Proposed 5G Broadband Telecom Network Solution over TVWS and Software Defined Radio

Yvan Paillard Kalia-Sya Dodoagnen, Eugene Baba Cyr Zabolo, Edgard Ndassimba, Nadege Gwladys Ndassimba and Samuel Ouya

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Abstract— **This paper proposes the deployment of a fifth generation (5G) broadband telecom network using TV white spaces (TVWS), software defined radio (SDR), virtualization techniques (SDN/NFV) and cloud, as well as telecom open source software (OSS) (Open5GS) to address the major concerns of lack of infrastructure, and the high costs of network deployment in rural areas in Africa. The proposed solution will support new telecommunications services and applications.**

Keywords— **TVWS, SDR, OSS, telecom networks, broadband, telecom services and applications, Cloud, SDN, NFV, 5G, Open5GS.**

I. Introduction

Rural communities in Africa often do not have universal access to telecommunications networks and services, and to ICTs as a whole.

In this paper, we propose the use of SDR, TVWS and Open5GS software to help reduce deployment costs by having a high performance mobile network. This new innovative technological approach would allow operators to easily and cost-effectively deploy new generation networks, based on SDN/NFV and Cloud network virtualization principles, in order to reduce capital (CAPEX) and operating (OPEX) costs. In addition, it also reduces the complexity of deploying or expanding networks, and the overall infrastructure to improve the return on investment of coverage expansion.

Several research studies have been conducted on 5G deployment. The authors in [1], explore the potential of 5G and network virtualization. Others in [2], implemented a new 5G radio cell search (RCS) equipment based on software defined radio (SDR). Others in [3], presented the opportunities and challenges of bridging the digital divide using 5G-enabled high altitude platforms and TVWS spectrum. In [4], the authors implemented an advanced telco cloud simulator and its use on modeling multi-cloud and multi-access 5G environments.

The rest of this paper is organized as follows. We first present the state of the art of TVWS and SDR, the Cloud, SDN/NFV technologies, architetcure5G SDN, Open5GS software. Then we propose an innovative 5G SA telecom network solution architecture based on TVWS, SDR and Open5GS software through an emulation experiment. Finally, we present the results and discussions before concluding.

II. State of the Art

A. TVWS and SDR

The operation of wireless networks using frequencies with high license fees is in contrast to the freely available license-free spectrum. These dynamic UHF and license-free TV white space (TVWS) spectrums have the potential to bring very high bandwidth to rural areas.

Since the migration from analog to digital television, researchers have conducted various experiments on the use of TVWS in different scenarios. Authors in [5], presented a study on TV white spaces (TVWS) to solve the connectivity of the Colombian National Army WiFi service in rural areas. The study analyzed the regulatory aspects and technical equipment to provide a free Internet access solution. The video transmission was validated experimentally, using the method of coding digital data on multiple carrier frequencies (orthogonal frequency-division multiplexing (OFDM)) with the Universal Software Radio Peripheral (USRP) Ettus N210. The authors in [6], designed and developed a prototype of a testbed for real-time testing of secondary user transmission in TVWS. Once an unused TV channel has been identified, the system uses this idle channel to transmit and receive a narrowband signal. The testbed is built on the Universal Software Radio Peripheral (USRP) 2901 device powered by GNU Radio software, the RTL2832U software defined radio and Tektronix MDO4054-3 spectrum analyzer. Based on the experimental results, they claimed that it is possible to use this approach to successfully implement narrowband dynamic spectrum access (DSA) by secondary users on an idle TV channel.

In contrast to the solutions proposed by these researchers; our approach is to use TV white spaces (TVWS) as a 5G access network, coupled with software-defined radio (SDR) and open source software (OSS) on virtual infrastructures to deploy a very high speed, low-cost, next generation mobile network for white areas. The impact of our solution is to reduce the digital divide and promote the development of new telecom applications and services such as IPTV, VoD, etc., with an adapted infrastructure and at favorable costs for isolated rural areas.

B. Cloud

Cloud Computing defined as a technology using the Internet in a client/server architecture to maintain data and applications for businesses and users, without installation. Cloud computing improves the efficiency of computing technologies by centralizing data storage, processing and bandwidth.

Current cloud computing services are based on the data center approach, where hundreds of thousands of dedicated servers are configured to provide services. Configuring the data center for the cloud is expensive and operating the infrastructure requires expertise as well as many resources such as high power for cooling, redundant power for assured availability, etc. For example, 45% of the data center cost goes to server acquisitions, 25% goes to specialized infrastructure for fault tolerance, redundant power, cooling systems and battery backup, while the power cost consumed by the machines accounts for 15% of the total amortized cost [7].

With the widespread use of virtualization techniques on servers and network equipment, many Internet-critical applications and services are located in data centers. Operators offer flexible, on-demand cloud services (computing power, storage, etc.) through Application Programming Interfaces (APIs), and they need to ensure a good quality of service for traffic in the data center [8].

C. SDN/NFV technologies

SDN is an architecture that separates the control plane, which is responsible for the intelligence behind the decision making for the transmission of packets in the network, from the data plane, which physically transmits the packets according to the decisions of the control plane (see Figure 1). The control plane can then be centralized in a controller that has a global view on the network and the available resources [8].

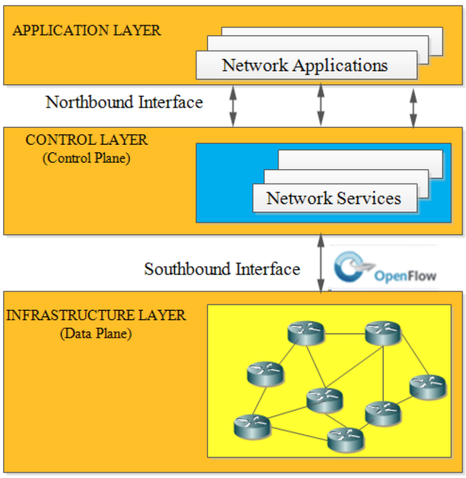

Figure 1. SDN architecture as defined by the Open Networking Foundation

The SDN architecture is designed based on the idea of separation between the control and data planes. SDN applications reside in the application plane of the SDN architecture where the northbound application programming interface (API) provides switching between the application and control planes, enabling a range of network services such as traffic engineering, intrusion detection, quality of service (QoS), firewalls and monitoring applications [9].

Network Functions Virtualization (NFV) is a way for network operators to reduce the cost of deploying services and applications. NFV and their management and orchestration systems (MANO) present themselves as elegant solutions, aiming to reduce the cost and complexity of implementing new services [9]. Virtual Network Functions VNF is the virtualization of a certain network function, which must run independently of others. Elementary Management Systems (EMS) can be used to monitor VNFs. NFV Infrastructure (NFVI): NFVI includes all the hardware and software required to deploy, operate and monitor VNFs. For this purpose, NFVI has a virtualization layer necessary for the abstraction of hardware resources (processing, storage and network connectivity). It guarantees the independence of VNF software from physical resources. The NFVI point of presence (NFVI-PoP) defines a location for network function deployments such as one or more VNFs. NFV Management and Orchestration (MANO): MANO consists of three components:

- The Virtualized Infrastructure Manager (VIM), which manages and controls the interaction of VNFs with the physical resources under its control (e.g., allocation, deallocation, and inventory).
- The VNF Manager (VNFM), which is responsible for managing the VNF lifecycle (e.g., initialization, suspension and termination).
- The NFV Orchestrator (NFVO), which is responsible for performing network services on NFVI. It also provides operations monitoring of NFVI as a means of collecting information for operations and performance management [11].

D. 5G architecture and SDN

With the demands of improving connectivity and accessibility to smart devices, the demands for mobile data traffic are increasing day by day. One approach to meet these demands is to deploy small cells alongside a homogeneous macrocellular network, giving rise to heterogeneous networks. In a heterogeneous network, cells can belong to several radio access technologies (RATs). The fifth generation of cellular networks (5G) initiated by the 3rd Generation Partnership Project (3GPP) is expected to meet these growing demands (enhanced mobile broadband (eMBB)) while providing massive machine-like communications (mMTC) and ultra-reliable low latency communications (uRLLC) as well as SDN. It brings flexibility into the network by decoupling the control plane from the data plane [12].

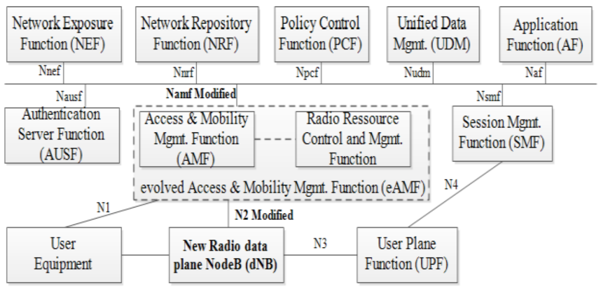

Figure 2. 3GPP 5G architecture [13]

The 5G network architecture proposed by 3GPP provides the following functions:

- Access and Mobility Management Function (AMF): acts as an endpoint for Non-Access Stratum (NAS) signalling, mobility management.
- Authentication Server Function (AUSF): Supports the authentication process of the UE.
- User plane function (UPF): Serves as an anchor point for intra/inter Radio Access Technology (RAT) mobility, packet routing, traffic reporting, manages user plane quality of service (QoS).

- Session Management Function (SMF): Supports establishment, modification and release of a data session, configuration of traffic control policies to UPF address assignment, Internet Protocol (IP) UE and policy enforcement.

In a conventional cellular network, all mobile data traffic must pass through the core network to access services. However, in the 5G era, the explosion of mobile traffic and the development of new radio access technologies are shifting the bottleneck of the mobile network from the radio interface to the backhaul and core networks. On the other hand, 5G is expected to support ultra-reliable low latency communications (URLLC). To solve the above challenges, we propose an NFV and SDN based architecture for the management and deployment of the 5G core network, as shown in Figure 2. The 5G service portal is the input of NFs to provide different services to users. The service management layer is responsible for orchestrating and configuring the NF modules based on the policy set by the Operations Support System (OSS) and the Business Support System (BSS). The 5G infrastructure management layer manages the 5G core infrastructure, including flow planning, NF deployment, network slicing, etc [13].

E. Open Source telecoms software Open5GS

Open5G is an open protocol for the interface between SRC and NGRAN. Open5G is based on the OF and OF-Config protocols with some modifications. OF is an open protocol that was introduced by the Open Networking Foundation (ONF) for communication between the control plane and the forwarding plane in an SDN-based network. The OF-Config protocol was introduced as a companion protocol to OF for configuring the forwarding plane entities so that the controller can control the forwarding plane entities via the OF protocol. [14].

F. Comparison of SDR with others solutions of telecoms software

The authors in [15] made a comparison of open source solutions for mobile networks using SDR, presented in table 1.

TABLE 1. AVAILABLE OPEN SOURCE SOLUTIONS FOR MOBILE NETWORK USING SDR [15]

Software	**eNB**	**gNB**	**EPC**	**5GC**
OpenAirInterface	Yes	Yes	Yes	Yes
srsRAN	Yes	In development	Yes	No
Open5GS	No	No	Yes	Yes
OMEC	No	No	Yes	No
free5GC	No	No	No	Yes

In [16], the authors addressed the latency problem with SIFS (Short InterFrame Space) which requires acknowledgement packets to be sent in 10µs/16µs (2.4GHz/5GHz) after successfully receiving a packet in an SDR architecture. Other authors in [17], introduced a multi-RAT RAN architecture based on SDN (SMRAN) highlighting the multiple access problem that prevents an optimized resource allocation, the dual connectivity problem based on the control plane. On the other hand in [18], the authors implemented a 5G NR network based on Software Defined Radio (SDR). capable of detecting NR cells by decoding the synchronization signal block (SSB) transmitted by nearby gNodeBs.

In [19] the authors in used the Internet of Radio-Light provides both direct WLAN-like access to the Internet using the 5G RAN and access to the Internet via mobile networks. An SDN is used to manage the different packet flows between the RAN, the Internet interface and the mobile network.

Another authors in [20] as well other illustrated the capabilities of the LayBack architecture and SDN-based management framework to memer a case study on a new fluid cloud RAN (CRAN).

These authors in [21] have dealt with the orchestration of RAN systems implemented with virtualization. Their work consists of implementing a flexible RAN system with an NFV model.

Our contribution in this work, consists in using TVWS with Open5GS to overcome the latency problem mentioned by some authors, but also to minimize the cost of deploying a 5G network in rural areas with a certain quality of service level.

Although OpenAirInterface is a complete solution already used by the academic world and the next generation telecom network industries, it would be interesting to couple it with Open5GS to build a 3GPP compliant 4G/5G network. In this article, our proposal is to deploy a 5G network, hence the use of Open5GS.

Open source solutions, automation and virtualization, and multi-domain RAN orchestration will play an important role in future 4G/5G network evolutions. To this end, three main elements help to achieve this goal:

- Open-RAN (O-RAN): replacing the legacy proprietary interfaces between the baseband unit (BBU) at the base of the cell tower and the remote radio unit (RU) at the top of the tower with open standards. This allows units from one vendor to interact with units from other vendors.
- Virtual RAN (vRAN): virtualize (and now also containerize) the baseband unit, so that it runs as software on generic hardware platforms. This allows baseband and radio software and hardware, and even different software and hardware components, to be provided by different vendors.
- Centralized/Cloud RAN (C-RAN): concentration and consolidation of baseband functionality across a smaller number of sites on the telco's network and cloud.

These solutions deployed today by operators are innovative, and allow to use IT instead of hardware to break the lock-in of telecom equipment manufacturers in order to significantly reduce capital and operating expenses for radio networks (RAN) [22], [23].

III. PROPOSAL OF THE SOLUTION

A. Proposed broadband telecom network architecture

Figure 7 shows the architecture of a 5G SA network using TVWS as the transport network, SDR and open source software.

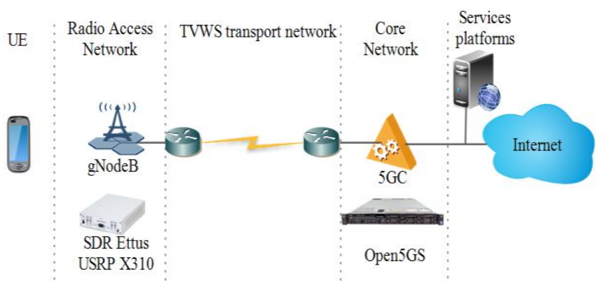

Figure 3. Proposed 5G SA network architecture

The 5G SA architecture proposed above consists of the following parts:

- Services: Internet with fibre optic connectivity, and an application server (kamailio IMS)
- The core network: 5GC based on Open5GS software
- The transport network using TVWS technology
- The RAN (gNB) using Ettus USRP X310 SDR
- The User Equipment (UE).

G. Simulated architecture

In the absence of software-defined radio hardware, we simulated our solution using two computers, one of which acts as the 5G network core (5GC) and the second as the 5G RAN shown in Figure 8.

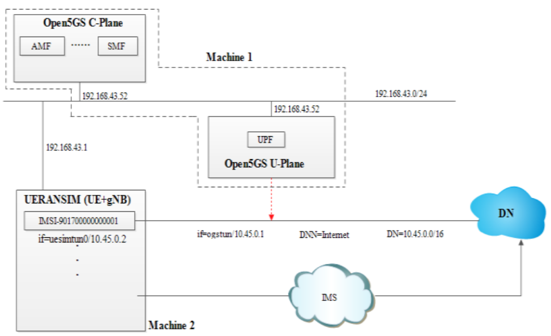

Figure 4. Simulated 5G SA architecture

To simulate the 5G network without RF hardware, we used the open source software Open5GS (5GC) and UERANSIM (5G RAN).

The above work concerns the 5GC mobile network (accessible via the Internet) for simulation with the aim of creating an environment in which packets can be sent from end to end with different DNs (Data Network) for each DNN (Data Network Name).

The following minimum configuration has been defined as a condition:

- The control plane (C-Plane) has a user plane (U-Plane).
- The User Plane (U-Plane) has a DN.
- The UE connects to a DN. If there are several UEs, they will connect to the same DN. The DNN can be Internet or IMS by setting APN='internet' or APN='ims'.

H. 5G SA emulation experiment

In this section, we describe the installation of the Open5G and UERANIM open source software on two Linux machines without the use of the physical RF SDR equipment.

The 5GC/RAN 5G software versions used are:

- 5GC: Open5GS v2.2.8
- UE/RAN: UERANSIM v3.1.9

The characteristics of the machines used are shown in the following Table 1:

TABLE 2. CHARACTERISTICS OF COMPUTERS USED

Software and roles	IP address	Operating system	Max memory	Hard disk
Open5G 5GC (C-Plane, U-Plane)	192.168.43.52	Ubuntu 18.04 amd64	4 Go	80 Go
UERANSIM RAN (eNB + gNB)	192.168.43.1	Ubuntu 18.04 amd64	2 Go	80 Go

IV. RESULTS AND DISCUSSIONS

This section presents the results obtained during the simulation tests of the 5G SA broadband network, and a discussion on these results.

To show the relevance of our solution we used instead of the user equipment (UE), and the gNodeB radio equipment an open source simulator UERANSIM, and then an open source software Open5GS which allows to deploy a 5G SA core network. We simulated TVWS connectivity with a WiFi network using a Proxim Wireless.

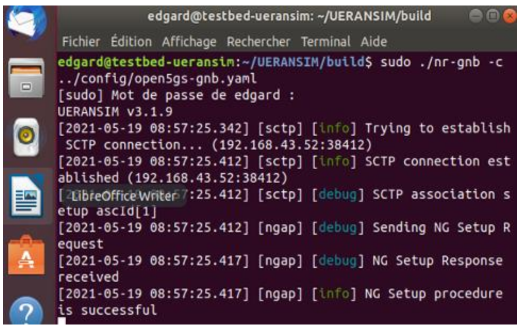

Figure 5. Starting gNodeB

the UE we got the following log from Open5GS C-Plane when it is run.

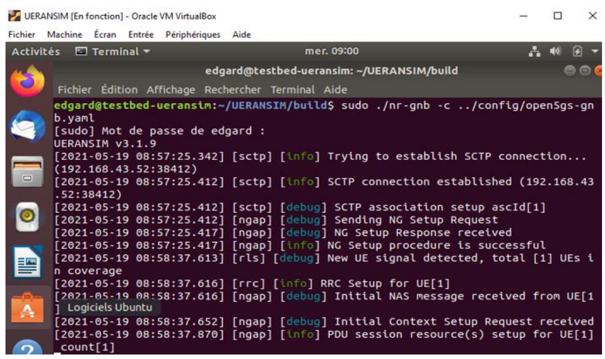

Figure 6. Establishment of the PDU session

Figure 6 showed the establishment of the PDU. This will register the UE with 5GC and establish a PDU session.

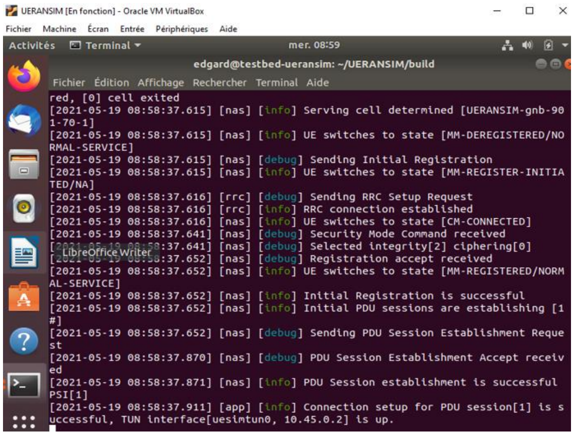

Figure 7. UE starting

Figure 7 showed the start of the UE. This will register the UE with 5GC and establish a PDU session. The UE has been given the IP address 10.45.0.2 by Open5GS 5GC.

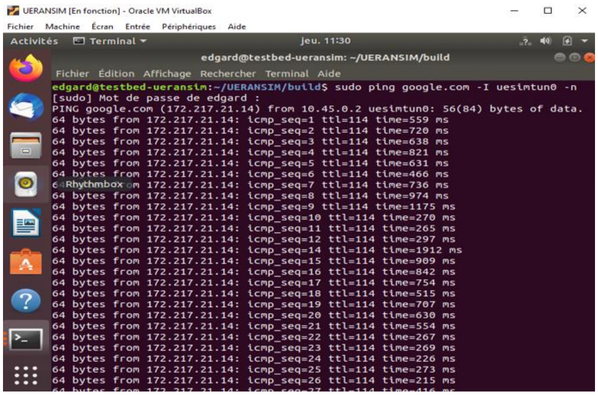

Figure 8. Ping command of Google.com

Figure 8 above showed the results of the ping command on the google.com site.

This showed that google.com is accessible from the EU. The ping from uesimtun0 (10.45.0.2) uses an ICMP Request to google.com (172.217.21.14) and a Reply response with a TTL=114 and a delay ranging from 559ms to 416ms.

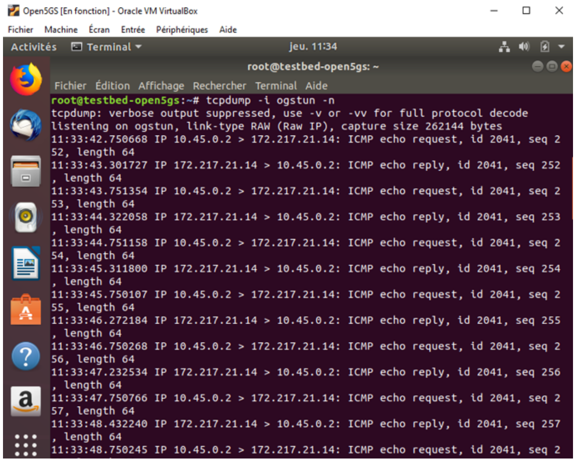

Figure 9. Tcpdump

Figure 9 above provided details of the traffic visible from the if=ogstun interface. The tcpdump run on U-Plane showed that packets are flowing on the if=ogstun TUN interface.

We can create the end-to-end TUN interfaces on the DN and send all packets over the network.

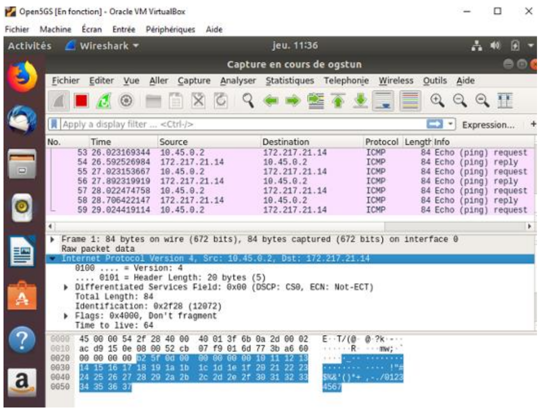

Figure 10. Frame analysis

Figure 10 showed the packet analysis from the source IP address of the if=ogstun interface (10.45.0.2) to the destination address of google.com (172.217.21.14).

The ICMP protocol sends Echo (ping) requests and receives Echo (ping) replies successfully on a time delay of sending/receiving packets for each sequence number.

V. Conclusion

In this paper, we have proposed a 5G high-speed telecom network solution using TVWS access network and software defined radio.

We simulated a 5G network using the Open5GS open source software for 5GC, the UERANSIM open source software for the RAN (UE, gNB), and the TVWS network simulated with WiFi, respecting the 3GPP standards. The various tests have shown that by replacing these simulators with RF SDR USRP hardware equipment, we can build a very high speed 5G telecom network, reducing costs, and establishing a TVWS ecosystem in the deployment of a high speed telecom network, supporting innovative services for aspiring emerging countries.

The impact of this solution is to deploy the 5G network at lower cost in white areas where there is a digital divide, and to offer new telecoms services and applications to the unserved population.

The future work is to build on the power and performance offered by SDN/NFV software-defined networks to manage the interface changeover from a 4G/5G network to a Wi-Fi network without interrupting the information flow.

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