

# Designing, Dimensioning and Testing SDN-NFV Private Cloud Architecture based realisation of 5GC with IIOT, MCS, CV2X & VONR Service

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**Abstract** - This paper describes 5G Stand Alone (SA) Core network Solution dimensioning with compliance to 3<sup>rd</sup> Generation Partnership Program (3GPP) Standards which is a norm and requirement for Digital Private Networks (DPN) evolution across the globe in the segments of Oil and Gas, Electric Utility, Transportation, Ports, Mining etc. The 5GC aimed to be dimensioned is proposed on Service Oriented Architecture (SOA) Framework, High availability (HA) & Software Defined Networks (SDN) / Network Function Virtualization (NFV) and Multi-edge computing (MEC) attributes. 5G Core (5GC) Solution dimensioned for the DPN includes all the functional, parametric, and operational requirements. In this paper we have presented the Factors considered for Dimensioning of DPN Standalone (SA) core, Integration of 5G SA Core with the important verticals of DPN i.e., MCS (Mission Critical Services), IOT (Internet of Things) and C-V2X (Cellular Vehicle to everything), VoNR (Voice over NewRadio). Also, the paper covers the 5G Core network capacity design for an Oil & Gas(O&G) Network use case with Optimized selection of relevant VNF's. Also, the paper covers the Functional Testing, Interworking and parametric load testing aspects of the VNF's (Virtual Network Function) along with Interworking Functions (IWF) of the SA core network. 5G Core Network (CN) for Oil and Gas is designed and dimensioned to handle the capacities of 4k to 6k Voice & Data users and a max of 10k to 15k IoT devices which includes 100 to 500 MCS users and 500 to 1000 Connected Vehicles and other application services required for O&G networks to be supported on the core network with capabilities of corresponding VNF functions on 3GPP specified relevant Core network interfaces. 5GC Solution designed meets capacity requirements at a typical O&G network with efficient Data Centre subsystems from reputed OEM like Intel, Dell, HP, Cisco for realizing the DPN SA core solution.

**Keywords:** Digital Private Network, 5G SA Core, Oil & Gas, NFV-SDN, MEC, MCS, C-V2X, IIOT, VONR, CUG, Testing & interworking

## I. FACTORS CONSIDERED FOR REALIZATION OF 5GC SA SOLUTION

The 5GC solution is designed & dimensioned to support the relevant 5G core network functions, interfaces, and IWF support to realize MCS, C-V2X, IIOT (Industrial IOT) and Voice over New Radio (VONR) applications. 5G SA Core Solution is dimensioned to support 1+1 HA architecture for deployment as a part of Private cloud architecture-based SA Core hardware subsystems to host all the relevant VNFs. The 5GC Solution designed is also envisioned to support distributed MEC functionality at 2 geographically distributed locations having a homing relationship to a cluster of Radio Access Network (RAN) subsystems covering connectivity for VONR, MCS, C-V2X, IIOT applications.

VNF dimensioning and hosting is also meant for distributed core network functional realization to have call and session

control with focus on network latency and High availability and maintainability. The 5G core network is proposed in SA mode with support of the critical parameters & Functionalities of 5G Core NW Layer conforming to 3GPP Rel15/16 standards & requirements to ensure interworking with other dependent VNFs.

The 5G Core is dimensioned to support VNFs classified under 4 major categories such as Mobility and Connection control, Session and Data Processing, 5G Service support, and 5G Business enablement functions.

1) Mobility and connection control VNFs [2] dimensioned to handle the relevant type of traffic as - Access Mobility Function (AMF), User Plane Function (UPF), Authentication Server Function (AUSF), Unified Data Management (UDM), Unified Data Storage Function & Unified Data Repository (UDSF&UDR), Equipment Identity Register (EIR).

2) Session control and Data processing with embedded Deep Packet Inspection (DPI) VNFs identified as - Session Management Function (SMF), UPF and Network InterWorking Function (N3IWF)

3) 5G Service support VNFs for network information and exposure functions identified as - Network Exposure Function (NEF) & Multi-access Edge Platform (MEP).

4) 5G Business Enablement VNFs [2] for charging, policing and Network slicing identified as Policy Control Function (PCF), Network Repository Function (NRF), NEF, Network Slicing Selection Function (NSSF).

5G Core also supports Application Function (AF)s such as IIOT, MCS, C-V2X, and VONR. Such AFs are hosted as software applications on a separate set of hardware servers with Virtual Machine (VM) capability in the private cloud architecture based 5GC.

5G Core is dimensioned to handle a total number of 4k to 6k Voice & data users and 10K to 15K IoT devices, 100 to 500 MCS users and 500 to 1000 Connected Vehicles. 5GC is proposed to be evolved by appropriate selection of the number of cores to be supported as Central Processing Unit (CPU) platform with corresponding memory to support the number of signaling channel transaction, control channel transactions and bearer channel transactions. 5GC solution is also considered to support diverse and extreme requirements for latency, throughput, and Quality of Service/Quality of Experience (QOS/QOE) needs as per the services and application needs for Oil and Gas segment. The 5GC Core network solution is considered to support all relevant Interworking functions (IWF) on 3GPP identified interfaces to host different Application Functions such as MCS, CV2X, IIOT and VONR.

## II. SELECTED VNFS FOR RELAISING 5G SA CORE SOLUTION

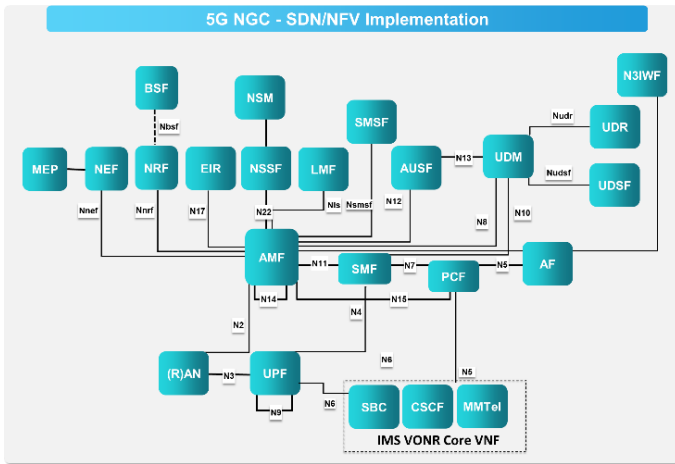


Fig. 1. 5G StandAlone Core Virtual Network Functions and Network Interfaces[1][2][5]

The 5G CN is proposed to be designed with identified NfV modules conforming to SOA on 3GPP defined interfaces as mentioned in the figure above[1][2][5]. The 5G SA Core architecture is finalized to support VNFs classified under 4 major categories such as Mobility and Connection control, Session and Data Processing, 5G Service support, and 5G Business enablement functions. The AF function indicated above will cover one each of the application namely MCS, IIOT, CV2X and support the IMS VONR Core VNF feature.

## III. MCS INTEGRATION TO 5G CORE NETWORK

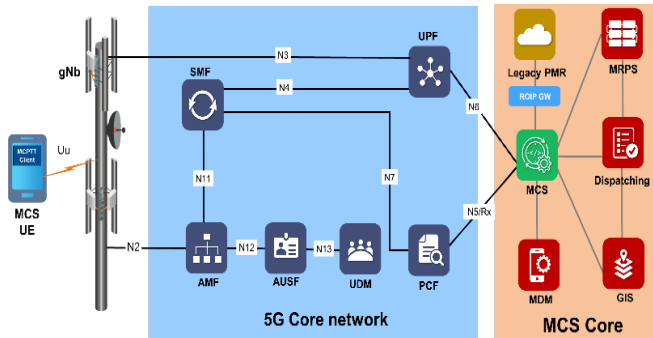


Fig. 2. Mission Critical Services Integration to 5G Core Virtual network functions

The MCS Application Function (AF) is realized as a critical element in the design and dimension of DPN's Core. The MCS AF will interface to 5G CN on 3GPP defined N5/Rx & N6 interfaces towards PCF & UPF respectively for bearer traffic channel origination and termination towards User Equipment (UE) with associated policy charging features.

Policy charging features such as Close User Group (CUG) calls, Unicast, Multi-cast & Broadcast call, Group call and Mission Critical (MC) Video calls and MC Video streaming/surveillance services. The MCS service is proposed to be enabled through 5G core function for call establishment, signalling & control through the functions of AMF, SMF, AUSF, UDM. MCS Data carrier functionality is supported through UPF on N6 interface towards MCS core. MCS Core functional modules include Dispatching function, Recording & Announcement function (MRPS), Global Information System (GIS) function for location identification and Mobile Device Management (MDM).

MCS core also supports ROIP (Radio over IP) gateway function for interworking with legacy Terrestrial Radio Access (TETRA) Public Mobile Radio (PMR) network. MCS AF is

also designed for configuration support of UE based Client application for invoking MCS service through the air interface supported by the gNodeB (gNB) through Uu interface. MCS AF function and its associated VNF modules like MDM, MRPS, GIS, Dispatching Gateway and ROIP (Radio over IP) Gateway are also hosted in a co-located cloud architecture-based server and storage farms alongside private cloud architecture based 5G CN.

## IV. IIOT INTEGRATION TO 5G CORE NETWORK

Industrial IIOT applications in Oil and Gas segments covers the control of valves at the oil well with corresponding flow meter and associated temperature and pressure measurements.

Such IIOT functions like valve control, flow control, temperature control and pressure control are enabled through corresponding Digital Twin enabled sensors to realize 5G enabled Machine Type Communication (MTC) application[3]. Such IIOT devices are usually enabled through configuration control with authentication function as any other UE type and/or with application enabled on corresponding Element Management System (EMS) of the IIOT application of the 5G network.

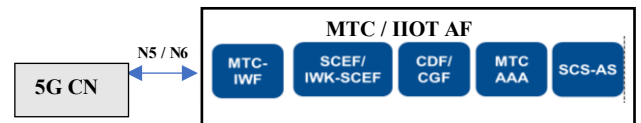


Fig. 3. Machine Type Communication Integration to 5G Core Virtual network functions

The Oil and Gas segment MTC/ IIOT Service support design consists of VNF subsystem modules like MTC- IWF, SCEF (service capability exposure function), CDF (charging data function)/CGF (charging gateway function), MTC Authorization, Accounting, and Authentication (AAA) & Services capability Server (SCS)- Application Server (AS).

The MTC Application in the external network is typically hosted by an AS and may make use of an SCS for additional value-added services. The AS communicates directly to the private network to perform direct user plane communications with the digital twin enabled IIOT device through corresponding radio interface without the use of any external SCS[3]. MTC-AAA supports the Authorization, Accounting, and authentication of IIOT devices.

The CDF/CGF modules are also identified to be a part of the IIOT AF. These modules are selected appropriately to understand the patterns of data rates that are accumulated by different IIOT components and thus CGF will collect and store the CDR's and perform the relevant correlations as needed for Billing. The control, Signalling and Bearer path channels involving data traffics types ranging from Low Kbps to medium Mbps to high n\*Mbps are supported through the corresponding standard VNFs from AAA to policy charging enablement.

SCEF is an essential IIOT VNF to enable the data and signalling paths of IIOT devices from the application function to the 5G CN through MTC-IWF. Thus, the 5G Core network is also complemented to support IIOT traffic handling capability through the massiveMTC(mMTC) applications services function of 5G as per 3GPP Rel 15/16. IIOT bearer signalling, and control channel traffic handling network functions are supported through by hosting on servers like SCS/AS through MTC AAA, CDF/CGF, SCEF, SCS-AS, MTC-IWF.

## V. C-V2X INTEGRATION TO 5G CORE NETWORK

C-V2X functionality in Oil and Gas segment based DPN envisages the functional utility of connected vehicles with ADAS (Automotive advanced driver-assistance systems). This feature of C-V2X is enabled by 5G connectivity interface units embedded in the vehicle namely On-Board Units (OBUs) with corresponding client application.

C-V2X application function (AF) in an Application Server (AS) as a part of collocated C-V2X application server with corresponding storage. The V2I (Vehicle to Infrastructure (RSU)), V2V (Vehicle to Vehicle), V2N (Vehicle to Network (AS)) and Vehicle platoon use cases are proposed to be supported on C-V2X application.

Emergency warning, emergency stop, crash sensing, Collision warning, wrong way drive warning, curve speed warning, road user monitoring, traffic flow optimization are some of the V2V, V2I and V2N use cases proposed to be supported by the network control commands directed towards C-V2X enabled vehicles.

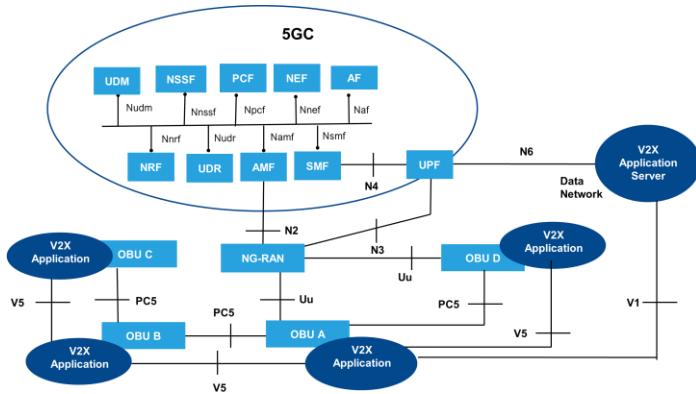


Fig. 4. Cellular- Vehicle to everything (C-V2X) Integration to 5G Core Virtual network functions

Every connected Vehicles/Trucks which is part of the DPN will be equipped with OBU to enable the C-V2X Communications. Roadside units (RSU) are required to communicate with OBU on the air interface and operates at Global Intelligent Transport System (ITS) Frequency Band of n47 5.9GHz and works independently of the cellular networks. The OBU talks to the RAN over the Uu interface and 2 OBU's communicate with each other via the PC5 interface. The C-V2X application server directly communicates to the UPF (Data plane network) on the N6 interface as shown in the above diagram.

The C-V2X functionality realized and supported through an AF on a server which supports application influence on traffic routing, accessing NEF & interaction with policy framework for policy control. The PCF provides the UEs with authorization and policy parameters for V2X communication over PC5 and Uu. The NRF helps other NFs choose the appropriate PCF based on corresponding CV2X capabilities.

C-V2X is supported with 5G Universal Subscriber Identity Module (USIM) by Uu interface which can store one 5G security context for 3GPP access networks and one 5G security context for non-3GPP access networks.

## VI. CAPACITY BASED CORE NETWORK IMPLEMENTATION FOR AN IMPORTANT USE CASE SCENARIOS IN DPN – OIL & GAS NETWORKS

### A. Factors considered for 5G Core network Design and Dimensioning of an Oil and Gas DPN

5G SA Core network Design and Dimensioning is done for an Oil & Gas sector spread across a few thousands of oil wells with corresponding tens of Industrial facilities over a cluster of Industrial Operational areas with built in Road network supported by 5G RAN enabled DPN.

The 5G SA Core Network is proposed to be Designed and Dimensioned to handle VONR, MCS, IIOT and C-V2X applications and services. Each of these varied applications and services are designed and dimensioned to handle simultaneous

traffic handling capacity from 4k to 6k voice users, 100 to 500 MCS users, 500 to 1000 CV2X enabled cars and trucks and about 10k to 15k of digital twin enabled industrial sensors based IIOT devices and other IOT application services. Industrial IOT devices include O&G assets with digital twin enabled sensors in Rigs, Reservoirs, Refineries and Gas Pipelines. The Other IOT applications in the O&G segment include drones, Video surveillance cameras, Inspection Robot/Automated Guided Vehicle (AGV), C- V2X etc. and these are considered for dimensioning of 5G Core network.

TABLE I. DIMENSIONING OF USERS, IIOT DEVICES & OTHER IP ENABLED AND 5G CONNECTED END DEVICES

End user Device (Voice & Data + IIOT + Other application devices)	Dimensioned Range
HD Camera for surveillance	150-300
Process Sensors as Digital twin for 3Rs (Rigs, Reservoirs & Refinery)	5k - 10k
Smart connected workers (SCW) with Mobile/Tablet	150 - 300
Smart connected workers (SCW) with Wearables	150 - 300
Smart connected workers (SCW) with Virtual Reality (VR)/Augmented Reality (AR) Headset	100 - 200
MCS Users	100 - 500
UAV/Drone	50 - 100
Inspection Robot/Automated Guided Vehicle (AGV)	10 - 50
Vehicle C-V2X (Connected Vehicle)	500 - 1000
Total Number of IOT Devices	10k to 15k
Number of 5G Voice users at Operational HQ (Head Quarter) and Industrial Operational areas	4k to 6k

Each of these types of devices and users contribute to the types of control channel transaction handling, signalling channel transactions capability and user/bearer channel capacity handling. Simultaneous and concurrent loading of the 5G Core network VNFs is estimated considering the above user capacity details in the table above.

The critical VNF sub systems are realized considering the call/IP session control-establishment message transactional loading and the corresponding interconnection to 3GPP defined interfaces between the VNFs (ex: SMF to AMF, AMF – UPF, SMF- UDM, SMF-UPF, NSSF- AMF etc.), message communication protocol handling capability. Each of the type of traffic, service and application requires different processing speeds to ensure low latency in call/session establishment and control[5]. Such latency and call control parameters with corresponding latency requirements dictate the type and selection of the number of cores of the CPU and clock speed.

Thus, the total design and dimensioning study of the 5G CN SOA performance capability involves the assessment and estimation by considering the user/device capacities to be supported in the network. Each of the applications and services type of traffic to be handled in the core network supporting varied user plane bandwidths with corresponding Uplink/Downlink (UL-DL) ratio, as indicated in the table below are also considered for dimensioning of the 5G Core network performance capabilities of the VNFs and the corresponding cloud architecture-based server and storage farms.

The cloud architecture considered for realization of 5G CN involves functionalities such as IaaS (Infrastructure as a service), PaaS (Platform as a Service) and SaaS (Software as a Service) on containerized micro services model.

TABLE II. COMMITTED INFORMATION RATE (CIR) BANDWIDTHS FOR END USER DEVICES AND IIOT APPLICATIONS

End user Device (Voice & Data + IIOT + Other application devices)	B.W(Mbps)		DL (%)	UL (%)
	Min	Max		
Processor Sensors including Refinery, Pipeline, Gas Station & reservoir	0.05	5	10	90
High Definition (HD) Video Surveillance Camera	1	10	10	90
Inspection Robot/UAV (Drones)/AGV	1	10	50	50
Smart connected workers with Mobile/Tablet	1	10	70	30
Smart Connected Workers (SCW) with Wearables	1	2	10	90
AR/VR Headset	50	100	50	50
MCS	0.1	5	30	70
Vehicle C-V2X (Connected Vehicle)	1	10	50	50

B. 5G Oil and Gas Network - Core Capacity Dimensioning for Voice, Data, Video Surveillance, MCS, C-V2X and IIOT

The factors at section (A) as above are considered for capacity dimensioning of the 5G CN. The selection criteria-based dimensioning of the servers is indicated below

TABLE III. CRITERIA-BASED DIMENSIONING OF THE SERVERS

5G Oil and Gas DPN - Core capacity & Server Dimensioning for hosting the VNF's for supporting Voice, Data, IIOT and Other Application services	Traffic Throughput capacity
Assumed per user data and voice targeted speed (for 4k to 6k users)	10 Mbps
Assumed Targeted speed per IIOT device (weighted average)	5 Mbps
Total Targeted Speed for (Surveillance Camera, SCW, MCS, Mobile Devices, Drones/UAV/AGV and Robotics, Connected vehicles AR/VR Headset)	140 Mbps
RAN capacity (for 600 gNBs with 800Mbps speed per sector and each gNB having 3 Sectors) built up over an operational area of tens of 1000s Sq.km with built in road network	1500 Gbps
Required Capacity - at 5 Mbps Max B.W per 12k devices IIOT device (Always ON Basis for IIOT 1:1 and no Contention)	(12K * 5Mbps) = 60Gbps
Required Capacity @ 140Mbps total capacity for other application services such as (Surveillance Camera, SCW, MCS, Mobile Devices, Drones/UAV/AGV and Robotics, Connected vehicles AR/VR Headset) – 3k Devices	(3k * 140Mbps) = ~400Gbps
Required Capacity @ 10Mbps for 5G Voice & Data for (including of Control, Signaling & Transmission Nw) – 6k Users	(6k * 10 Mbps) = 60Gbps
Total Required Core Nw Capacity for Voice, Data & IIOT & Other envisaged use case applications including all Signaling, Control, Tx for 5G	520 Gbps
For 5G Core Nw Deployment we have considered Industry standard Servers (each 14 Cores, 128 GB Random Access Memory (RAM), 2TB Hard Disk Drive (HDD), CPU speed of 2.1GHz) which is estimated to support traffic Throughput of 80 Gbps with 100% DPI (deep packet inspection) for slicing support and supported control plane transactions per second at 240K.	7 + 7 14 Servers (for High Availability)

Thus, we conclude that a total of 14 Hardware Servers with the relevant configurations as mentioned are required to support the capacity requirements and on a High Availability (HA) and redundancy Architecture. The VNF's (AMF, UPF, AUSF, UDM(UDSF&UDR), EIR, SMF, UPF, PCF, NRF, NSSF, MEP, NEF and N3IWF.) as required to support the application services and use case needs will be loaded onto the servers.

Figure below shows the architecture finalized with the required VNFs, AFs, and the interfaces between VNFs and AFs. Private cloud architecture-based Industry Standard server and storage farms are used to realize Standalone 5G CN for Oil and gas DPN. EMS software for different Network Element,

Layers, Services and Applications is also hosted on the same cloud architecture-based server farm.

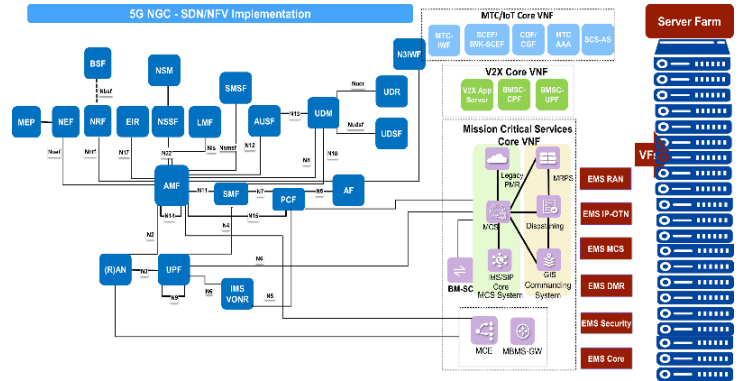


Fig. 5. 5G Core Network Interworking with Mission Critical services, Machine type communication and Cellular- Vehicle to everything (C-V2X) hosted on Server Farm

VII. FUNCTIONAL TESTING AND INTERWORKING OF THE VNF'S ALONG WITH PROTOCOL CONFORMANCE OF THE CALL/IP SESSION CONTROL

5G Core network consisting of VNFs as shown above is tested for the Standalone VNF functionality and performance.

Each of the VNFs are also tested for its interface related integration with other VNFs with appropriate message communication protocol as per 3GPP defined conformance testing procedures. The VNFs are also tested for its interoperability with corresponding IWFs for support of services and applications like MCS, CV2X, IIOT and IMS for VONR

The core network VNF scope of testing involves the following

- Protocol conformance testing and Functional testing of each of the VNFs with relevant interface paths and the associated protocols corresponding to 3GPP standards is carried out as a method before the deployment of such DPNs.
- Virtual Network function creation and testing for realizing of end-to-end signalling, bearer and control traffic and message flow
- Capacity and capability Handling testing of each of the VNFs.
- Interoperability testing of the RAN to the CN

A. Protocol conformance Functional testing of Core Network

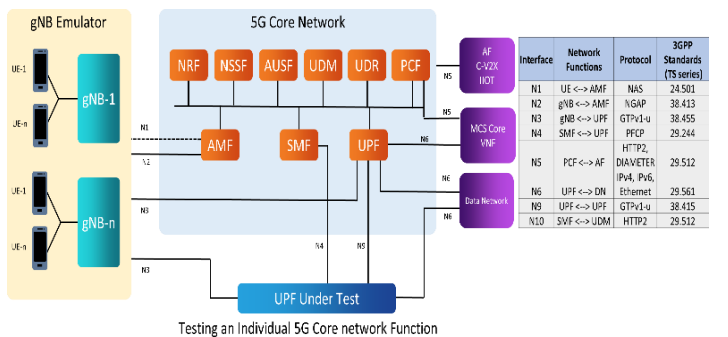


Fig. 6. 5G Core Network User Plane Function Protocol Conformance testing setup

The above diagram shows the protocol level testing carried as an example for one of the VNF such as UPF[4][6]. The UPF is tested on the N5 and N6 interface to the AF and MCS core interoperability with the associated message communication protocols as shown in above diagram. The same process of testing is repeated for testing each of the critical VNFs such as AMF, SMF, NSSF, UDM, etc., by corresponding message flow

communications and protocol conformance between the VNFs. Each network interface as mentioned above is tested with the relevant protocols defined as per 3GPP standards and the message flow logs are stored and analysed.

### B. Parametric Load (Capacity Handling) testing of Core Network

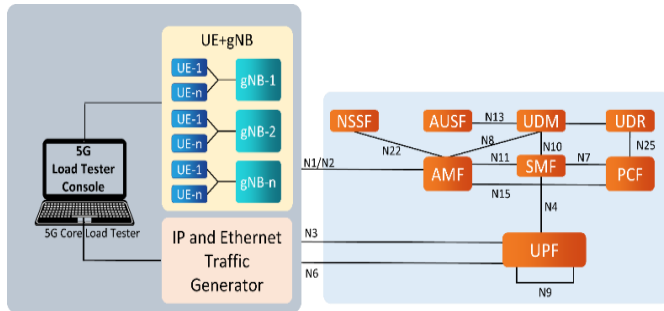


Fig. 7. 5G Core Network Parametric Load Test setup

The above diagram shows the parametric load testing that is carried out on the 5G Core network with all the relevant VNF's[4][6].

A traffic generator in conjunction with UE and gNB emulators are used to generate the total amount of traffic (control and user plane) for Voice, Data, IIOT, MCS, C- V2X and other application services as mentioned in the capacity dimensioning table in above section VII - A & B and the core network VNF's are tested on the Interface and Protocol level layer 2 and 3 to handle the traffic without any congestion or network degradation.

5G load tester console is used as a platform to configure, test, and manage different VNFs with corresponding interfaces between relevant VNFs and associated message communication protocols. The load and traffic handling at each of the VNF is analysed based on the control, signalling, and user plane message flow between network interfaces with corresponding message communication protocols.

### SUMMARY

The paper summarizes the Design and Dimensioning of 5G Standalone, Private Cloud, MEC, SDN/NFV enabled Core Network solution for Digital Private Network. The paper also realizes the design and dimensioning of 5G SA Core architecture for Oil and Gas industry DPN on HA (High Availability) and maintainability features in conformance to 3GPP Rel.15/16 VNF functions for call control and session control to support applications like MCS, CV2X, VONR and IIOT. Optimum selection of the 5G SA core network having all the relevant VNFs (AMF, UPF, AUSF, UDM(UDSF&UDR), EIR, SMF, UPF, PCF, NRF, NSSF, NEF, MEP and N3IWF) to support application bandwidth requirements for MCS, C-V2X, IIOT and VONR services are addressed. The 5G Core network dimensioning is realized for 4k to 6k voice and data users, 10k to 15k IoT devices which includes 100 to 500 MCS users and 500 to 1000 Connected Vehicles (CV2X) and other applications services as mentioned in the end use devices table. Thus 14 Hardware Servers with relevant configurations (each 14 Cores, 128 GB RAM, 2TB HDD, CPU speed of 2.1GHz) from industry standard Original Equipment Manufacturers (OEMs) is proposed to realize the 5G SA Core based on Private Cloud Network architecture to support the user and application bandwidth requirements in the Oil and Gas networks. Protocol conformance functional testing of 5G Core Network for all the relevant VNFs is performed to ensure protocols at each network interface including interface to AF through IWF are in conformance with 3GPP standards. Parametric Load testing of 5G core network is performed to ensure the traffic load

handling capabilities are supported as per the capacity requirements for Oil and Gas networks.

### REFERENCES

- [1] 3GPP TS 23.501 - System architecture for the 5G System
- [2] 3GPP TS 29.507 - Access and Mobility Policy Control Service
- [3] "Digital Twin for the Oil and Gas Industry: Overview, Research Trends, Opportunities, and Challenges" IEEE Published By - THUMEERA R. WANASINGHE, LEAH WROBLEWSKII, BUI K. PETERSENI, RAYMOND G. GOSINEI, LESLEY ANNE JAMESI, OSCAR DE SILVAI, GEORGE K. I. MANN, AND PETER J. WARRIAN.
- [4] "5G CORE TESTING CONSIDERATIONS" Daniel Musat, Keysight.
- [5] 3GPP TS 23.501 – Procedures for 5G System
- [6] "5G Core Network Validation" - Keysight