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SDN Integrated 5G Network Architecture: A Review, Benefits and Challenges

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Abstract

The scenario of modern day internet communication system has been changed drastically. Billions of hyper connected devices carrying huge amount of information on either side. Next generation devices are much of IoT enabled and automotive in nature demands much higher data speed with low latency. In addition, these modern tech shifts need such a network, which is much flexible, radio resource effective, dynamic, programmable and simplified in nature. Several exertion has been carried out to establish a next generation network architecture, which are operator centric. 5G technology deployment with full IP connectivity has been done in some countries but not flawless. Evolved Packet Core (EPC) associated with 3GPP release 15 has been orchestrated. In this context, we will inspect a decentralized 5G architecture, which is accredited with Software Defined Networking (SDN) and Virtualized Network Function (VNF). A cloud based distributed architecture with dispute is manifested. A comprehensive study of research work so far has been accumulated in the context of architecture, network management and functionality.

Keywords: Software Defined Networking (SDN), Evolved Packet Core (EPC), 5G, OpenFlow, ForCES

I. INTRODUCTION

Due to ever emerging growth of data communication over the internet, the next generation network requires high data rate with low latency and enhanced Quality of Service (QoS). A new architectural proposition is necessary to fulfil this resource constraint requirement. IP based 5G network is proposed to include all types of advanced dominant technologies. Nevertheless, to support different application specific service management with reliability and ensured QoS, standardize new architecture is still a challenge. Cloud computing, Internet of Things (IoT), Software defined Network (SDN) now becoming an indispensable core technology for 5G network. However, the standardize endeavor for 5G are still under its arrival and complete realization is forecasted in 2021 in South Korea, Japan China and US[1]. Future networks for last couple of decade demand more heterogeneous support where connected users ranging from wired, infrastructure based (e.g. celluar-based network, wireless mesh network) to infrastructure-less, wireless network (e.g. mobile ad-hoc networks, vehicular). Main issues to handle this kind of networks is the resource utilization efficiently especially in the case of wireless multi-hop ad-hoc network as the wireless capacity by default limited. That too has to be achieved in ultra-high data speed. The expected data rate is 30.6 exabytes produced by the mobile data traffic with mean connection speed of 3Mbps up till 2017[2].

The answer for all these demand is Software Defined Network (SDN) and Network Virtualization Function (NVF). Software Defined Network gradually becomes main source of attraction from both industry and academic. SDN has the potential to ease the installation and efficient management of network application and service with better efficiency. Most witnessed application of SDN is came into light in data center and cloud computing [3]

Rest of the paper is organized as follows: Section II describes the detail literature review about the integration of cellular network with SDN. Section III describes the difference between the features of traditional network and SDN enabled network. The detailed structure of SDN architecture is described in section IV. Section V explains the different proposed SDN integrated 5G architecture. The challenges and the different design issues are elaborated in section VI and finally section VII is the conclusion of the paper.

II. LITERATURE REVIEW

A. Cellur Network Architecture through SDN

The first manifestation of SDN enabled celluar network was initiated by LiErrant et. Al. in [4]. They name it CellSDN. Policies for each attribute defined for individual user in the LTE network. Radio Access Network (RAN) individually handle network as a collection of base station in which cross functionality is hard to obtain due to distributed coordination algorithm.

Manipulation of distinct flexibility can enhance network performance. Soft RAN is proposed by S. Tomovic et al. in [5] used SDN principle in 4G LTE network.

SDN and SDR are integrated in 5G architecture is proposed in [6] called hybrid SDN/SDR. It exploits frequency spectrum and link information in 5G network. The controller distributes the allocation of frequency spread spectrum and the flow of traffic in an efficient way.

SoftAir [7] by Ian F. Akyildizet. al proposed the 5G network exploiting virtualization for a strong network. It provides efficient load balancing and resource allocation. Entire phenomenon can be done through logical realization. Different algorithm and protocol has been established in virtual network.

Next generation network architecture design parameters like higher capacity, higher data rate, low latency, a large number of device connectivity, less expenditure and operational cost of the network operator should be addressed. A generalized software defined wireless network architecture with common Core Network (CN) functions along with design consideration have been presented in [8]. CN functionalities and a number of Radio Access Network (RAN) defined by a single SDN controller named as Software Control Radio.

Software Control Radio, an integrated management of celluar network proposed in SDN&R [9]. Radio status and information in the control plane maintained by SDR and it is implemented in base station (BS). Radio allocation accomplished by OpenFlow enabled control plane in base station (BS).

B. Cellur Network Management through SDN

Jararweh et al. in [10] proposed a framework model for IoT management and control based on SDN. Different configurations of SDSys (SDN, SDStore and SDSec) advocated and elaborated. Data is collected from the sensor board and send to IoT bridge. This information is passed to SDSec in next phase where SDSec is a variant of SDSys. A database is maintained to authenticate the device.

M. Boussard et al. [11] introduced SDN based network management, control and solution for IoT devices where many devices connected together in a smart environment. By imposing SDN principle and logical abstraction of the devices, a software-based solution proposed named as “Software Defined LANs (SD-LAN)”. This plan uses Universal Plug and Play (UPnP) and Simple Services Discovery Protocol (SSDP) for finding new devices. Author also the shown prototype implementation for home network.

C. Network Security Management through SDN

Security issue is an important concern in celluar data network. However, it has not discussed much latest research papers. Aaron Yi Ding et. Al. discussed security concern for wireless mobile network [12]. Author advocates that the way forward is to integrate SDN and fully utilize its feature to solve the problem.

As far as the security, concern SDN enabled network subdivided into enterprise networks, cloud & data center, home & edge access and general design. For enterprise network Ethane controller [13] impose the network security better than OpenFlow controller does by considering central network management, regulation and authentication process.

Another endeavor is Resonance [14] which apply SDN to control the access of IoT devices dynamically in enterprise or campus environment. It embrace dynamic policy specification framework and rely on OpenFlow based programmable switches and controller for distributed network monitoring. The key point of Resonance is dynamic access control in which network devices can treat traffic differently by following the controller's view toward end host's security class and state.

The recommendation of SDN based implementation of four algorithms for Anomaly Detection System (ADS) and prescribes software based solution for more specific identification of malevolent activity in a home network environment is represented in [15]. It is proved to be better that which is being deployed in ISP. These algorithms can reduce the extra burden of ISP from monitoring a large number of home network. This work need modification of control plane.

OpenFlow Random Host Mutation (OF-RHM) [16] mutates the IP-address of end host randomly and frequently such that launch of attack based on static IP fails. This mutation of host IP address based on probability algorithm enable to hide the end host from adversaries' scanners. This technique is transparent to the host. To provide transparency host's real IP address (called rIP) keeps intact but OF-RHM associates each host to a random and short-lived virtual IP address (called vIP). These vIP are translated to rIPs before the host and IP mutation is done with high unpredictability at a very high speed to distort the attacker's knowledge and increase dissuading attack planning. OF-RHM based on OpenFlow controller but does not consider the feature of local optimization, mobile scenario or cross- domain interoperability.

NetFuse [17] another proposal for cloud and data center based environment where large network suffers failure and performance deformation due to external (e.g. DDoS attacks) and internal (e.g. workload changes, operator error, routing misconfiguration). NetFuse lies between switches and controller of OpenFlow network. To relieve the large network pressure from the controller and improve the efficiency NetFuse uses three steps: (1) Uses OpenFlow control message to determine a number of active network flows. (2) To identify the overloading behavior NetFuse uses a multi-dimensional, flow aggregation special algorithm, which detect only the cluster of active flow. (3) NetFuse deploy toxin-anti-toxin mechanism that adaptively modify the data rate to resist the malicious flows. NetFuse also rely on the OpenFlow standard but does not modify the control plane and data plane.

CloudWatcher [18] a new framework based on SDN constantly keep an eye over services in a large and adaptive cloud network. CloudWatcher controls the data flow to remove all unnecessary data packet inspected by some security device. It writes a policy script language to empower network administrator use this framework without any difficulty. This framework does not change control and data plane but utilizes routing algorithm for security monitoring.

III. SOFTWARE DEFINED NETWORK (SDN) VS TRADITIONAL NETWORK

In traditional network data packets transmitted from point-to-point through routers and those routers governed by routing protocol like ICMP, TCP/IP etc. Routing protocol creates table to find the best route to transmit data packets. Router transmits data packets with header to adjacent router and determine the best route or less congested route to the destination. This can be accomplished by control plane of the each router. By this way router transmits data packet to the end user as shown in fig. 1. On the contrary, of this if receiver send acknowledgement or any information to the sender it is not necessary that data packet have to be travelled through the same route. It depends on the particular router each time.

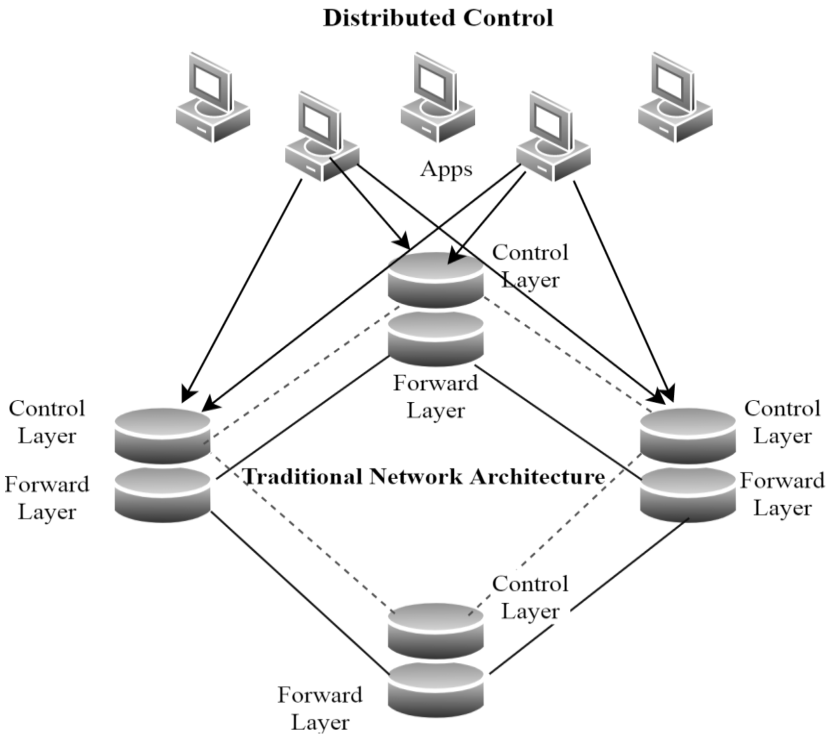

Fig 1. Traditional Network Architecture

In counterpart of this scenario, Software Defined Network (SDN) divides each router in control plane and data forwarding plane. Control plane is responsible for finding out the less congested route and act like a brain of the router. On the other hand, data forwarding plane only forward the packets. In software defined network (SDN) traditional routers replaced by SDN enabled router where data-forwarding plane only resides in the router and control plane replaced by a centralized SDN controller, which acts like a brain of the entire router as exhibited in fig. 2. All the routers connected with the SDN controller either physically or through cloud. Since the routers exits only with data forwarding plane, it can be replaced by normal switch with TCAM hardware. Whenever data packet need to be transmitted, the SDN controller predetermines the best route. Therefore, routers do not have to check routing table before forwarding to the adjacent router. The biggest advantage of this, it enhances fast forwarding of data from one end to other. Routers from different vendors or different models of the same vendor comes with five hundred pages of data sheet with it. As the network expands, network engineer have to configure each router individually. This overhead burden minimized if all routers replaced by SDN enabled router and SDN controller. In addition, routers which re very costly in the market replaced by normal switch, so this type of arrangement is very cost effective. Once the SDN controller established in the network, network security is also centralized. Proper firewall deployed in the SDN controller to drop the unwanted data packet.

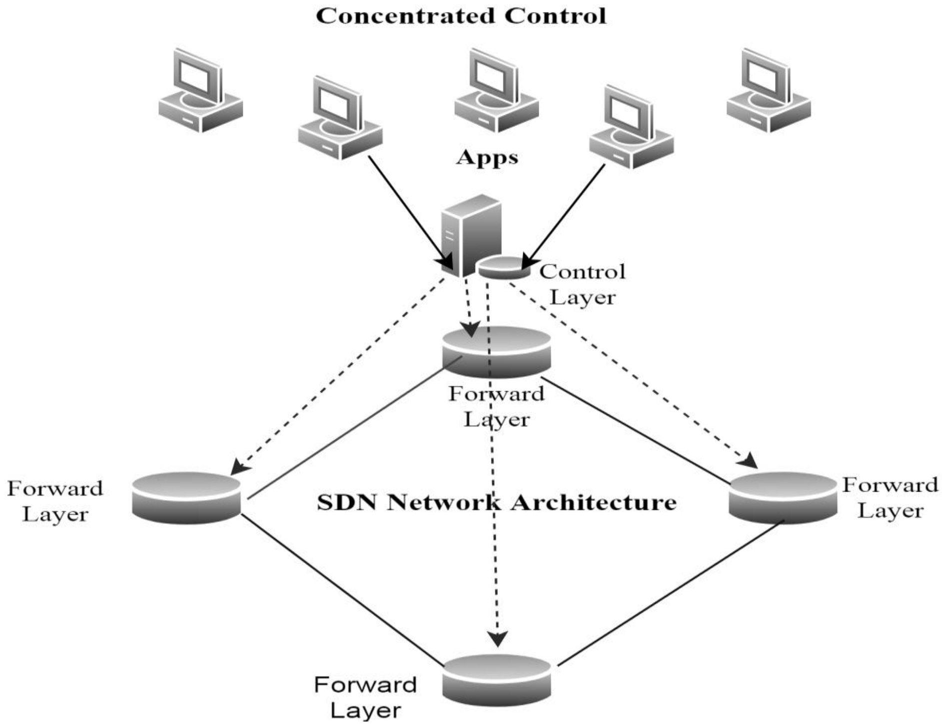

Fig. 2 Software Defined Network Architecture

IV. SOFTWARE DEFINED NETWORKING (SDN) ARCHITECTURE

SDN is three-layer architecture (1) Data plane layer, (2) Control plane/controller layer, and (3) Application layer depicted in fig. 3. SDN layers communicate each other layer via open API called Northbound Interface (NI) API and Southbound Interface (SI) API.

There are two well-defined architecture has been realized yet, ForCES and OpenFlow. These are software-based controller. In case Forwarding and Control element separation (ForCES) the separation between forwarding and control element remains same as per the basic concept SDN.

Communication carried out through ForCES protocol and the protocol based on master slave model where forwarding element (FEs) are slaves and control element (CE) are master. ForCES relies on logical functional block.

In the counterpart OpenFlow, securely communicate with the controller layer via open flow protocol. OpenFlow controller deals with flow tables where flow entries were written. Whenever data packets arrived, header field extracted from packets and matched with the field entries in the flow table. For successful match with flow entries the proper switch act according to the instruction predefined by the controller whether to forward or drop the packet. Now a day's many controllers are available in the market such as OpenDaylight [19], Floodlight [20] and NOX/POX [21] etc.

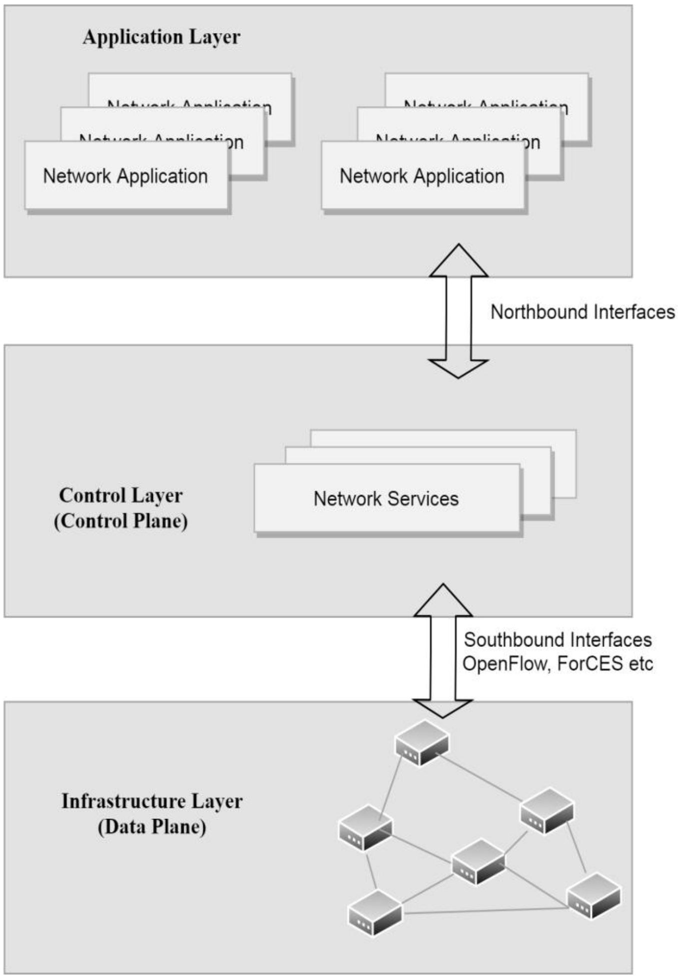

Fig. 3 Software Defined Network Architecture

V. SDN INTEGRATED 5G NETWORK

In coming day's celluar network will be consists of much of the IoT based user equipment like appliance control system, mobile devices, tablets, industrial automation device, drone, IoT enabled medical devices, agricultural equipment which are on move. For these kinds of next generation devices, network accessibility will play a huge role. Celluar network consists of two parts Radio Access Network (RAN) and Mobile Core is as same as presently existing 4G network depicted in fig. 4.

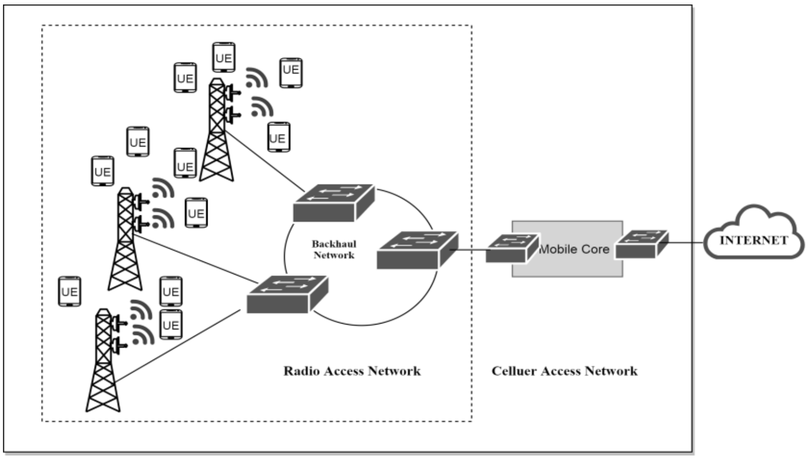

Fig. 4. Celluer Network with RAN and Mobile Core

In this context realization of the SDN integration in 5G will be depicted in two parts.

A. Network Design through SDN

Radio Access Network manages radio spectrum and meets the demand of every user and mobile core network decides the switching of packets efficiently. The drastically changed next generation network architecture (e.g. 5G) is that the whole network does not rely on routing and switching technologies anymore [22]. Next generation network will be able to provide open communication system to cooperate with satellite system, celluar network, cloud and data centers. The main feature, which empowers of flexible network, is to add programmability. 5G architecture have (i) different feature for one or more network functions according to the service provided (e.g. different mobility management procedure for different types of traffic) and (ii) to re-design network functions without the need of deploying new hardware entities to run such functions. The term flexibility be well accomplished by disaggregating control plane and user plane by software-defined networking (SDN) enabled routers. The integration of SDN in 5G architecture adds dynamicity as it enables network administrator to establish link and path configuration and placement of different functionalities only to the core Network. Depending upon traffic computation capabilities disaggregation of U/C plane is implemented and is placed at the edge of the network [23]. Core Network is distributed in nature with a distributed core network entities and central cloud. User centric information while establishing call setup and data connection are stored in a central cloud addressed by a central cloud SDN controller. Whereas core network SDN controller looks after core network entities, which is again distributed in control plane and user plane entities. Entire core network orchestrated by a central SDN controller. This enables VNF manager to deploy functionalities across virtualized infrastructure. Enhancement from 4G to 5G empowers Radio Access Network keeps as intact while changing decentralized core network furnish a complete new method and means to deploy network services, attenuate cost and boost up performance. Total scenario has been depicted in fig. 5.

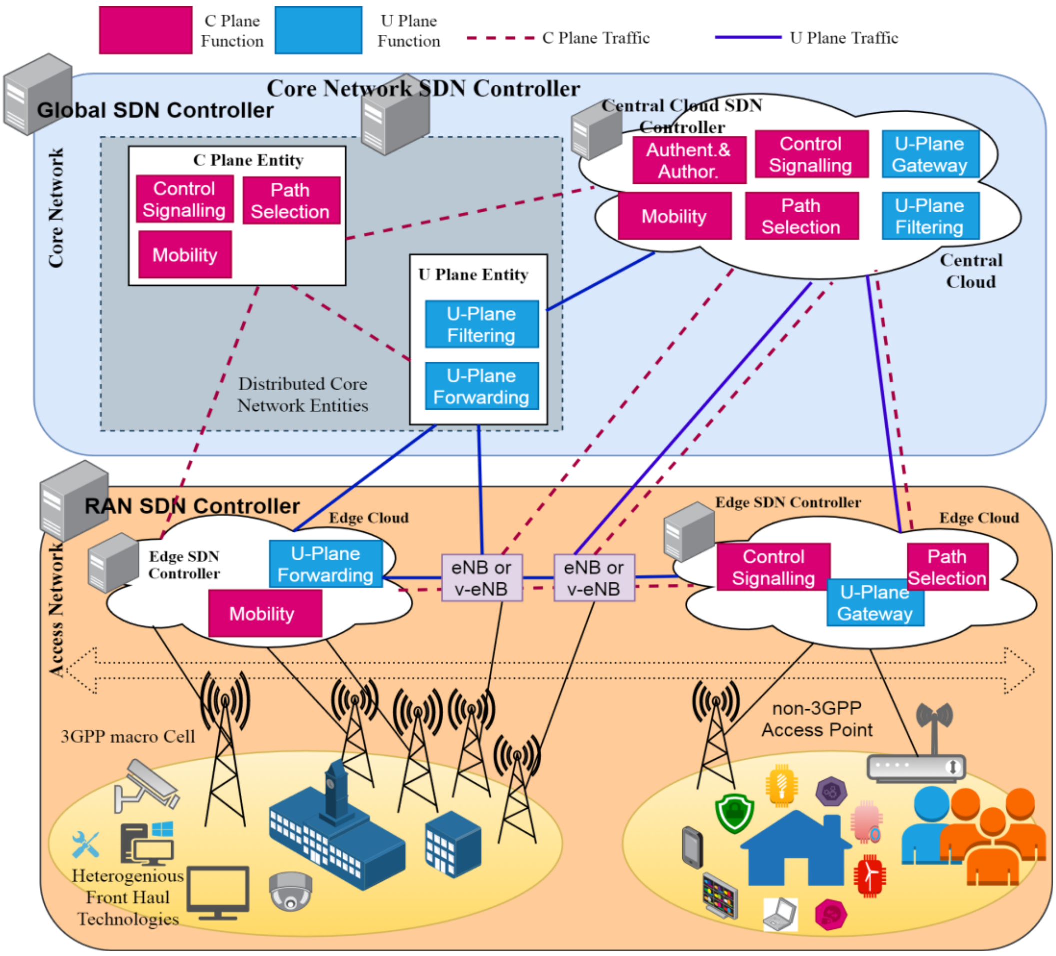

Fig. 5. SDN enabled 5G Architecture

B. Network Functionility through SDN

5G mobile core which 3GPP calls as NG-Core (next generation core) which adopts micro service based functionality. Following are the first group of functional block run in the control plane and counterpart run in Evolved Packet Core (EPC) illustrated in fig. 6. EPC is the 3GPP's released version 4G. 5G Core is a new network architecture introduced in the 3GPP Release 15. A bus is connected to the every block for traffic forwarding.

- AMF (Core Access and Mobility Management Function): Deals with connection establishment, mobility management, user authentication and authorization.
- SMF (Session Management Function): Deals each UE (User Entity) session

including proper allocation of IP, selection of UP function, QoS and control aspects of UP routing.

- PCF (Policy control Function): Manages the policy rules of other CP function and employ.
- AUSF (Authentication Server Function): Essentially an authentication server.

Second group also run in control plane but not direct counterpart run in EPC

- UDSF (Unstructured Data Storage Network Function): “Helper” service used to store structured data in SQL Database” in a micro service based system.
- SDSF (Strutted Data Storage Network Function): Same like UDSF unless structured data
- NEF (Network Exposure Function): Responsible to select capability to third party services including preparation of translating internal and external representational of data.
- NRF (NF Repository Function): Responsible to invent available services. This block can be deployed as a “discovery service” in a micro service based system.
- NSSF (Network Slicing selector Function): Responsible to select logical network slice to serve a given UE. It is a means to allocate different network resources allocated to different user. NSSF completely depends upon the service provider.

Third group runs in the user plane

- UPF (User Plane Function): Acts as bridge between RAN and internet and forward the traffic to both the side. It is similar to S/PGW combination in EPC. Along with packet forwarding this element is also responsible for policy enforcement, lawful intercept, traffic usage reporting and QoS policing.

The key essence of NG core is migration network functionality and signaling on the cloud. Research work has been carried out on cloud migrated architecture are in [24], [25], [26], [27], [28]. Centralized cloud migrated U/C plane separation allows operator to be cost effective and less complex as cloud based storage avoids setup costing of database and servers over the world.

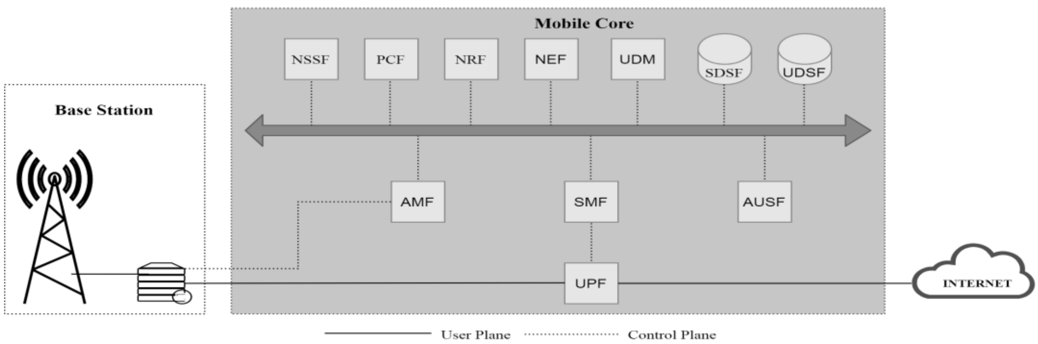

Fig. 6. 5G Core Functionality

VI. CHALLENGES AND BEYOND

In last few sections, we have reviewed the SDN prototype for the applications on celluar network architecture, celluar network management and network security management. SDN become has its wide range of uses in enterprise networking, cloud services and virtualization function, data center, optical network and infrastructure based and infrastructure less wireless access network. However, these are not error free. OpenFlow protocols are becomes widely used now a day among industry and researchers due to its advantage of table lookup entries. Controller checks the table lookup entries unlike ForCES. However, OpenFlow suffers high monitoring overhead and incomplete sample information.

Though, the centralized approach is an important concern for OpenFlow protocol. Software Defined Networks mostly implemented in virtually centralized controller architecture. In this case, TCAM hardware enabled switches directly connected with a centralized SDN server, which controlled programmatically. This connection is either in physical manner or through cloud services. A single point of failure in any point can disrupt the total network. In addition, there could be chance of hacking or phishing in centralized SDN server. Though significant efforts has been carried out has been addressed in [13], [14], [15], [16], [17] and [18].

Cloud services, which demands high bandwidth with low latency (1mS for 5G) whereas bandwidth limitation globally well known.

Heterogeneous operational environment and operator with heterogeneous technologies leading to a complex migration process, privacy issue and QoS pose a huge challenge for SDN security.

SDN has inherent characteristic about its receptiveness of deploy any solution need to face challenge of backward and forward compatibility (e.g. 5G and 4G) as the operator need to maintain and interconnect with different generation technologies.

VII. CONCLUSION

As a concluding remark, we can say the way future applications mostly depend upon cloud based services, mobile ad-hoc network, vehicular network, self-organizing network by doing that internet communication will becomes the only means of the society in coming days. With more and more world population the number of connected devices expected to increase by 18-fold up to next couple of years. To mitigate the demand significant research has to be accomplished to set up unified programmable unified flawless 5G architecture.

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