Demonstration of 5G Core Software System in India's Indigenous 5G Test Bed

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***Abstract*—This demonstration will present the operation and main features of the 5G Core software system based on 3GPP Release 15/16. The system is being developed as part of the Indigenous End-to-end 5G Test Bed project, led by IIT Madras. The 5G Core is based on Network Function Virtualization concepts and Service Based Architecture (SBA). The main features which will be demonstrated are UE Registration, Deregistration, PDU session and QoS Flow Establishment, Modification and Release.**

I. Introduction

There has been significant activity during the past several years in defining the 3GPP standards for the fifth-generation of cellular networks or the 5G Networks [1], [2]. 5G Networks are designed to overcome many limitations of 4G and promises much higher bit-rates, lower latency and better connectivity. 5G networks are expected to substantially enhance the experience of mobile users and devices, with definition of services such as Enhanced Mobile Broadband (eMBB), Massive Machine Type Communication (mMTC), and Ultra-Reliable Low Latency Communication (URLLC).

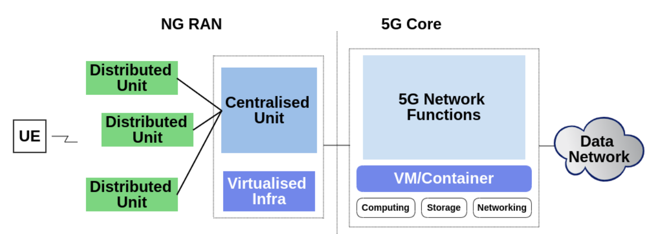

Fig. 1. Overview of 5G System Architecture.

The major components of the 5G System Architecture are Next Generation-Radio Access Network (NG-RAN), Transport, and 5G Core, as shown in Fig. 1. The end devices (smartphones, smart devices and others), termed as User Equipment (UE) communicate with the Remote Radio Heads (RRH) at the base stations, with some of the NG-RAN processing being done at the Distributed units (DU), and the rest in the Centralised units (CU). The DUs and CUs can be virtualized and the CUs can be deployed in a cloud data center. The Centralised unit of NG RAN communicates with the 5G Core over the Transport layer, which can be using various technologies like mmWave, Carrier Ethernet and Optical Network technologies. The 5G Core is fully virtualised and realized using different network functions (NFs) using containers or Virtual Machines. The 5G Core is connected to the Data Networks such as Internet, Intranet, IMS etc.

In 2018, the Department of Telecommunications (DoT) funded a large scale 5G test bed project, titled "Indigenous End-to-End 5G Test Bed Project" [3], [4]. The end goal of this project is to create 5G prototypes and a test bed setup. The test bed development is being led by IIT Madras and is jointly developed with institutions including IIT Bombay, IIT Delhi, IIT Hyderabad, IIT Kanpur, IISc Bangalore, Center of Excellence in Wireless Technology (CEWiT) Chennai, Society for Applied Microwave Electronics Engineering and Research (SAMEER) Chennai, and leading industry partners including startups. UE nodes, MIMO antennae systems, Base stations, 5G Core and a basic Management system form the 5G test bed. The 5G test bed project focuses on building a test bed that closely resembles a real-world 5G deployment. This test bed could become a basis for many commercial deployments.

The proposed demonstration at COMSNETS 2021 will showcase the 5G Core (5GC) software system, developed by CEWiT, IIT Bombay and IIT Madras.

II. 5G Core System Components

The 5G system architecture is designed to support data connectivity and services that makes use of deployment techniques like Network Function Virtualization, Service Based Architecture and Software-Defined Networking (SDN). The 5G architecture aims to separate the User Plane (UP) functions from Control Plane (CP) functions which, allows for easier scalability, evolution, and deployment. Wherever applicable, the procedures (the set of interactions between Network Functions) are defined as services so their reuse is possible. The architecture supports "stateless" Network Functions that allow compute resources to remain decoupled from storage resources.

Fig. 2 shows a service-based representation of 5G architecture, where Network Functions allow authorized Network Functions to access their services. The various Network Functions that constitute the 5G core are described below and are all designed in compliance with 3GPP Release 15/16 [1], [2].

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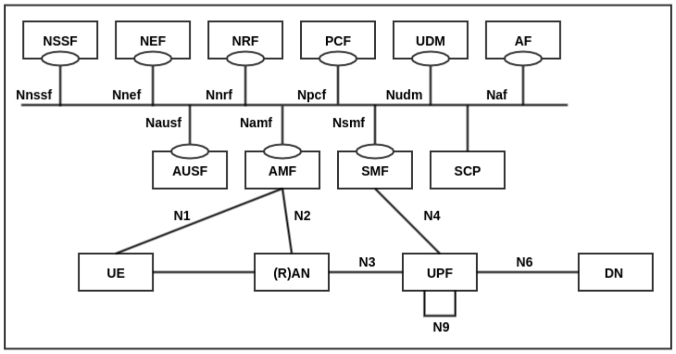

Fig. 2. Service-Based Architecture of the 5G Core.

AMF: The Access and Mobility Management Function (AMF) is primarily responsible for handling connection and mobility management tasks. Further, the AMF receives all connection and session related information from the User Entity (UE) and plays the role of an access point to the 5G core. The AMF also manages mobility, authentication, separate security context state of a UE connected via 3GPP, non-3GPP access or 3GPP access and non-3GPP access simultaneously.

SMF: The role of the Session Management Function (SMF) is to interact with the decoupled data plane, managing session context with User Plane Function (UPF), and creating, managing, and updating Protocol Data Unit (PDU) sessions.

UPF: The role of User Plane Function (UPF) is to process and forward user data. The UPF interconnects to the external data networks and serves as an anchor for the UEs with respect to external networks during the UEs' mobility. The UPF also handles Quality-of-Service (QoS) marking of packets, enabling them to receive appropriate treatment in the 5G Core and NG-RAN networks.

UDM: Unified Data Management (UDM) Function manages subscriber data for authorization, registration, and mobility management. It generates authentication credentials for UE Authentication. The UDM also stores the context from serving AMF for a UE and the serving SMF for a UE's PDU session. For each UE, the UDM stores the subscription data for both 3GPP and Non-3GPP access.

UDR: The Unified Data Repository (UDR) is used for the storage and retrieval of subscription and policy data. Subscription data includes the 3GPP and Non-3GPP context data, PDU session management data, and keys required for generating the authentication credentials. The policy data comprises the access and mobility related policies, session management related policies, and UE policies.

AUSF: The Authentication Server Function (AUSF) mainly acts as an authentication server. AUSF is responsible for authenticating the UE based on NF requests.

NRF: The Network Repository Function (NRF) maintains the Network Function (NF) profiles of the available NF instances and their supported services. Additionally, the NRF also supports the discovery of an NF instance based on certain criteria and records the status of the NFs periodically.

NEF: The Network Exposure Function (NEF) securely exposes the NFs capabilities and events for external applications. The NEF also provides a mode for the application functions to securely provide information to the 3GPP network. Additionally, the NEF may take care of Packet Flow Description (PFD) management and also handle the translation of internal and external information.

PCF: The Policy Control Function (PCF) is primarily responsible for maintaining a unified policy framework necessary to govern network behaviour. It is also responsible for making effective policy decisions using the subscription information from the UDR.

There are several other functions such as those dealing with data analytics and network slicing, but are not described here.

III. Features Supported in 5G Test Bed

The following 5G features have been implemented in the 5G indigenous testbed as of November 2020.

A. UE Registration

The registration call flow is the process to authenticate and authorize 5G services to a UE. UE registration procedure begins when a UE sends a registration request to the Radio Access Network (RAN). The RAN forwards this request to the AMF. Upon receiving the registration request, AMF discovers a suitable AUSF with the help of NRF and forwards the request to AUSF. AUSF, in turn, finds a suitable UDM with the help of NRF and the chosen UDM generates the authentication credentials. UDM returns these authentication credentials to the AUSF, which then forwards some of the keys to UE via AMF. The UE uses these keys to generate authentication credentials at its end and passes it to AUSF via AMF. After comparing the credentials coming from UDM and UE, AUSF sends an *Authentication Success* message to the AMF and the UDM. Once authentication is completed, Security in terms of Integrity protection and Ciphering is negotiated and activated (both for the Non access and Access stratum). AMF then requests UDM to provide the subscribed slice information for the UE. Upon receiving the response from UDM, AMF determines the allowed and currently rejected slices and forwards this list to the UE along with a *Registration Accept*.

B. PDU Session Establishment

On receiving a PDU Session Establishment request from UE via RAN, AMF discovers a suitable SMF that serves the DNN and Slice for the requested PDU session using the help of UDM and NRF. The AMF then requests the SMF to create a Session Management (SM) Context. Once the SM context is stored, SMF retrieves the SM data from the UDM and sends a response to AMF. SM data contains Service and session continuity (SSC) modes, PDU session types, and default QoS profile. SMF selects the UPF based on the slice and Data Network Name (DNN) information with the help of NRF. IP address for the current PDU session is assigned by SMF. SMF then establishes an N4 session with UPF with the appropriate Rules after which it sends a *PDU Session Accept* message back to the UE (via the AMF and RAN). SMF also sends an N2 PDU Session Resource Setup message to the RAN to setup appropriate radio related resources and trigger the corresponding air interface procedures. This also triggers the setup of the N3 GTP tunnels to exchange the user plane packets between RAN and UPF by communicating the tunnel information back to UPF via N4 session modification procedures. Now, the UE can send or receive packets to or from the Data Networks.

C. PDU Session release

Test bed supports a PDU session release procedure initiated by the UE. When this is received, AMF forwards the release request to the SMF, which then initiates an N4 session release request to UPF. Upon receiving the request, UPF drops any remaining packets and releases all tunnel resources and contexts associated with the N4 session and sends back a N4 session release response to SMF. SMF finishes the release procedure and sends the update back to AMF.

D. UE Deregistration

Upon receiving the request from UE, the AMF checks if there are any currently active PDU sessions for the UE. If there are no active PDU sessions, the AMF directly sends *Deregistration Accept* to UE and closes the connection between the UE, RAN, and AMF. If there are active PDU sessions, the AMF requests SMF to release the SM contexts. The SMF, in turn, requests the UPF for an N4 session release. UPF releases the N4 sessions as described above in Section III-C. Subsequently, UPF sends an N4 session release response back to SMF. SMF then sends back the SM context release response to AMF. On receiving the response from SMF, the AMF sends a *Deregistration Accept* to UE. UE registration and session contexts and resources towards RAN are released.

E. RAN Emulator

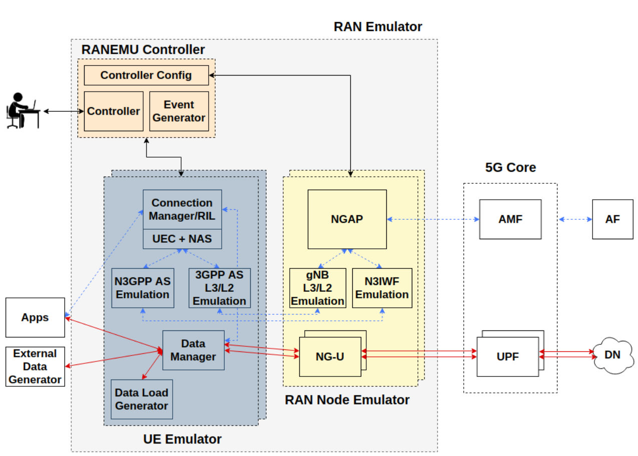

Fig. 3. RAN Emulator.

As part of the development efforts, there is a need to test and validate several functional and non-functional requirements. We have developed a RAN Emulator (RANEMU) that emulates thousands of UEs and a number of Access Network nodes such as gNodeBs or N3IWFs (non-3GPP Interworking Function for connecting over WiFi). The RANEMU has been developed in order to validate the 5G Core described earlier. This enables system testing without the RAN testbed components, that can be integrated later.

The RANEMU consists of: a) UE Emulators that run the complete NAS stack along with the higher layers and b) RAN Node Emulators that run the full NGAP stack to provide the N1 and N2 interfaces, respectively. It has the GPRS Tunneling Protocol (GTP) stack as the N3 interface for the User Plane. RANEMU provides the complete Non-Access Stratum (NAS) functionality while the Access stratum functionality is emulated. The key behaviours of the Radio Access Network are programmed in the UE and RAN Node emulators.

RANEMU can take inputs from third party applications enabling integration and demonstration of services such as IMS, Edge computing, Vertical Apps etc. Another unique facility provided by RANEMU is the creation of typical field scenarios by defining a set of procedures to be run automatically as configured by the User.

The overall 5G core system has been tested using the RAN Emulator for up to 1,000 UEs. Fig. 4 shows the screenshot of the RANEMU output for 100 UEs that go through registration, session establishment and release, and deregistration. The demonstration will present the details of the workings of the system.

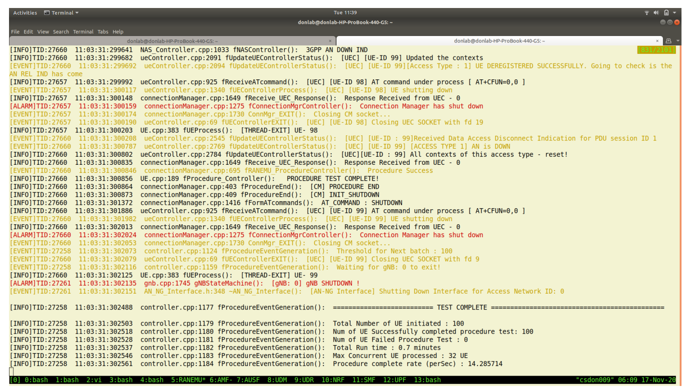

Fig. 4. Screen output, for testing with 100 UEs.

IV. Summary

This paper described the Indigenous End-to-end 5G Test Bed and, specifically, the 5G Core subsystem that has been developed. It currently supports procedures like UE registration, UE deregistration, PDU session establishment, PDU Modification and PDU session release. We intend to showcase our 5G test bed, exhibiting the capabilities of our system, through the demonstration of these procedures.

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References

[1] "3GPP Specification Set: 5G release 15," Apr. 2019. [Online]. Available: https://www.3gpp.org/release-15

[2] "3GPP Specification Set: 5G release 16," Jul. 2020. [Online]. Available: https://www.3gpp.org/release-16

[3] "Indigenous 5G Testbed project," Nov. 2020. [Online]. Available: http://www.ee.iitm.ac.in/5g/

[4] "Indigenous 5G Testbed project," Nov. 2020. [Online]. Available: https://cewit.org.in/testbed/