

Developing a Magma-based Private 5G SA Network Supporting COTS UE with Global Connectivity

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Abstract—Although a variety of 5G NSA or SA networks have been developed based on a handful number of open-source software platforms, documented examples of Magma-based 5G SA networks that support global connectivity for COTS UEs are hardly revealed. In this paper, we present the design, implementation, and evaluation of a private 5G SA network using Magma as the core network and OAI RAN or srsRAN as the radio access network. Our full-stack open-source 5G network is deployed on a single Dell R650 server which bears both core and RAN functions and is connected to a USRP X300 SDR serving as the RU for COTS UE connectivity. Through real-life experiments, we showcase the operability and performance of our testbed with respect to end-to-end connectivity, data rates, user experience for video streaming services, as well as policy-based traffic control and subscriber-specific QoS enforcement.

Index Terms—Private 5G SA network, open-source software, Magma, COTS hardware, implementation and experiments.

I. INTRODUCTION

In full swing of worldwide deployments of fifth generation (5G) mobile networks in recent years, more and more 5G systems are deployed as or upgraded from non-standalone (NSA) to standalone (SA) networks, *connecting radio access networks (RANs) and the core network (CN) in a single architecture* [1]. Along the path from 5G NSA to 5G SA and further towards sixth generation (6G) systems, a salient feature of this evolution is the transition from vendor-specific proprietary solutions to software-centric common infrastructure supporting standard network functions and flexible service creations.

In parallel with this evolution, another trend is the steadily growing popularity of private 5G network development. Residing on its premises, a business or property owner can deploy a dedicated 5G NSA/SA network which can be operated either independently (i.e., with full-scale user data ownership) or be interconnected with a commercial 5G network in cooperation with a mobile network operator [2]. This paradigm shift is facilitated by the recent advancement in a software-based and virtualized network function development for both RANs and CNs, especially through open-source software implementations and commercial off-the-shelf (COTS) hardware [3].

Developing open-source based 5G NSA/SA networks relies heavily on the availability of open-source software suites for both RAN and CN. Among various implementations, *software radio systems radio access network (srsRAN)* and *OpenAirInterface (OAI) RAN* are the two most popular platforms for RAN. On the other hand, the most prominent open-source implementations of 5G core (5GC) are *Open5GS*, *OAI CN*,

free5GC, and *Magma*. While the first three 5GC platforms have been extensively investigated in both academia and industry, Magma remains the least explored platform so far, with very limited publicly available information and documentation.

Different from the other three platforms which focus solely on 5GC implementations, Magma features not only its compliance with 3rd generation partnership project (3GPP) 5GC standards but also its capability of integrating non-3GPP radio access technologies (RATs) like wireless fidelity (WiFi) to the same CN platform. As an initial effort, [4] performed a qualitative comparison of Open5GS, free5GC, versus Magma, and selected Magma due to its versatility, however, without real-life testbed implementation. Through a small-scale testbed, [5] made a comparison study of OAI CN and Magma and pointed out the immaturity of Magma code and documentation. With strong industry engagement, the authors of [6] shared their experiences in designing and deploying Magma-based real-life networks, supporting both fourth generation (4G) cellular and WiFi access. More recently, [7] presented a testbed demonstrating the migration of Magma network functions between Kubernetes pods, without involving any RAN or COTS user equipment (UE). As such, how to build a Magma-based private 5G SA network with global connectivity for COTS UEs triggered our motivation to perform this study.

In this paper, we present the establishment of a functional prototype all-in-one 5G SA network with Magma as the CN supporting global connectivity for COTS UEs. For the RAN compartment of our testbed, both srsRAN and OAI RAN are integrated with the Magma CN and a universal software radio peripheral (USRP) software defined radio (SDR) that functions as the radio unit (RU) connecting UEs over the standard 5G new radio (NR) interface. Extensive experiments are carried out to assess the performance of our system with respect to end-to-end connectivity, uplink/downlink capacity, video streaming quality, as well as subscriber-specific access control.

The remainder of this paper is organized as follows. After a brief introduction of Magma and the building blocks of our testbed in Sec. II, we present the design and implementation of our system in Sec. III. Then we perform real-life experiments and demonstrate the performance of our system in Sec. IV, before concluding the paper in Sec. V.

II. PRELIMINARIES AND TESTBED BUILDING BLOCKS

In this section, we first present the Magma CN architecture and then introduce the main building blocks for our RAN.

A. Preliminaries on the Magma CN Architecture

1) *Magma core architecture*: Initially developed by Meta, Magma is an open-source Linux Foundation project offering a software platform, supporting not only 4G, 5G NSA, and 5G SA but also non-3GPP RAT connectivity. There are three major components in the *Magma Core* architecture, namely, an *access gateway (AGW)*, an *Orchestrator (Orc8r)*, and a *federation gateway (FeG)*.

While the AGW integrates both control- and user-plane functionality including network services and policy enforcement as well as an interface toward the Internet, the Orc8r provides various functions including subscriber management, monitoring, logging, and alarm handling for the private network. As our testbed does not intend to integrate any non-3GPP RAT into our 5G SA system, the FeG is not involved in our system design and implementation.

2) *Magma versus 5G service-based architecture (SBA)*: Magma core is 3GPP compliant. Although Magma version 1.8 supports 5G core, its architecture is not designed to provide a one-to-one match to the 5G SBA which contains legacy 5G network functions such as access and mobility management function (AMF), session management function (SMF), and user plane function (UPF). Instead, Magma employs a generalized and modular design that is compatible with both 4G and 5G. As a result, the AGW performs multiple roles simultaneously, including functionalities that in a standard 5G SA network would be distributed across multiple distinct network functions.

In addition to the *inbuilt* subscriber database and *policy and charging rules function (PCRF)*, Magma can also be integrated with third-party solutions like home subscriber server (HSS) for commercial 4G network management as well as other PCRF toolboxes for traffic control and quality of service (QoS) provisioning in 5G networks.

B. Building Blocks for RAN – Software and Hardware

The Magma CN presented above is co-located with a next-generation nodeB (gNB) (centralized unit (CU)–distributed unit (DU)) powered by two popular open-source RAN software suites. An SDR functions as the RU connecting the gNB (CU–DU) with one or multiple UEs.

1) *srsRAN*: Developed by *Software Radio Systems (SRS)*, srsRAN provides modular implementations of full-stack 4G long term evolution (LTE) and 5G NR components with 3GPP Release 17 and O-RAN compatibility. It includes a standards-aligned gNB, UE and core-integration modules, and is widely used for research, prototyping, and SDR-based testbeds, thanks to its lightweight configuration and stable operation in small-scale deployments.

2) *OAI RAN*: OAI provides an open-source research, development and testing platform for both CN and RAN, developed by the *OAI Software Alliance* lead by *Eurecom*. OAI offers broad support for SDR platforms, including the USRP X300. OAI RAN supports both frequency range (FR) 1 (numerologies 0 and 1) and FR 2 (numerologies 2 and 3) as well as bandwidth of 10, 20, 40, 80, and 100 MHz.

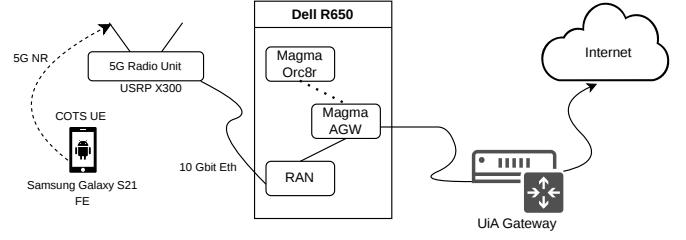


Fig. 1: Network sketch: Magma-based 5G with global connectivity.

3) *USRP X300*: Developed by *Ettus Research*, the USRP X300 offers a high-performance SDR platform with multiple high-speed interfaces. It supports up to 160 MHz of baseband bandwidth, enabling direct communication between gNB and COTS 5G UEs. Although X300 supports up to four antenna ports, only two antennas are used in our experiments.

III. SYSTEM DESIGN AND IMPLEMENTATION

The designed and implemented system in this work provides global end-to-end connectivity for COTS UEs covered by a local SDR-based 5G gNB, supporting UE registration, authentication, and data transfer through the Magma CN platform.

A. System Overview

As illustrated in Fig. 1, our testbed consists of three major compartments, i.e., UE, a 5G gNB RU, and a server which hosts both RAN and CN software components.

1) *UE*: Upon the availability of COTS UEs in our lab, the following UE models have been tested in our system: *Samsung Galaxy S21 FE 5G*, *OnePlus 12*, *OnePlus 10 Pro*, *OnePlus Nord 5*, and *Xiaomi Redmi Note 10 Pro*. All these UEs are subscribed to our system, each using a Sysmocom subscriber identity module (SIM) card.

For the experiments and results presented later in Sec. IV, Samsung Galaxy S21 FE 5G is selected as the UE. Our RAN is operated in the time division duplex (TDD) mode in band 78. The RU forwards the uplink data to the gNB software, which then sends it to the AGW through a general packet radio service (GPRS) tunneling protocol (GTP) tunnel.

2) *RAN*: Our RAN compartment can be operated on both **OAI RAN** and **srsRAN**, supporting a distributed, fully virtualizable architecture in which the key gNB functional layers, such as physical layer (PHY), radio link control (RLC), and radio resource control (RRC) are implemented as a software suite *running on a virtual machine (VM)*. This design allows seamless switching between different gNB implementations, such as OAI and srsRAN, without requiring modifications to the fundamental system architecture.

RU: As a component of RAN, a USRP X300 SDR serves as the RU, and it functions as the radio frequency (RF) front-end for the software-driven gNB. It performs the digital–RF conversion required for 5G NR, transmitting and receiving baseband samples provided by the gNB software.

3) *CN*: Our CN compartment is built based on Magma v1.8, with AGW and Orc8r running in two separate VMs.

AGW: The AGW is the central component of the Magma CN, responsible for processing both user- and control-plane

TABLE I: Hardware and software composition of our 5G testbed

Hardware components: Co-located CN and RAN			
Server	CPU	RAM/Storage	OS: Ubuntu
Dell R650	Intel Xeon Gold 5315Y, 32 cores	64 GB/4.8 TB	20.04.6-live server (CN) 22.04.5-live server (RAN)
Hardware: RU and UE			
RU	USRP X300	UE	Samsung Galaxy S21 FE 5G
Software versions and functions			
Software	Version	Function	
Proxmox	8.4.13	Virtual environment	
Magma	v1.8	5G core	
OAI RAN	v2.3.0	gNB	
srsRAN	25.10	gNB	
UHD	v4.8.0.0	SDR driver	
Docker	28.1.1	Containerization	
5G Switch	4.0.1	UE configuration	

traffic. The AGW exposes its *service gateway interface* (SGi) toward the Internet, and provides each user with access to their authorized services based on subscriber-specific policy rules.

Orc8r: It functions as the central management and monitoring component within the Magma CN architecture. It handles AGW configuration, subscriber management, monitoring, logging, and alarm generation. Although the AGW and the Orc8r are co-located on the same server in our testbed (which is a small-scale network), a single Orc8r can be connected to multiple AGWs distributed at different locations through secure tunnels for a large-scale network.

To reach the global Internet, the server which hosts RAN and CN software suites is connected via Ethernet (10 Gbps) to a gateway belonging to the university campus network. Network address translation (NAT) is performed at the gateway.

B. Hardware Implementation

Multiple components are needed to support the operation of the system, with the two main ones presented below.

1) *Dell PowerEdge R650 for RAN and CN:* Dell R650 serves as the central platform for our 5G testbed, hosting both the CN and the RAN components. A *Proxmox* virtual environment (VE) is operated on the server, and it provides virtualization, resource management, and isolation between the deployed VMs. With the specification shown in Tab. I, this server enables concurrent execution of the 5G RAN/CN software and auxiliary services.

2) *USRP X300 SDR for RU:* The SDR is physically connected to the Dell R650 server via a dedicated 10 Gbps Ethernet cable for transmitting baseband complex samples between the gNB software suite and the SDR. The device is configured to operate in the n78 frequency band, with configurable center frequency, bandwidth, and gain parameters.

The SDR is controlled through the USRP hardware driver (UHD), which provides the interface between the gNB (CU–DU) software suite and the hardware component.

C. Software Implementation

Resided on a Dell R650 server, a *Proxmox* hypervisor is created, hosting three VMs. The main software suites and versions adopted for our implementation are summarized in Tab. I, together with the hardware components.

```

ubuntu@agw4:/etc/netplan$ ip a
1: lo: <LOOPBACK,UP,LOWER_UP> mtu 65536 qdisc noqueue state UNKNOWN group default qlen 1000
    link/loopback 00:00:00:00:00:00 brd 00:00:00:00:00:00
    inet 127.0.0.1/8 scope host lo
        valid_lft forever preferred_lft forever
    inet6 ::1/128 scope host
        valid_lft forever preferred_lft forever
2: eth0: <BROADCAST,MULTICAST,UP,LOWER_UP> mtu 1500 qdisc fq_codel state UP group default qlen 1000
    link/ether bc:24:11:d3:73:18 brd ff:ff:ff:ff:ff:ff
    inet 192.168.0.39/24 metric 100 brd 192.168.0.255 scope global eth0
        valid_lft forever preferred_lft forever
    inet6 fe80::be24:11ff:fed3:7318/64 scope link
        valid_lft forever preferred_lft forever
3: eth1: <BROADCAST,MULTICAST,UP,LOWER_UP> mtu 9000 qdisc fq_codel state UP group default qlen 1000
    link/ether bc:24:11:ef:bc:b1 brd ff:ff:ff:ff:ff:ff
    inet 192.168.40.15/24 brd 192.168.40.255 scope global eth1
        valid_lft forever preferred_lft forever
    inet6 fe80::be24:11ff:feef:bcb1/64 scope link
        valid_lft forever preferred_lft forever

```

Fig. 2: AGW IP address and interface configuration.

1) *Proxmox VE and VMs:* Based on the established Proxmox VE, which is a server management platform to provide virtualization for enterprise servers, three VMs are created, each for **AGW**, **Orc8r**, and **RAN**, respectively.

In addition to the default network shared by all VMs, an extra network bridge is configured to provide a dedicated connection between the AGW VM and the RAN VM, enabling direct communication between them.

2) *Magma CN:* Two Magma CN components are implemented in our testbed, as briefly presented below.

AGW (IPv4 addresses: 192.168.0.58/24 and 192.168.40.15/24): The AGW currently only supports Ubuntu 20.04. AGW relies on Linux kernel space to create GTP tunnels with the RAN, requiring a kernel version between 5.4 and 5.8. The AGW requires a *netplan* configuration file named *50-cloud-init.yaml* that performs configurations for both *eth0* and *eth1*.

Through the execution of the script by Magma [9], we install the *Docker* platform, apply network configurations, and pull the necessary *Docker* images for the AGW. The AGW IP address allocation and interface configuration in our testbed implementation is illustrated in Fig. 2.

Orc8r (IPv4 address: 192.168.0.50/24): It must be set up before the AGW, as the AGW requires certain certificates generated by the Orc8r.

In our implementation, the dockerized version of Magma is adopted. Once the *Docker* images are built, another Magma script is initiated to start the Orc8r. By default, Magma starts in the 4G mode, but it can operate as a 5G CN as well. When the Orc8r runs for the first time, it generates certificates for ensuring encrypted communication between the Orc8r and the connected AGWs, allowing the Orc8r to be hosted centrally (e.g., within a mobile network operator’s premises) while AGWs being deployed closer to end users.

3) *RAN:* (IPv4 address: 192.168.40.10/24) This VM operates the gNB (CU–DU) software suite (either OAI RAN or srsRAN, but not simultaneously). It has also an interface with the RU, i.e., SDR USRP X300 for our implementation.

OAI RAN: The OAI RAN source code [10] from its GitLab repository is cloned onto our RAN VM and the build scripts are executed to compile the gNB and NR-UE binaries from the source. Based on the configuration template provided by OAI, the testbed is configured as MCC: 999; MNC: 70; AMF IPv4 address: 192.168.40.15.

srsRAN: The srsRAN option of our gNB is built based on the source codes from [11]. CMake is used to compile

```

ubuntu@magmademon:/etc/netplan$ uhd_find_devices
[INFO] [UHD] linux; GNU C++ version 11.4.0; Boost_107400; UHD_4.8.0.HEAD-0-g308126a4
-----
-- UHD Device 0
-----
Device Address:
  serial: 3243FD3
  addr: 192.168.40.2
  tpga: HG
  name:
  product: X300
  type: x300
ubuntu@magmademon:/etc/netplan$

```

Fig. 3: Verification of the RU–Magma CN connection.

all source codes into the final executables that are installed in the RAN VM. A configuration file is created for srsRAN, containing multiple parameters including SDR settings such as the IP address. Unlike OAI, the srsRAN gNB provides limited logging during runtime. Connection status is verified via log entries at the Magma CN.

RU: The USRP X300 RU is directly connected to the Dell R650 server through an Ethernet cable and it is reachable from all VMs through IPv4 address: 192.168.40.2/24.

To allow other software interact with the RU, a UHD and the corresponding firmware images are installed. After the installation of the required build tools and dependencies and the compilation of the code base, the gNB component is integrated with the RU and the CN. Fig. 3 illustrates the verified connection between USRP X300 and Magma CN.

4) **UE:** The SIM card adopted in our testbed for COTS UE subscription is the Sysmocom `sysmoISIM-SJA5`. This SIM card is programmable and it is delivered by Sysmocom with all required subscriber information pre-configured [12]. Subscriber-specific parameters are registered in the CN database through the Magma network management system (NMS). No additional programming of the SIM card is required in our implementation, as all the tested UEs support transmission of the subscription permanent identifier (SUPI) during registration.

For Samsung Galaxy S21, the UE must be configured to run in the `NR-only` mode. To force the UE to operate exclusively in this mode, a third-party application, 5G Switch, is used.

5) **Network management:** Magma is managed via two main interfaces, namely, the Swagger application programming interface (API) and the NMS. The Swagger API is representational state transfer (REST)-based, allowing network parameters to be configured through hypertext transfer protocol secure (HTTPS) requests with Javascript object notation (JSON) payloads. The NMS provides a graphical interface for creating and managing subscribers, configuring policies through PCRF, and assigning service types such as subscriber-specific resource mapping and QoS classification. In our testbed, the inbuilt subscriber database and PCRF in Magma are adopted.

IV. EXPERIMENTS AND NUMERICAL RESULTS

In this section, we first illustrate the implemented Magma-based 5G network which is deployed in an indoor lab located on UiA's Grimstad campus. Various experiments are carried out to assess the performance of the prototype testbed.



Fig. 4: Implemented testbed: Magma CN–gNB(CU-DU)–RU–UE.

A. Testbed Illustration and Network Components

Fig. 4 illustrates the deployed small-scale 5G SA network developed based on the hardware and software listed in Tab. I. A Dell R650 rack that hosts both Magma CN and gNB (CU-DU) is inserted into a server cabinet administered by the university, through which our private 5G SA network is connected to the global Internet.

B. End-to-End Connectivity

To verify that the deployed private 5G SA network operates as intended and provides connectivity to the global Internet, a series of connectivity experiments have been performed using a command `ping` or `traceroute`. In Fig. 5, we illustrate an example of such an experiment showing the path from a UE with a private IPv4 address 192.168.128.12 obtained from our network towards `apple.com`. Specifically,

- **Hop 1** – 192.168.128.1 corresponds to the IP address of the GTP bridge in the AGW. This component

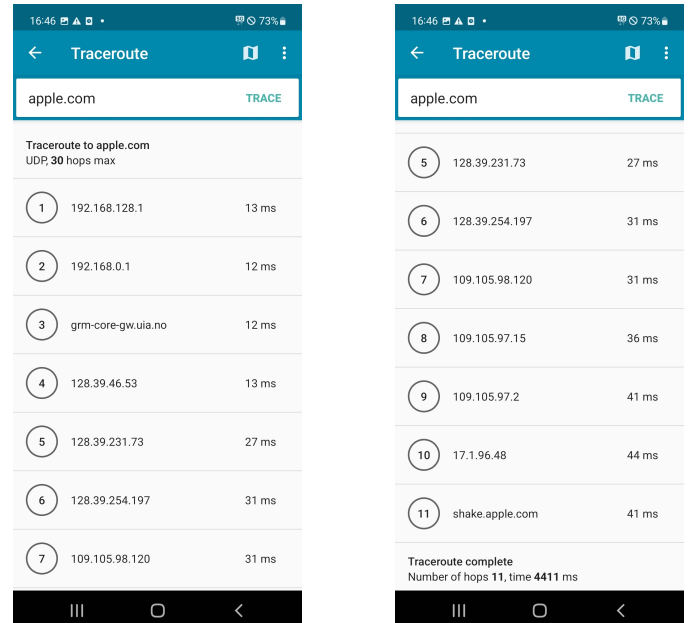


Fig. 5: Illustration of a traceroute result for COTS UE, OAI RAN towards `apple.com`. Left: Hops 1–7; Right: Hops 5–11.

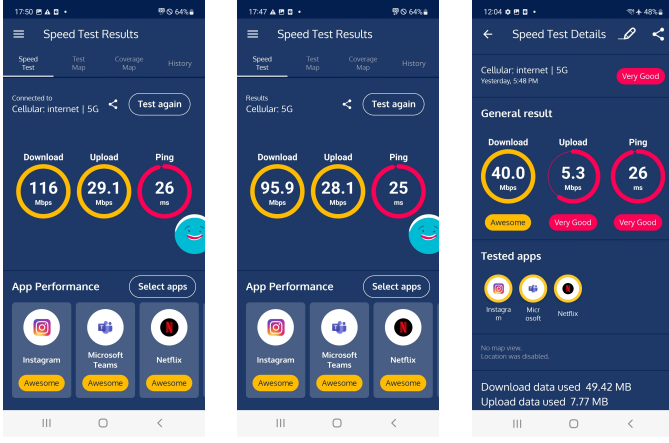


Fig. 6: Speed test results for OAI RAN: <1 m, 5 m, and 15 m.

connects the UE to the internal Magma network and bridges UE traffic to the uplink interface.

- **Hop 2** – 192.168.0.1 is the IP address of the internal Proxmox gateway. This gateway receives traffic exiting the AGW VM and forwards it towards the UiA internal network gateway.
- **Hop 3** – grm-core-gw.uia.no represents the UiA internal gateway, which performs NAT and assigns a public IP address to outgoing traffic.
- **Hop 4** – A publicly routable IP address belonging to SIKT, the Norwegian Agency for Shared Services in Education and Research.

The path for the remaining hops (**Hop 5 – Hop 11**) follows the standard IP routing on the global public Internet until it reaches shake.apple.com.

C. Data Rate and Delay with Variable Locations

This set of experiments is performed by placing the UE as stationary at three different locations inside the on-campus indoor lab with the transmit power configured as 10 dBm. For data rate and delay measurements, the Meteor APP which provides both downlink and uplink speed as well as delay, is installed on the COTS UE's. The gNB is operated as a single cell in band n78 (central frequency 3.5 GHz) with 40 MHz channel bandwidth and a 30 kHz subcarrier spacing (SCS) (numerology 1), with 106 physical resource blocks for user data traffic.

In Fig. 6, we illustrate in a graphic format the obtained capacity and delay based on the OAI RAN and Magma CN combination. As shown in the figure, awesome service performance is achieved at the short and medium distances, but not at the long distance.

For comparison, we present in a table format the corresponding performance for OAI RAN versus srsRAN in Tab. II. The OAI-based setup achieves higher throughput than the srsRAN-based setup, likely due to the differences in implementation maturity and scheduling behavior.

D. Quality of Experience: Video Streaming

To evaluate to which extent the deployed network could maintain stable downlink performance at high resolutions, we

TABLE II: Performance as UE location varies: Indoor environment

UE	RAN	Distance	UL[Mbps]	DL[Mbps]	Ping[ms]
Samsung S21 FE 5G	OAI RAN	<1 m	29.1	116.0	26
		5 m	28.1	95.9	25
		15 m	5.3	40.0	26
Samsung S21 FE 5G	srsRAN	<1 m	17.2	34.9	25
		5 m	12.6	33.9	23
		15 m	10.1	28.1	33

perform a set of video streaming experiments on a COTS UE, Samsung S21 FE 5G. In our experiments, the same video which offers video resolutions ranging from 144p to 2160p is selected [8] and a fixed distance of 5 meters between the UE and the gNB (both OAI RAN and srsRAN) is configured.

Each experiment is divided into two evaluation phases: *playback duration* and *skip response time*. While playback duration refers to continuous video playback for at least five minutes with observed stable stream, *playback quality* is classified into four stability levels, *Stable*, *Mostly Stable*, *Unstable*, and *Unusable*, based on service continuity and buffering behavior during a streaming session. Skip response time measures the interval between stepping into an unbuffered position in the video and the resumption of playback, serving as an indicator of responsiveness and buffering performance.

As shown in Tab. III, both OAI and srsRAN achieve *Excellent* video streaming quality for resolutions equal to or lower than 1080p (high definition (HD) or full HD). No dissatisfactory performance is observed, with the playback being stable, and the skip time of 1-2 seconds for all of the resolutions below 1440p. For the quad high definition (QHD) 1440p streaming, stable playback and skip time of 3 seconds is experienced, marking them as *Good* in terms of quality of experience (QoE). However, 4K streaming faces unpleasant user satisfaction with a longer skip time of 7 seconds for both network configurations, with its QoE classified as *Poor* and *Unacceptable* respectively.

E. Core Network Policy and Traffic Control

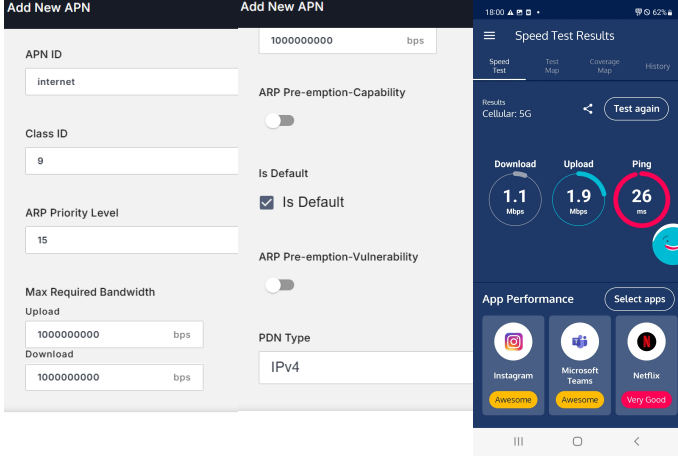
Magma offers mobile operators with several options to facilitate differentiated services to subscribers. Through its NMS, an operator can configure policies that restrict access to specific services and control the maximum data rate allocated to subscribers. In what follows, we demonstrate two such policies that are defined through the NMS interface.

1) *Capacity control*: This example reveals the effect of imposing a subscriber-specific capacity restriction on an access point name (APN) through Magma's PCRF. The experiment is performed by configuring a given value of the *Maximum Requested Bandwidth* for uplink and downlink of a user in the Magma Orc8r. As shown in Fig. 7a) and 7b), no constraint is introduced at the APN (with an upper-bound of 1 Gbps). However, through policy control by Magma's PCRF which imposes a limited capacity of maximum 1 Mbps, the measured uplink and downlink data rates at the UE which is located <1 meter from the gNB are approximately 1–2 Mbps respectively, as restricted by the policy (as shown in Fig. 7c)).

Comparing this result with the one shown in Fig. 6a) where the UE at the same distance achieved 116 Mbps downlink and

TABLE III: QoE evaluation for video streaming with different display resolutions

Video Quality	Resolution	YouTube Label	gNB: OAI; UE: Samsung S21 FE			gNB: srsRAN; UE: Samsung S21 FE		
			Playback	Skip [s]	QoE	Playback	Skip [s]	QoE
HD	1280 × 720	720p HD	Stable	1	Excellent	Stable	2	Excellent
Full HD	1920 × 1080	1080p HD	Stable	1	Excellent	Stable	2	Excellent
QHD	2560 × 1440	1440p HD	Stable	3	Good	Stable	3	Good
4K	3840 × 2160	2160p (4K)	Stable	7	Poor	Unstable	7	Unacceptable



(a) APN data rate configuration. (b) APN rate upper-bounded by 1 Gbps. (c) Obtained DL/UL data rates.

Fig. 7: Unbounded APN versus policy controlled DL/UL data rates.

29.1 Mbps uplink respectively, it is evident that the configured limit for access capacity has been successfully enforced.

2) *Subscriber-specific IP access control*: This experiment demonstrates Magma's ability to enforce subscriber-specific access control policies. As an example, a policy is created in the Magma NMS to block traffic to and from the IP address of *nrk.no*. The policy configuration at Magma's PCRF includes:

- **Uplink DENY:** source = 0.0.0.0/0; destination = 23.33.119.66/32
- **Downlink DENY:** Source = 23.33.119.66/32; Destination = 0.0.0.0/0

This policy is then applied to the same subscriber whose Internet connectivity has been demonstrated in Subsec. IV-B above. Through the Internet control message protocol (ICMP) ping command, we illustrate in Fig. 8 the reachability result before and after inferring access control.

As shown in Fig. 8a), the subscriber was able to successfully ping the target IP address before imposing the policy. After applying the policy, all ping attempts failed, as illustrated in Fig. 8b), revealing that the access control rules have been correctly enforced by the network operator.

V. CONCLUSIONS

In this paper, we have demonstrated the successful deployment and operation of a private 5G SA network built based on open-source Magma core, integrated with two open-source RAN software suites, OAI RAN and srsRAN. Using Proxmox for virtualization and a USRP X300 as the radio unit, multiple network configurations supporting end-to-end connectivity

```
ubuntu@magedemon:~/openairinterface5g/cmake_targets/ran_build/build$ ping 23.33.119.66 -i oaiun_ue1
PING 23.33.119.66 (23.33.119.66) from 192.168.128.14 oaiun_ue1: 56(84) bytes of data:
64 bytes from 23.33.119.66: icmp_seq=1 ttl=56 time=14.9 ms
64 bytes from 23.33.119.66: icmp_seq=2 ttl=56 time=15.2 ms
64 bytes from 23.33.119.66: icmp_seq=3 ttl=56 time=13.3 ms
^C
--- 23.33.119.66 ping statistics ---
3 packets transmitted, 3 received, 0% packet loss, time 2003ms
```

(a) Ping results before applying the policy. 0% Packet loss.

```
ubuntu@magedemon:~/openairinterface5g/cmake_targets/ran_build/build$ ping 23.33.119.66 -i oaiun_ue1
PING 23.33.119.66 (23.33.119.66) from 192.168.128.12 oaiun_ue1: 56(84) bytes of data:
^C
--- 23.33.119.66 ping statistics ---
9 packets transmitted, 0 received, 100% packet loss, time 8192ms
ubuntu@magedemon:~/openairinterface5g/cmake_targets/ran_build/build$
```

(b) Ping results after applying the policy. 100% Packet loss.

Fig. 8: Illustration of subscriber-specific IP access control.

have implemented and evaluated. A series of experiments have been conducted, assessing various performance aspects, including connectivity, capacity, QoE, and subscriber data rate management. Overall, the experimental results reveal that the developed network provides sufficient throughput and stability to support high-quality video streaming up to QHD resolution.

REFERENCES

- [1] Ericsson, "6G without the complexity: a simpler, single path from 5G", Jun. 2026, [Online]. Available: <https://www.ericsson.com/en/blog/2026/6/blog-6g-architecture-standalone-simpler-evolution-5g>
- [2] M. Wen, Q. Li, K. J. Kim, D. López-Pérez, O. A. Dobre, H. Vincent, P. Popovski, and T. A. Tsiftis, "Private 5G networks: Concepts, architectures, and research landscape," *IEEE J. Sel. Topics Signal Process.*, vol. 16, no. 1, pp. 7–25, Jan. 2022.
- [3] A. Martian, Razvan F. Trifan, Teodora C. Stoian, M.-C. Vochin, and F. Y. Li, "Towards open RAN in beyond 5G networks: Evolution, architectures, deployments, spectrum, prototypes, and performance assessment," *Comput. Netw.*, vol. 259, art. no. 111087, pp. 1–19, Mar. 2025.
- [4] F. J. de Souza Neto, E. Amatucci, N. A. Nassif, and P. A. Marques Farias, "Analysis for comparison of framework for 5G core implementation," in *Proc. Int. Conf. Inf. Sci. Commun. Technol. (ICISCT)*, Nov. 2021, pp. 1–5.
- [5] N. Aryal, F. Ghaffari, S. Rezaei, E. Bertin, and N. Crespi, "Private cellular network deployment: Comparison of OpenAirInterface with Magma core," in *Proc. 18th Int. Conf. Netw. Service Manag. (CNSM)*, Nov. 2022, pp. 364–366.
- [6] S. Hasan, et. al. "Building flexible, low-cost wireless access networks with Magma," in *Proc. 20th USENIX Symp. Netw. Syst. Design Implementation (NSDI)*, Apr. 2023, pp. 1–15.
- [7] K. Kaur, F. Guillemin, and F. Sailhan, "Live migration of containerized microservices between remote Kubernetes clusters," in *Proc. IEEE Int. Conf. Comput. Commun. (INFOCOM) Workshops*, Apr. 2023, pp. 1–6.
- [8] Youtube, "Relaxation Film (4k), Norway scenic relaxation film with peaceful relaxing music and nature video ultra HD", [Online]. Available: <https://www.youtube.com/watch?v=KLuTLF3x9sA&t=11400s>
- [9] Magma, "Install docker-based access gateway on Ubuntu", 2026. [Online]. Available: https://magma.github.io/magma/docs/ite/deploy_install_docker
- [10] OpenAirInterface, "OAI RAN", 2026. [Online]. Available: <https://openairinterface.org/ran/>
- [11] srsRAN, "O-RAN gNB components", 2026. [Online]. Available: https://docs.srsran.com/projects/project/en/latest/knowledge_base/source/gnb_components/source/index.html
- [12] Sysmocom, "sysmolSIM-SJA2 programmable SIM/USIM/ISIM cards," *Sysmocom GmbH*, 2026. [Online]. Available: <https://sysmocom.de/products/sim/sysmoussim/index.html>