Decentralized Mobile Cloud Computing using 5G Networks

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Abstract— **Nowadays, a lot of businesses are moving to the cloud, because cloud computing increases efficiency, improves cash flow, offers scalability, flexibility, disaster recovery, security etc. However, there are challenges regarding communication bottlenecks so that cloud resources can be made available on mobile devices. Considering the advantages of the cloud and the exponentially increased capabilities of the 5th generation (5G) mobile networks, MCC (mobile cloud computing) will enable the development of applications which can change people's life styles. In this paper the authors present the implementation of a cloud platform using 5G network capabilities implemented on a USRP (Universal Software Radio Peripheral) hardware equipment with GNU Radio software. We propose a decentralized cloud computing solution that can be used for enterprise data backup or resilience using small devices, like smartphones and tablets. Finally, a series of experiments and tests are conducted in order to evaluate the platform's performance.**

Keywords- MCC; 5G; USRP; GNU Radio; Cloud.

I. INTRODUCTION

With the exponentially increased capabilities of 5th generation (5G) mobile networks, Mobile Cloud Computing (MCC) will become even more powerful and will develop to such an extent that it is anticipated that it will change people's life styles and patterns. As of today there are over six billion connected devices that can benefit from cloud-based applications. The evolution towards 5G is considered to be the convergence of Internet services with legacy mobile networking standards, leading to what is commonly referred to as the 'mobile Internet' over Heterogeneous Networks (HetNets), with very high connectivity speeds [1].

In this paper we present a Software Defined Radio (SDR) approach for 5G networks based on Universal Software Radio Peripheral (USRP) and GNU Radio, an open-source software that offers tools for developing software and offers modules for digital signal processing used for implementing radios defined virtually. GNU Radio can be interconnected to real hardware equipment such as RF hardware platforms in order to create SDR equipment. GNU Radio applications are written in Python programming language, and functions are implemented in C++.

The paper is organized as follows: in Section II there are introduced some general aspects of Cloud Computing; Section III contains the description of networking concepts related to 5th generation mobile network, while Section IV consists of the implementation of the cloud platform including results and future applications.

II. RELATED WORK ON CLOUD COMPUTING

Cloud Computing formal definition enacted by the National Institute of Standards and Technology NIST is as follows "Cloud computing is a model for enabling ubiquitous, convenient, on-demand network access to a shared pool of configurable computing resources (e.g., networks, servers, storage, applications, and services) that can be rapidly provisioned and released with minimal management effort or service provider interaction" [2]. In this section we present the principles, deployment and service models of cloud computing, as well as a generic architecture.

A. Principles of Cloud Computing

In this section, the main five essential characteristics of cloud computing are presented:

- On-demand self-service
- Broad network access
- Elastic resources pooling
- Rapid elasticity
- Measured service

B. Deployment Models

Deployment refers to the way that the cloud services are made available to the end users depending on factors such as location and structure. The main deployment models are:

- Private cloud
- Public Cloud
- Community Cloud
- Hybrid Cloud

C. Service Models

There are 3 kinds of services described in [2] that are available to end users in regards to cloud computing applications:

- Software as a Service (SaaS)
- Platform as a Service (PaaS)
- Infrastructure as a Service (IaaS)

D. Cloud Computing Architecture

The Cloud architecture describes the functional mode in which the cloud works. It includes components and services that are used. The cloud is a technology completely dependent on an Internet connection to function.

According to [3], the cloud can be divided into 4 layers, as presented in Fig. 1:

- Layer 1 – User/Client Layer - the place where the client/user initiates the connection to the cloud;
- Layer 2 – Network Layer - facilitates the connection of the user to the cloud;
- Layer 3 – Cloud Management Layer - represents all software used in managing a cloud. The software is typically an operating system.
- Layer 4 – Hardware Resource Layer - represent the actual hardware resources available.

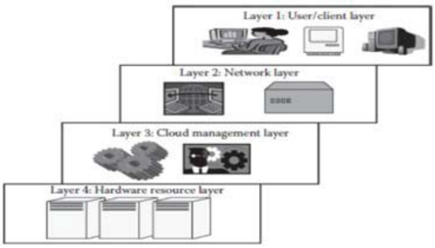

Figure 1. Generic cloud computing architecture

All these layers require virtualization of resources, such as SDR and Software Defined Networking (SDN), in order to provide the deployment and service models of cloud computing.

III. PROPOSED METHODS FOR 5TH GENERATION MOBILE NETWORK

Wireless technologies have become an important part of our daily life and have a profound impact in our daily task giving us access to a full range of services for multimedia (videos, video-conferences, images), information services (encyclopedias, academic content) and access to several applications used for e-commerce, health emergency applications. „If analysts' prognostications are correct, just about every physical object we see (e.g. clothes, cars, trains, etc.) will also be connected to the networks by the end of the decade (Internet of Things)" [1]. 5G gives us not only an upgrade in speed but implements a power and cost effective wide area coverage network powered by HetNet's.

A. Standards and Features

The Next Generation Mobile Network Alliance (NGMN) defines in the white paper for 5G requirements for a full functioning 5G Network [4]. In summary the NGMN suggest the following:

✓ Data rates of up to 1Gb/s should be supported in specific environments such as indoor offices, while at least 50 Mb/s shall be available everywhere cost-effectively.

✓ The 5G system should provide 10ms E2E latency (duration between the transmission of a small data packet from the application layer at the source node and the successful reception at the application layer at the destination node plus the equivalent time needed to carry the response back) in general and 1ms E2E latency for the cases that require very low latency. The end user should have the perception that he is always connected. The establishment of initial connection to the network should be instantaneous from the perspective of the user.

✓ In case of mobility, 5G should not assume mobility support for all devices and services but provide mobility on demand only to those devices and services that need it.

The above parameters are summarized in Fig. 2 below:

Use case category	User Experienced Data Rate	E2E Latency	Mobility
Broadband access in dense areas	DL: 300 Mbps UL: 50 Mbps	10 ms	On demand, 0-100 km/h
Indoor ultra-high broadband access	DL: 1 Gbps, UL: 500 Mbps	10 ms	Pedestrian
Broadband access in a crowd	DL: 25 Mbps UL: 50 Mbps	10 ms	Pedestrian
50+ Mbps everywhere	DL: 50 Mbps UL: 25 Mbps	10 ms	0-120 km/h
Ultra-low cost broadband access for low ARPU areas	DL: 10 Mbps UL: 10 Mbps	50 ms	on demand: 0-50 km/h
Mobile broadband in vehicles (cars, trains)	DL: 50 Mbps UL: 25 Mbps	10 ms	On demand, up to 500 km/h
Airplanes connectivity	DL: 15 Mbps per user UL: 7.5 Mbps per user	10 ms	Up to 1000 km/h
Massive low-cost/long-range/low-power MTC	Low (typically 1-100 kbps)	Seconds to hours	on demand: 0-500 km/h
Broadband MTC	See the requirements for the Broadband access in dense areas and 50+Mbps everywhere categories		
Ultra-low latency	DL: 50 Mbps UL: 25 Mbps	<1 ms	Pedestrian
Resilience and traffic surge	DL: 0.1-1 Mbps UL: 0.1-1 Mbps	Regular communication: not critical	0-120 km/h
Ultra-high reliability & Ultra-low latency	DL: From 50 kbps to 10 Mbps; UL: From a few bps to 10 Mbps	1 ms	on demand: 0-500 km/h
Ultra-high availability & reliability	DL: 10 Mbps UL: 10 Mbps	10 ms	On demand, 0-500 km/h
Broadcast like services	DL: Up to 200 Mbps UL: Modest (e.g. 500 kbps)	<100 ms	on demand: 0-500 km/h

Figure 2. Summary of 5G parameters

Other considered requirements are that spectral efficiency should be increased significantly compared to the current 4G networks, coverage should be increased and also signal efficiency should be greatly enhanced.

5G is in research stage, but 5G are expected to be operational around Q4 of 2020. According to NGMN [4] the current timeline for 5G is represented in Fig.3.

Figure 3. 5G Roadmap

Meanwhile several important vendors have begun research and development for 5G in 2013 and in 2015 several 5G laboratory trials have begun [5].

B. 5G Architecture

5G will be a fully converged system that will support a multitude of applications ranging from data, voice and multimedia to critical communications, Internet of Things, low latency applications (for example driverless cars) and can function on moving platforms due to increased mobility [1]. A variety of 5G applications are represented in Fig. 4.

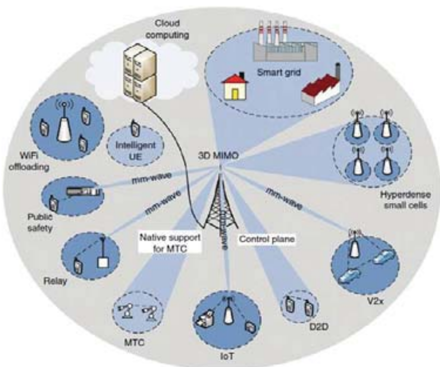

Figure 4. Generic 5G Architecture

The Network architecture of 5G can provide the following capabilities:

- Integrates the Radio Access Network (RAN) in various frequency bands. The radio frequency range will vary from 6GHz up to 100GHz. According to 5G requirements the RAN will provide virtually zero latency.
- Flexible deployments can be implemented using wireless and relying on optical technologies;
- HetNet Implementation;
- Cloud Computing can be applied to the RAN. This capability is combined with the transformation to cloud-based radio access;
- Virtualization of network functions will optimize network resources which improves scalability. This will be done in communication with data centers and will enhance Software Defined Networking (SDN) capabilities;
- Full usage of SDN capabilities;
- Networks will become self-aware, cognitive, and implement extensive automation and continuous and predictive learning [5];
- Internet of Things (IoT) integration;
- Usage of mmWaves;
- Massive MIMO (Multiple Input Multiple Output).

C. Heterogeneous networks (HetNets)

A heterogeneous network is a network in which multiple radio access technologies are used (e.g. GSM, WCDMA, and LTE) along with base stations that vary in size. A heterogeneous network is an efficient way of expanding mobile network capacity.

A heterogeneous network is made of two components: small cells (provides mobility) and macro cells (increase coverage and capacity). A HetNet is an evolution of a mobile access network in which an operator can add macro cell capacity as demanded. HetNet can extend closer to the end-user by positioning low cost and low power access nodes indoors or outdoors. (E.g. roadside, posts, corporate buildings) To facilitate deployments, 3G, LTE, 5G and Wi-Fi interfaces can be embedded within cells.

The HetNet access nodes are as follows:

- Macro/Micro Cells - Macro and micro cells provide universal coverage due to the fact that they have an inter-site distance of more than 500 meters;
- Small Cells – Small Cells are better suited for cloud applications due to higher speed demand. Small cells include:
  - Picocells – Picocells must be placed at about 200 meters or less;
  - Femtocells – The Coverage range for a Femtocell is about 100 meters;
  - Distributed Antenna System – A network of spatially-placed antennas connected to a common source via wireless;
  - Relay Nodes – Base stations that provide coverage/capacity to macro cells. Relay Nodes are connected via a Donor eNodeB (through a radio interface).

A generic HetNet architecture [6] that makes use of these access nodes is represented in Fig. 5:

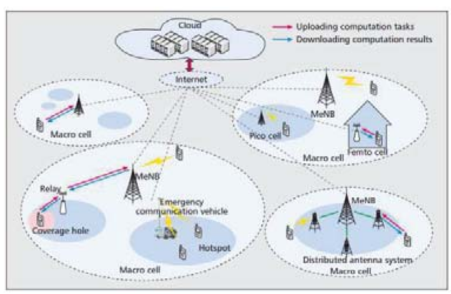

Figure 5. Generic HetNet architecture

D. 5G Application – Software Defined Network

The Software Defined Networking approach is composed of a logically centralized entity called the Controller which manages the associated network data plane using an Application Programming Interface (API) that allows configuration of parameters such as forwarding tables of network equipment. (E.g. router, switch) [7]. A comparison between traditional network architecture and the SDN approach is presented in Fig. 6.

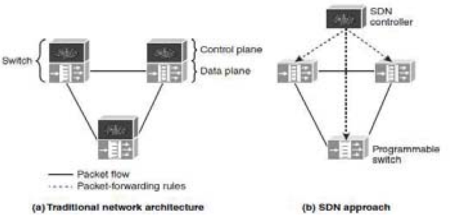

Figure 6. Comparison between traditional networks and SDN Approach

As presented in Fig. 7, the 5G technology can benefit from the programmability and scalability of SDN and NFV (Network Function Virtualization) technologies.

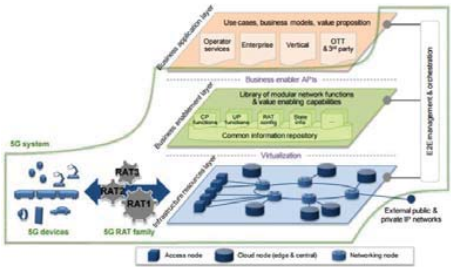

Figure 7. 5G and SDN convergence

As such, the 5G architecture is a native SDN/NFV architecture covering aspects ranging from devices, (mobile/ fixed) infrastructure, network functions, value enabling capabilities and all the management functions to orchestrate the 5G system [4]. APIs are provided on the relevant reference points to support multiple use cases, value creation and business models.

IV. Measurement Results

In this section we present the measurement results from the implementation of a decentralized Cloud platform using 5G networks.

A. Proposed measurements

The purpose is to create a 5G Network using the USRP platform and implementing a cloud platform. The 5G Network will be implementing using a BPSK modulation for header and QPSK modulation for data transmission. In order to encode data on multiple carrier frequencies, OFDM (Orthogonal frequency-division multiplexing) will be used. The performance of the Cloud platform will be evaluated by measurements done for the transmission of a UDP data stream.

B. Proposed measurement environment

In this section we present the hardware and software connections between the USRP and the PC, which can be a physical machine or a VM in the cloud, as presented in Fig. 8. We ran it on Windows 7.

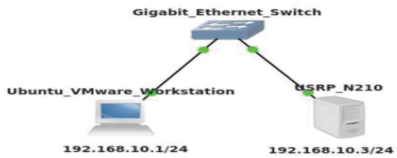

Figure 8. Proposed measurement environment

1) USRP

Universal Software Radio Peripheral (USRP) N210 Networked Series [8] is a hardware designed by Ettus Research and used by research labs and universities to implement software defined radio systems. The USRP connects to a host computer having a software (i.e. GNU Radio) that controls the USRP hardware in order to receive and transmit data.

2) VERT900 Antenna

The VERT900 Antenna is an omnidirectional antenna functioning in 824-960 MHz, 1710-1990MHz Quad-band Cellular/PCS and ISM bands working at 3dBi gain.

3) GNU Radio

GNU Radio is an open-source software that contains a series of tools for implementing software defined radios. It contains blocks for signal processing as well as virtual sources and virtual equipments in order to emulate real equipment. GNU Radio can be used with external hardware (i.e. USRP) in order to create a software-defined radio.

The measurement environment was used in the SaRaT-IWSN project [9], and its main objective is to implement a radio transceiver that is capable of handling multiple communication requirements in a versatile manner, there is a need for a very flexible platform, in which the implementation of physical layer protocols is object-oriented, flexible and easy to modify. The OFDM transmitter and receiver are presented in the Fig. 9, respectively Fig. 10

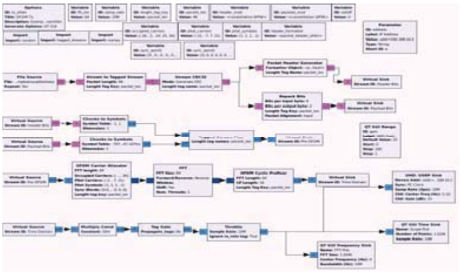

Figure 9. OFDM Transmitter in GNU Radio

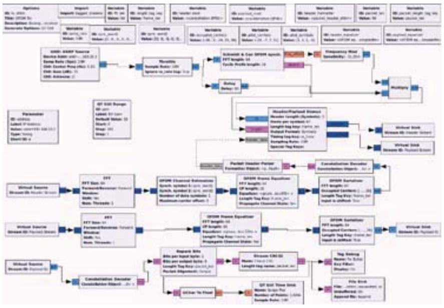

Figure 10. OFDM Receiver in GNU Radio

The results for a 5 GHz frequency (central frequency is 5.1 GHz) and a 25 dB gain at reception and emission are as represented in the Fig. 11, respectively Fig. 12.

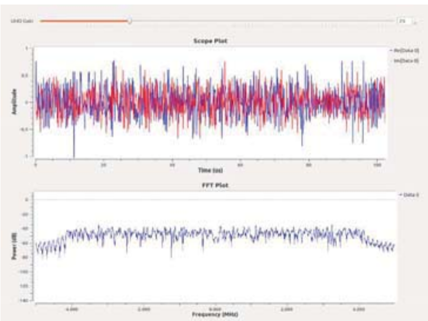

Figure 11. Amplitude/Phase representation at emission

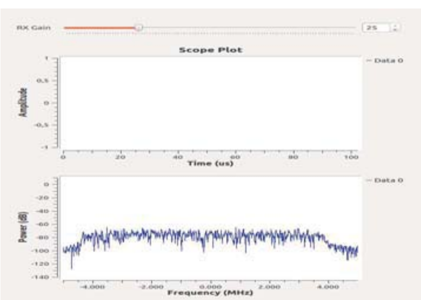

Figure 12. Amplitude/Phase representation at reception

The results for sending a text file using UDP protocol for different transmission and reception gain values are represented in Table 1.

TABLE I. RESULTS BASED ON DIFFERENT GAIN VALUES

Frequency [GHz]	TX Gain [dB]	RX Gain [dB]	Error Rate [%]
5	25	25	8
5	25	20	11
5	25	15	22
5	25	10	28

The error rate was calculated for 100 UDP packets and the results show an high error rate which needs further error detection and correction algorithms.

V. CONCLUSIONS

In this paper we presented an approach of implementing a decentralized Cloud platform using 5G Networks. Also, we presented measurement results, making use of 5G's capabilities that enabled a resilient and reliable cloud platform. Furthermore, 5G gives the mobility to have a cloud everywhere it is considered to be necessary. As future work we envision possibilities of implementation and development of the proposed system for neutrino detection in the SARAT project, but there are endless other use cases including Internet of Things, M2M and countless Cloud applications.

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