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Heterogeneous signaling and user provisioning Traffic for 5G core network functional testing.

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***Abstract*—In the next 10 years, the telecommunication sec- tor will be dominated by the deployment ubiquitous networks available in a wide range of heterogeneous scenarios using 5G technologies SDN (software-defined networks), NFV (Network functions virtualization) and Network Sliding Technologies used by 5G will provide the "software" network functional elements that open up the network provider ecosystem to a large number of suppliers from traditional manufacturers to start-ups focusing on specialized functions. Due to the need to enforce the expected interoperability of the implementation and development of this set of network functions, the validation set Tools are needed to explore traffic patterns under different scenarios and thereby enable performance software modules to be evaluated. This research paper presents the design of software tools that aim to provide a way to generate signaling and user traffic in 5G networks, enabling the definition of new pure software test beds for 5G that includes real signaling and user traffic. The tools were designed to support a set of test signaling procedures that cover the basic core operation of 5G networks and which enable the transmission of user traffic over the network. The tools were implemented and licensed as Open Source and verified by deploying them in a virtualization 5G environment which includes the core 5G network.**

***Index Terms*—SDN, NFV, 4G-LTE, Network Virtualization.**

I. INTRODUCTION

The gradual deployment and use of 5G technology have brought new conditions to the telecommunications industry, such as the development of IoT networks and other new ser- vices. Chapter 5G Deployment, Chapter 5G Non-Standalone Network (NSA)[1]. With this technology, operators such as Telecommunication are working with and promoting 5G pene- tration with over 75Percentage coverage [2] in Spain. Vendors are using the 5G standalone (SA) version in the future [3]. But this first use of 5G is not "true 5G", there is 4G LTE infrastructure based on at the base that provides innovation. Users will try to increase the bandwidth, but the promise of 5G is not yet supported to reduce latency. The design of Chapter 5G core reflects requirements compared to previous models, including the concept of separation of user traffic and guidance (Control/User Plane Separation, CUPS) supported by a software-defined network (SDN) in Clause. Virtualization (Network Functions Virtualization, NFV) and Deployment of Private Networks (Network Slicing), with a clear commit- ment to the use of server-based equipment. Infrastructure

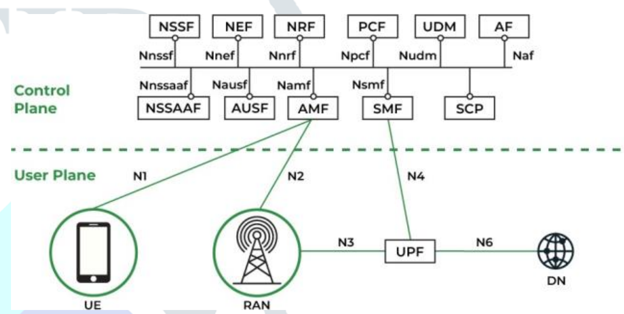

Fig. 1. 5G

provides computing power (CPU), storage capacity (memory) and communication capacity (network) for the performance of critical functions (NF). This innovation can reduce the dependency on a few specialist hardware companies, thus opening the normally closed market in communication from the professional company to new markets. This is a well- known "network software" that aims to provide software-based network functionality running on a cloud-like infrastructure. Use of open interfaces Core architecture defined by 3GPP and Open RAN [4] This is the problem of new efforts to distribute radio access, so some of it will be on the server farm which is the link to the model interaction [5]. New participants: telecommunications operators will be able to choose different software components for these ritualized networks, developing more flexible and secure networks since they will not have a single provider.

- Reduction of the development cycle and implementation of new functionalities: allowing advanced functionalities such as network automation, self-optimization of radio resources, coordination of radio access nodes, and exposure to third-party multi-access edge computing applications through open Ap- plication Programming Interfaces (API), and their integration with virtualization core and transport networks.
- Resource sharing: Improving coverage in rural areas with difficult access or low population density, in which a sharing model is more profitable, such as in dense urban places where a large number of small cells is required.

The new requirements and challenges that arise from the use of these new technologies make it necessary to design and develop tools that can be used to test the different scenarios that will emerge, in terms of performance, security, architecture, etc. The current state of the 5G technology, along with the cost of actual 5G infrastructure deployment, makes it difficult to provide efficient ways to test the 5G environ- ment. Taking advantage of the network software process, it is possible to develop testing environments that implement the main functions of the network, at a reasonable cost and with a commodity-based infrastructure. Many proposals for the development of 5G core network functions have been proposed in the last years, but it is necessary to design and develop infrastructure around the core to build a functional test environment, including ways of measuring tests, capturing traffic, and generating traffic in the 5G network. This document provides a solution to this kind of requirement system that helps in testing and evaluation processes emerging 5G Core solutions. This environment will based on a set of network functions (NFs) derived from a vendor ecosystem, guaran- teeing responsiveness to various load scenarios or conditions as well as capability exchange of data traffic and functional traffic testing 5G access network. We focus on the design and development of specific tools that can be used to inject traffic into the network with regard to signaling and user traffic which would be routed through the 5G core. This approach is interesting and novel due to the lack of currently available tools designed specifically for defining software-based test scenarios in 5G networks. Moreover, this type the tool can be used for other scenarios such as cyber security training at Cyber Ranges. Our development was released as open source and is accessible in [6]. The remainder of this document is organized as follows:

- In Part I we present a background study of the 5G enabling technology and the resulting scenarios a new type of network.
- In Part II, we provide a survey of related works on available tools for testing the 5G environment and we will briefly describe the main software base implementations.
- In part III we present the proposed architecture system and its relationships with the 5G core and others 5G infrastructure and more detail about each of them one of the two tools making up the system (for signaling and user traffic).
- Section IV describes the deployed virtual test environment and how our design supports embedding signaling and user traffic in the network.
- In Section V, we present the validation of the designs by conducting experiments using a test environment.
- Finally, in Section VI, we present the main conclusions and future work for this line of research.

II. RELATED WORK

This section describes the available testing tools. Classifica- tion in 5G environment and part of it The open-source platform is available for deployment 5G main network.

A. 5G Testing tools

Given the relative novelty and specific challenges associated with 5G technology, it is essential to anticipate various tools and methods for testing and evaluating these networks, taking into account the difficulties associated with their deployment real infrastructure for these purposes. In this part we will review some of the main tools developed to help with testing of 5G networks, providing an overview of the topic and con- textualizing our proposal. According to the survey presented in [18], it is possible Categorize 5G testing into four main areas:

- Technology Testing: Related tools and methods Testing 5G Multiple Access, Adaptive Beamforming, Full duplex radio technology, etc. In general, anyone Testing the technical aspects of 5G networks.
- Application Testing: Tools and methods for testing appli- cations running over 5G networks Different scenarios (NB-IoT (Narrow band IoT), M2M (Machine to Machine) communica- tions, vehicle communications, etc.).
- Architecture testing: tools and methods that are intended To test 5G architecture, such as novel air interfaces, core infrastructure, network slicing, etc.

Device Testing: Tools and Methodologies Used test the equipment needed for 5G deployment networks (antennas, terminals, base stations, etc.). Regarding technology testing, there are studies and analyses on multiple access techniques in 5G [19][20] proposals for techniques and tools for measure- ment aspects of beamforming on 5G [20] or the use of small cells deployment for radio access testing [19]among others research proposals. Application testing on the other hand does was the target of various proposals, such as [18] where the authors propose the development of a 5G network for testing applications, or [24]where they offer an an integrated end-to- end platform based on vertical use cases (energy, transport, Industry 4.0, etc.). Actually these types application-oriented end-to-end designs can also be seen as architectural test tools because they allow kernel testing features and general architecture of 5G.

III. 5G CORE SOFTWARE-BASED PLATFORMS

This research work aims to provide tools for 5G test scenarios, implementation of the core network Functions are required in the 5G core. Several platforms are being offered to deploy 5G core networks, which can Commercial and open- source projects will be categorized. Getting access to SA 5G is very difficult these days Core platform. Therefore, using this platform a A way to enable full test scenarios deployment. most of Available platforms are still under development and are Intended to offer interfaces and functions as defined by 5G Standards are being developed as pure software solutions that can Will run on commodity hardware. Using this platform, it is Possible:

- Development of vendor-independent software integration, openly accessible to anyone. Initial assessment of interoper- ability and functionality developed
- Availability of simulated platform to facilitate Develop- ment of tools and services that can be repeatedly tested in real environments. Currently, there are various efforts in the

development of 5G platforms or associated equipment, distinguishing open-source solutions or license proposals. Among the solutions based on open source, the following Stand out:

• Open Air Interface [17], led by universities and companies such as EURECOM, Fujitsu, Interdigital, Orange, Qualcomm, and Nokia Bell-Labs, among others, have been Presented as a flexible platform for research, it can be Used to define realistic and controlled scalable scenarios. Recently, Open Air Interface has been connected will offer a fully open-source 5G platform called Fire Cell Private 5G [19]. Free5G Core [14], which is led by several universities in Taiwan With support from the Ministry of Education, Science And technology, and economic affairs, is a project The aim is to release a fully open-source 5G core network, as defined in the 3GPP standards.

• Open5GS [3], a project that aims to provide users with Simple Way to Deploy NR/LTE Network, Implementation a A complete 5G core using C as the programming language. In addition, there are some proposals for the simulation of 5G network, rather than the full implementation of the network Works This is a simulation case of 5G k-SimNet [12]. Based on, a platform developed by Seoul University Extending the NS3 simulator to evaluate end-to-end Performance in 5G networks. On the other hand, the open The Networking Foundation (ONF) has introduced open-source The 5G connected edge platform, called Aether [3], includes 5G core network among other cloud-based functionalities For edge computing.

A. PROPOSED ARCHITECTUR

Functional testing in 5G networks requires a set of functions that enable the deployment of the basic 5G infrastructure and the subsequent creation of realistic scenarios. emulated through it. Some of these functions, such as virtualization of basic network functions or their creation virtual connections between them and with external networks can be achieved using existing technologies such as these discussed in the state-of-the-art section of this document. However, emulating user equipment and its behavior to define specific 5G traffic scenarios requires a design and the development of specific tools that can interact with virtualized infrastructure. We de- signed and developed tools accordingly for 5G signaling traffic emulation and tools for injecting diverse user traffic through the 5G infrastructure, which in conjunction with specific infrastructure can provide a full test platform for 5G. The goal of our proposal is, on the one hand, to mimic the signals of different user devices (i.e. establishing sessions, performing authentication operations, etc.) without using actual hardware devices or radio access networks, but an emulator directly communicating with the kernel. And on the other hand, The reason for embedding data traffic is to provide a flexible tool for generating different types of user traffic, and emulation of network usage in different cases. The operating environment. In this figure, we show the relationship between the designed components the so-called Signaling Traffic Generator (STG) and User Traffic Injector (UTI), and network work in the 5G core. Note again that the proposed solution does not require the use of a radio access network, nor base station for connection

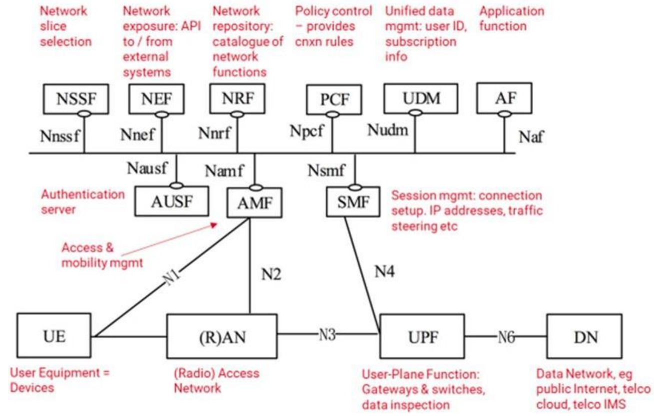

Fig. 2. 5G- core architecture.

emulated UE, thus providing a completely software-based an environment that can be easily virtualized. Our design has two main modules: • Signaling Traffic Generator: Contains functions required for simulating signaling operations In the core 5G network through the N2 interface. • User Traffic Injector: Contains functions required for simulating user data traffic exchange With internet via Core 5G using N3 interface. For the design of test equipment, it is necessary to define Terminal architecture that allows traffic growth An emulator for evaluating core network functions. To do this, 5G is based on a protocol stack of data and control planes. The protocol implemented by the tools are shown in Figures 7 and 8. As seen in these figures, Radio access protocol with direct access to N2 and N3 Interfaces have been replaced by STG and UTI. As explained Previously, this would have made it unnecessary to calculate the real Radio network or g NB nodes for the test environment. Modules are designed to implement protocols that allow signaling and user traffic communication. at the top This software can be used in general-purpose applications For configuring signaling traffic and user injection Traffic from external sources, depending on the scenario.

B. TESTING ENVIRONMENT

A prototype implementation of the proposal has been developed using the Go language for both STG programming. and UTI modules. The software is developed Released using an open source license and can be found in [6]. Implemented tools are integrated into testing scenario, based on a virtualized environment where we have deployed the implementation of a 5G core. As a 5G core, we have selected Free5GC [3] due to its maturity level and its open code philosophy. Moreover, we have used part of the implementation of the protocols from the Free5CG project in our prototype, in order to avoid a re-implementation of message structures and exchange mechanisms, building the software modules above the protocol implementation, especially in the case of the STG module.

The tools have been developed considering the virtualized environment which will be deployed along with the rest of the 5G infrastructure. We have used an Open Stack environment to deploy every 5G network function along with the tools. Each network function has been deployed as a separate Docker container, connected internally by creating virtual internal links between the NFs. The containers run inside an Open Stack instance, and each module can connect to the required NFs (AMF and UPF) through the instance's network interfaces. The modules have also been deployed as a different Open Stack instance, using Linux as the operating system.

To complete the testing environment, we have configured the UPF network function to be able to reach the Open Stack network through one specific instance interface, and eventually, reach the Internet through the virtualized environment Internet connection. Other Open Stack instances have been added to the environment to act as servers (web servers, video streaming servers, file sharing servers) and clients (traffic generation virtual machines that will generate the actual traffic to be sent to the UPF in the 5G core). These clients can act as main traffic generators (emulating the user traffic from specific UEs) or as background traffic generators (emulating other traffic that can be found in the network, that can be generated by synthetic models or by traffic re-injection, giving more realism to the scenarios). In the testing scenario, virtual networks are configured to be able to capture traffic at any point in the network, generating data sets for further analysis or other purposes. The integrated testing environment including the implemented tools and every other element in the scenario. As the diagram shows, the environment is basically composed of the 5G Core NFs running in different docker containers communicated internally through docker virtual networks, the software connecting clients running in Open Stack instances running user applications (web browsing apps, video streaming apps, etc.) or can run a traffic generation client, which can be used for instance for background traffic generation, depending on the specific testing scenario requirements, and a set of local servers. These servers can also run server-side apps such as web servers, streaming services, or traffic generation servers. The environment is also connected to remote servers and to the Internet, so any Internet-based services can also be included in the testing.

IV. EVALUATION

Using the test environment described earlier We have conducted a number of tests to validate the section Proposal functionality. First, for initial validation, we tested individually each of the use cases is defined for signaling efficiency. As the table shows, each test was related to basic functions carried out successfully. These tests are conducted by configuring the STG tool Only perform each operation that composes each use case. Exchange messages between STG software. STG/UTI implementation use cases validation results.

The AMF module has been monitored by capture and analysis Traffic using Wireshark. The results show that the message The flow is correct and in each case, the result (eg a new session is established), is expected. Another set of tests was conducted in the environment Regarding the validity of works related to User traffic. For this, we have selected some heterogeneous ones User-level applications that can be used by clients Virtual environment and then we tried to use it Through 5G infrastructure. Three different Scenarios considered:

- Web Browsing: We use the Firefox web browser In is installed in one of the client's virtual machines A test environment for browsing both local web pages Served from one of the servers in the environment, and Browsing Internet-based web pages, accessing them Log out of the Internet in an Open Stack environment.
- Video Streaming: VLC has been used for video streaming Between virtual machines in a test environment, Directing video traffic through the 5G core.
- File Downloading: Contains files located in virtual machines downloaded from the client's virtual machines. These tests are essentially based on determining, from a user point of view, that "normal" user behavior in a UE can be achieved using our tools. The "normal" user behavior means that it is possible to browse web pages, download files or watch video streaming with acceptable performance. The actual performance values were not measured in these tests, as the main goal was to validate the functionality of the STG/UTI modules. The actual performance tests were measured using pre-defined traffic profiles based on actual traffic captures, using a professional traffic generation tool, as will be shown later in this section. Again, results show that it is possible to use the designed tools to generate and inject real traffic of different types into the 5G network as it is summarized.

We have also tested the behavior of the environment when used with different heterogeneous traffic. To achieve this, we have established different types of traffic profiles based on the ITU recommendations [16, [15], and then we have tested them using a synthetic traffic generator. For these tests, we have used the IXIA Breaking Point tool [12], which has been integrated into the virtual testing environment and configured to send traffic through the STG/UTI software. The traffic profiles for these tests were selected in order to cover the main types of traffic that could be considered in most scenarios are the following:

- Conversational traffic: Real-time human-based conversations, such as VoIP services, interactive games, etc. This type of traffic requires limits in delay and packet loss. A profile based on a capture from Google Hangouts conversations was used for this test.
- Interactive traffic: Used by request and response end-user services, such as chat messages, interactive web browsing, voice messaging, etc. This kind of traffic requires a low BER and a low Round Trip Delay, as it is very sensitive to transfer delays and packet loss. To test this type of traffic we have used a model based on capture for IRC chat.
- Streaming traffic: Mainly unidirectional traffic with high utilization and low time variation within a single flow. Basically, any real-time traffic where delay, jitter, and packet loss rate are not strictly limited, except for QoS requirements. In this case, traffic from Netflix streaming has been used to carry out the test.

- Elastic traffic: Used by store and forward services, like FTP file transfer, or e-mail downloading. It can be transported at random transfer rates, and it tolerates delay and jitter. However, data loss cannot be permitted, meaning that a packet recovery system is usually needed (adding more delay to transmission). It might require high bandwidth due to the size of the exchanged files or messages.

In order to test this type of traffic we have used a profile based on captures from G talk calls. Using these profiles we have carried out different tests, obtaining the results summarized in Table 5. To emulate each type of traffic we have used specific profiles from real-life applications that are available within the IXIA Breaking Point tool that has been selected for each traffic type as shown in the previous paragraphs. Although measuring the maximum performance of the tool is not the main goal of these tests, we measured the Throughput (Mbps) and Frame rate (fps) for each test, in order to validate that the performance was sufficient to carry each type of traffic. The results show that it is possible to use the proposed software to inject virtually any type of traffic in the 5G corenetwork, with highly stable results in terms of throughput andframe rates, regardless of the actual traffic profile used in the tests.

In order to complete the evaluation process, we have defined general metrics to determine if the designed tool and the developed prototype meets the minimum required performance values to be used in virtualized realistic environments, taking into account that the testing environment has not been designed for performance tests and the available resources might not be up to real-life environmental standards.

- Regarding the number of required instances for a testing environment to work properly, we have determined that at least one instance for each NF in the 5G core should be able to be deployed (although in our testing scenario we deploy NFs as containers within a single virtual instance), and a set of virtual instances that work as clients, emulating UEs within the environment. This means that the virtual environment should be able to deploy around 20 virtual machines. Optionally, a set of virtual instances containing servers or routers could be needed in the platform.
- We have tested the limit in the number of clients that can be connected concurrently with the STG/UTI deployment. We found that it is possible to connect up to 15 clients to A single STG/UTI, and above that number receives a performance downgrade.
- About the average throughput that can be obtained By using a virtualized infrastructure and directing all traffic through STG/UTI software, tests show that The average value will be 0.65 Mbps, which will be of course Each depends on a specific deployment resources case.

V. Analysis

Using the test environment described above section we performed several tests to verify design functionality.

First, we tested individually for initial validation each of the use cases defined for the signaling functions, obtaining the results shown in Table 3. The table shows each test related to the basic functions was performed successfully executed. These tests are performed by configuring the STG tool to perform only each operation that makes up each use case. Exchange of messages between STG software. STG/UTI implementation use case validation results. The AMF module was monitored by capturing and analyzing traffic using Wireshark. The results show that the message flow is correct and that the result in each case (eg new session is established), is expected. Another set of tests was performed in the environment regarding the validation of functions related to user traffic. For this, we selected some heterogeneous ones user-level applications that clients could use virtual environment and then tried to use them through 5G infrastructure. Three different ones scenarios were considered: Web browsing: We use the Firefox web browser installed on one of the client VMs in test environment for browsing a local website served from one of the servers in the environment a browse and access websites through Internet output in the Open Stack environment.

- Video Streaming: VLC was used for video streaming between virtual machines in the test environment, routing video traffic through the 5G core.
- Downloading files: Files located in virtual machines have were downloaded from client VMs These tests are based on determining, from a from the user's point of view, the "normal" behavior of the user in the UE can achieve with our tools. "Normal" user behavior means it is possible to browse websites, download files or watch streaming videos with acceptable performance. Actual performance values were not measured in their tests because the main goal was to verify functionality STG/UTI modules. The real performance tests were measured using pre-defined traffic profiles based on real captured traffic using a professional traffic generation tool, as will be shown later in this section. Again, the results show that it is possible to use the designed tools to generate a put real traffic of various types into the 5G network. Conversational traffic: Real-time human conversations such as VoIP services, interactive games, etc. This type of traffic requires delay and packet throttling loss. Profile based on Google Hangouts recording Conversations were used for this test.
- Interactive traffic: Used by end-user services based on requests and responses, such as chat messages, interactive web browsing, voice messages, etc. This kind of traffic requires low BER and low round trip delay as it is very sensitive to transmission delay and packet loss. To test this type of operation we used a model-based capture for IRC chat.
- Streamed traffic: Mostly one-way traffic with high utilization and small time variations within a single stream. Any real-time traffic where there is lag, jitter, and the packet loss rate is not strictly limited, except for QoS requirements. In this case, traffic from Netflix streaming was used to perform the test.
- Flexible operation: Used by store and redirection services, e.g FTP file transfer or email download. It can be transmitted at random baud rates and is delay tolerant and nervous. However, data loss cannot be allowed, ie that a packet recovery system

(add longer transmission delay). May require high bandwidth due to the size of files or messages exchanged. We used a profile to test this type of traffic based on intercepted Gtalk calls.To complete the evaluation process, we have defined generic metrics to determine whether a designed tool a taking into account that the test environment was not designed for performance tests and available resources may not meet the standards of the real environment.

- We determined the number of instances required for the test environment to function properly that at least one instance for each NF in the 5G core should be deployable (although in our testing scenario we deploy NF as containers within one virtual instance) and a set of virtual instances that are running as clients, emulating the UE in the environment. This means that the virtual environment should be capable deploy approximately 20 virtual machines. Optional set a virtual instance containing servers or routers needed in the platform.
- We tested the limit on the number of clients that can be connected simultaneously to the STG/UTI deployment. We found that up to 15 clients can be connected A STG/UTI will give you a functional decline above this number. Average power obtained Using a virtual infrastructure and sending all traffic through STG/UTI software, testing showed: The average value is 0794 Mbps, of course It depends on each specific deployment source.

CONCLUSION

As shown by the results from the previous section, tools proposed in this research were verified in a realistic visualize scenario. Validation shows that the designed tools can generate 5G signaling traffic that can be used emulate the signaling process from real UEs and gibs in 5G networks. In addition, the tools can forward any user-generated traffic from any network application that could be deployed in a user emulation environment traffic from one or more UEs in the network. In other words, the developed software can use signaling messages to perform the main required functions for UE emulation in the network (such as registration UE, PDU session management, etc.) and enables injection of user traffic into the network that can be obtained from a heterogeneous origin (for example, user applications, traffic generation tools, or traffic playback tools). Validation tests show that the main signaling processes (such as registration, PDU session management, etc.). and that they can communicate effectively with NF core, generation of new sessions for UE a allowing capture, encapsulation, and other user traffic sent to the corresponding UPF in the 5G network. The design of the STG/UTI software enables extremely flexible way of defining different traffic profiles or mixing to be used in the test processes of 5G networks. His a design that emulates signaling but leaves the generation of user traffic to another instance or set of instances facilitates this use or develop specific applications to generate user traffic depending on the requirements of each scenario. We have ran tests using the IXIA BreakingPoint traffic generator to inject different types of traffic into our test scenario, obtaining similar results for each type of operation and verifying the functionality and flexibility of the tool. further we tested real applications such as web browsers or video streaming tools to determine if traffic can be embedded into the network. The results also show that there is limited throughput we can achieve this with our tool, which could lead to some limitations on the scenarios where the tool can be used. This limitation was identified as creating a bottleneck available resources of the basic implementation which we use for testing purposes and also for centralized approach followed by our proposal in STG/UTI tools. The the first cause of this limitation can be overcome by assignment more resources to the kernel (which could be created in different virtual instances or even on different physical servers, due to the modular nature of NF). Could be more UPF is used in the scenario to balance the traffic that passes through core. On the other hand, centralized design STG/UTI and its scalability limitations can also be avoided using more than one instance of the STG/UTI tool deployed in in the same or a different virtualized environment. Considering all this communication between STG/UTI instances, clients emulating UE user applications and basic NF (AMF and UPF) are based on IP links and that management UE is performed in core NF, it is possible to run more than one instance of STG/UTI tools at the same time. Another limitation of these tools is related to the types of user traffic that can feed into the 5G core and receive back to emulated UEs. Although any type of application traffic can be sent through our tools, traffic must be sent to STG/UTI in IPv4 datagrams such as software currently ready to capture IP traffic (more specifically, Ethernet frames containing IP datagrams) and uses ARP for determining the physical destination of the return traffic from the 5G core to client virtual machines. In each case, with some modifications, our proposed tools should be able to use specific mechanisms used by traffic packets send to the kernel (eg IPv6) as long as it can encapsulated in GTP- U tunnels. The work presented here can be further improved functionality conditions (adding new signaling use cases, for example) and performance. For the others as future work, we intend to explore the possibilities of implementation STG/UTI function using a dedicated programmable Hardware. Another line of future work is based on designing scenarios where this tool can help in testing 5G networks, especially in the cyber security environment. Finally, we also plan future research, use designs presented here in an early evaluation of mobile devices networks over 5G.

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