements (MME, SGW, PGW) of the Evolve Packet Core (EPC) of the LTE network of CAMTEL, we divided the work into three chapters. Chapter one permitted us to situate the environment of our work which involves the LTE and its core network (EPC), and Virtualization in particular. We presented in a concise manner the problem statement and finally a state-of-the-art review on research that has been done in this domain. Most importantly, we were able to understand the key concept of Network Function Virtualization (NFV) and related aspects. Next was chapter two where we presented the methodology adopted to solve the identified problem. In the third and last chapter, we presented in a clear and concise manner, the results that we obtained.

The main target of Network Function Virtualization (NFV) is to decouple the dependency between hardware and software and enable the development of network solutions by using multi-vendor hardware that can effectively cooperate with multi-vendor software platforms. NFV also brings to an end the phenomena where most malfunctioned hardware equipment are totally replaced by brand new ones.

As a solution tool to the problem faced, a simulation module for a proof of concept was developed which is fully running and exploitable. This module can provide Core network engineers and agents with the ability to design, analyze and test variable types of network scenarios. The results obtained from such analyses can be of great help during a final network deployment stage for production. With this we can say our objectives have been attained as the network can easily be scaled, with optimum resource utilization, dynamic performance analysis, and the time to market a service reduced.

As perspectives for some future works or aspects that can be developed to ameliorate our work, we can integrate the SDN protocol called "OpenFlow" with LTE in the NS-3 simulator. We can also integrate Data Plan Development Kit (DPDK) used to achieve packet processing efficiency by processing packets in the user space rather than the Kernel space and also SR-IOV which stands for Single Root I/O Virtualization and which is a technique used to bypass a hypervisor and permit VNFs to access the Network Interface Cards of a server hardware directly.

Conflicts of Interest

The authors declare no conflicts of interest.

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