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Review of State of Art of Software-Defined Networking for 5G

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Abstract: The advent of services on the Internet has led to an increased demand for enhanced data rates and connectivity throughout the world. Mobile communication is a complex phenomenon which involves multiple entities working towards increasing the data rates and improving the performance of the cellular networks. Software-defined networking (SDN) is one such paradigm which focuses on decoupling of the data and control planes in order to enable the direct programmability of the network and its corresponding functionalities. The power of SDN is used to fuel the upcoming generation of 5G cellular networks. A detailed study is made with respect to the recent research that has been conducted on the use of SDN in 5G cellular networks. The details of the test beds that are currently available for experimenting with SDN and 5G technologies are mentioned, along with the organizations that are currently working on SDN for 5G. Furthermore, the development of 5G in the Indian scenario is also described.

Keywords: 5G, Mobile cellular networks, Software-defined networking.

I. Introduction

The society of the current world is a digitally connected society, wherein most of the devices in the network are interconnected and are accessible easily, from any given location. The complexity of setting up and managing the traditional IP networks has given rise to multiple technologies which are focused on the reduction of such complexities by introducing a paradigm of abstractions in networking, thereby simplifying the management of networks and aiding in their evolution.

Networking devices like routers and switches run network protocols, which provide distributed control for the transmission of information via packets to different networks across the world. These protocols are widely adopted; however, they are very complex and thus management of networks running these protocols is difficult. The networking devices are individually configured by the operators of the network using primitive commands, which are often specific to the vendor providing the devices. In addition to this, the networking environment is required to be adaptable to changes in network load and also to defend and sustain itself in the event of faults in the network. There is lack of automatic reconfiguration and mechanisms to provide proper response in the current IP networks. Furthermore, the existing networks are vertically integrated, that is, the control plane and the data plane are present as one entity in all the networking devices in a particular network. The handling of network traffic is done by the control plane, whereas the forwarding of network traffic based on the analysis done by the control plane is done by the data plane.

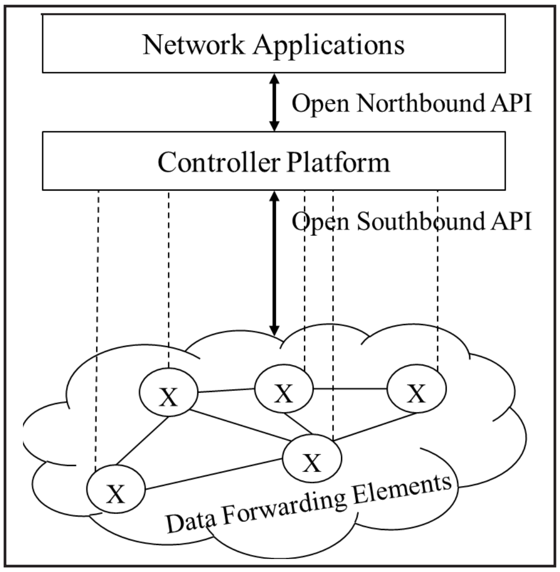

Fig. 1: Architecture of a Software-Defined Network

A. Software-Defined Networking (SDN)

Software-defined networking (SDN) is an emerging technology paradigm that involves the dismantling of vertical integration of control and data planes of traditional IP networks, and replacing this by a logical centralization of network control and addition of the ability to program the network. Fig. 1

shows the architecture of a software-defined network. It can be observed that there exists a clear distinction of the controller platform from the network elements. The users present in the management plane are able to program the network such that the control plane handles the traffic and the data plane forwards the packets in the network.

Some of the terminology used in SDN is described as follows:

- *Data Plane:* Represents the network infrastructure which consists of forwarding devices which are interconnected to each other.
- *Control Plane:* Used to establish control over the data plane and it is considered to be logically centralized in the SDN controller.
- *Management Plane:* Consists of functions that use control plane functions and application programming interfaces (APIs) to manage and control network infrastructure.
- *Forwarding Devices:* Hardware devices or software that are present in the data plane, that conduct the process of forwarding of data.
- *Flow:* consists of a continuous sequence of data packets that travel between the source and destination. Each packet is treated similarly at forwarding devices.
- *Flow Rules:* Consists of a set of instructions that are set to execute on incoming packets; for example, drop, forward to controller, accept.
- *Flow Table:* Consists of rules that can be used in handling the packets of flows.
- *Southbound Interface*: Consists of a set of instructions that can be used in programming of the data plane and the communication protocol between the data plane and control plane. Example of a southbound interface is the OpenFlow API.
- *Northbound Interface:* The control plane consists of an API that is used to develop applications for network management and network control.

B. 5G Cellular Networks

5G is usually regarded as the fifth generation of broadband-based cellular network technologies. 3GPP defines any system that uses 5G NR (5G New Radio) software as "5G," a term that went into public use by the later part of 2018. Others may retain the phrase for devices that fulfill the ITU IMT-2020 standard criteria, representing more countries. 3GPP shall submit to the International Telecommunications Union (ITU) its 5G NR technology. Currently, five companies across the world sell 5G radio hardware and 5G systems for carriers: Ericsson, Nokia, Samsung, Huawei and ZTE.

There are two main driving forces behind the need for 5G communication, namely networked society and technical drivers. Networked society represents some of the most needed features in the existing network scenario which include improvement of user experience, existence of high amount of traffic, large number of connected devices, large number of services, and also, transformed industries. Technical drivers include efficiency of resources and energy, automation of network and services, existence of virtualization and implementation of cloud environments, new technologies for both hardware and software. Fig. 2 depicts the architecture of 5G with respect to the applications catered. The architecture of 5G consists of various functionalities that are used for data transmission and access between the inter-networked devices on the large-scale communication networks. Cloud or data centers are used for setting up the databases and storage, whereas the management and control planes are used to manage and control the entire network. 5G also provides accessibility to Internet of Things (IoT)-enabled devices and industrial cloud infrastructures.

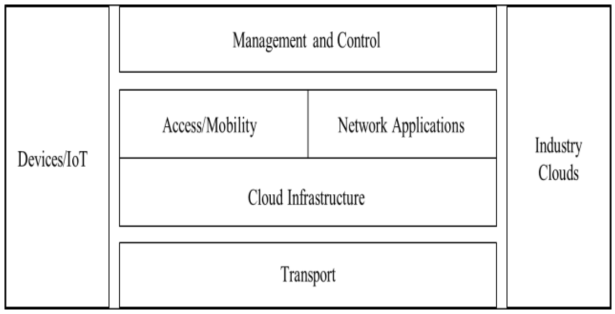

Fig. 2: Architecture of 5G

The current mobile core has features that would help to develop the infrastructure and services, but there are several limitations which need to be rectified. It consists of single network architecture that is used for various services. The functions of the current mobile core are a mixture of both control plane and data plane functions. Also, the core relies on appliance-based realization of the network. Fig. 3 depicts the current mobile core.

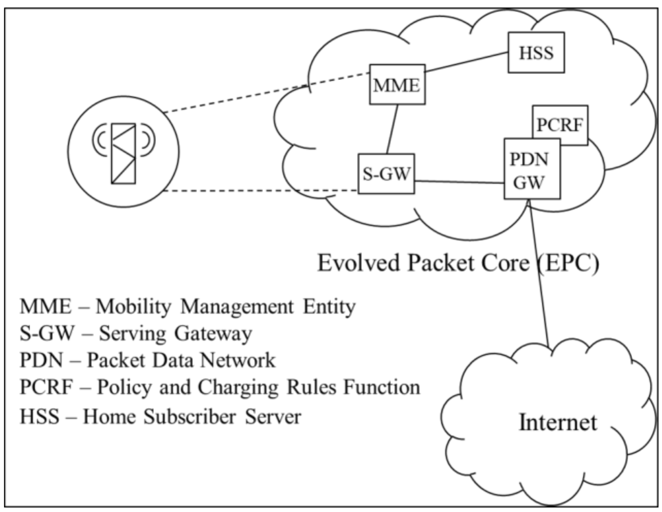

Fig. 3: Architecture of the Current Mobile Core

The main limitations of the current mobile core include the difficulty to customize the operating environment and its parameters, and also the limited scalability options. This can be improvised with a flexible core architecture, which 5G aims to achieve. Fig. 4 depicts the flexible core architecture designed for 5G.

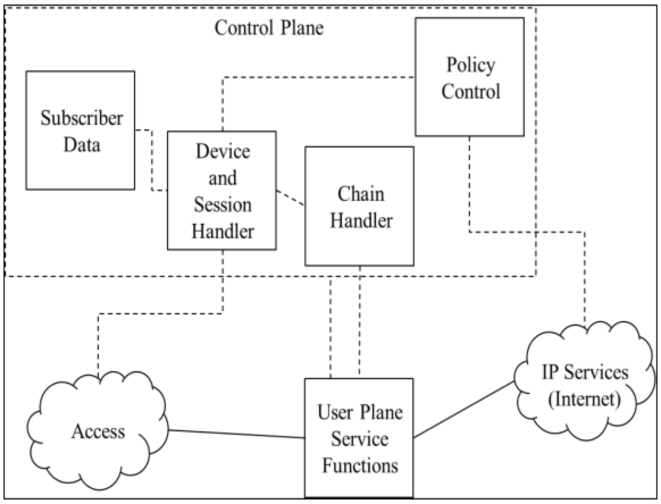

Fig. 4: Architecture of Flexible Core for 5G

There is clear-cut separation of functions of the control plane and user plane in the architecture of the flexible core. This is used to decompose the core functionality into different modules and granular functions. Network functions can be virtualized and this leads to a concept called Network Function Virtualization (NFV). The advantages of this particular core architecture are that it allows for centralized control and selective scaling of the network resources. It also utilizes cloud environment effectively for its operations.

Furthermore, the transport network in the current mobile core faces several issues:

- It has a single block-based implementation of the functions of network control and forwarding.
- There exist proprietary management interfaces for each component in the core.
- The complexity of control and management in the network is very high.
- It consists of several technological domains with independent control.

These issues lead to some limitations that have to be resolved using programmable transport layering. These limitations include, but are not limited to, inefficient utilization of resources, difficult cross-layer optimization, lengthy and manual creation of services or scaling, and application being unaware of how the communication takes place.

Programmable transport, which mainly separates the control and forwarding functions of the network, is the solution to these limitations. It defines interfaces between control and forwarding for easier access in the network. It also defines an open control plane which can be used for programming software and code. Finally, it is also used to develop efficient resource-sharing mechanisms.

The advantages of such programmable transport are as follows: dynamic creation or updation of connections or tunnels, automation of network and services, efficient cross-layer optimization, resource-optimized operation, and radio-aware adaptations.

C. Need for SDN in 5G

There exists a need for the use of SDN in 5G systems. This is because the upcoming 5G networks will span a huge scale and will be a heterogeneous network with several advanced features. It should also be able to provide the agility and flexibility of network nodes in the system. There is a need for robust remote control of the applications and resources and their optimized allocation. It should also be able to support the efficient management of cloud-based networks.

However, several practical issues currently exist, which have made the deployment of SDNs for 5G systems a bit delayed. It is a very challenging task to deploy these infrastructures practically. The softwarization of the networks has to be done using NFV. In the recent years, there has been a rapid evolution in technology and thus the upgradation of the existing technology in a fast-changing environment is complex. There also exists a huge data demand and overhead from the cloud. The use of SDN for 5G also poses the question of provision of cost-effective and sustainable wireless connectivity and services. It may not be affordable to the general public, due to the increased complexity of the network equipment involved. It should also be able to provide on-demand security.

D. Organization of the Paper

Section I describes the introduction to SDN and 5G cellular networks, along with the need for the use of SDN in 5G. Section II describes the recent research that has been done on use of SDN in 5G. Section III gives an account of the organizations working on SDN for 5G, whereas Section IV gives information about the testbeds that are currently available for experimenting SDN and 5G technologies. This is followed by Section V, which describes the current situation of 5G in India. Finally, Section VI gives the conclusion of the study of SDN for 5G.

II. Recent Research on SDN for 5G

The topics of SDN and 5G are now a worldwide phenomenon, which have therefore drawn the interests of various researchers and industry professionals, who have published articles, research papers and white papers on this topic.

An efficient infrastructure is created in the device-device (D2D) communication paradigm in 5G networks, enabling the use of different intelligent metropolitan apps like public safety. The tight deployment of wireless sensor networks in future smart cities can be integrated with D2D communications into 5G networks. D2D communication offers direct communication between neighboring user devices using cellular or unique communication lines, thus enhancing the use of spectrum, device capability and energy efficiency of the network. D2D's hierarchical communication architecture is discussed in which the centralized SDN Controller communicates with the Cloud Head (CH) to decrease the amount of LTE communication lines required, thus enhancing power consumption. The architecture's efficiency and ability is assessed, offering a public safety situation when a catastrophe strikes, disconnecting portion of the network [1].

Millimeter-wave (mmWave) frequency bands provide a new frontier for wireless networks of the next generation, widely known as 5G, to facilitate multi-gigabit communication; however, the availability and reliability of mmWave transmissions is significantly restricted owing to their unfavorable propagation features. Thus, to solve significant path-loss, mmWave networks depend on directional narrow-beam transmitters. It is essential to ensure the availability of mmWave transmitting connections to mitigate the effect of transmission-reception directionality and provide continuous network services. A unique flexible network architecture is suggested to ensure effective resource coordination during customer movement between service base stations. The main concept of this integrative architecture is to use SDN technique with mmWave communication to create a flexible and durable architecture of the network. In addition, an efficient and streamlined uncoordinated network arrangement is provided to assist reliable communication in highly dynamic situations identified by highly mobile and dense wireless devices. A new transmission design is incorporated to guarantee that at least one base station is linked to the UE at all moments to guarantee high reliability and to protect against prospective failure of the radio link. Simulations validate the suggested transmission scheme [2].

Visible Light Communication (VLC) is a powerful supplement that has recently gained tremendous attention and has become an advantageous technology for the 5G networks in short-range communication environments. VLC has a range of prominent characteristics to meet the highly demanding 5G system requirements for high capacity, high spectral efficiency, high data rate, low battery consumption, low latency and high energy efficiency. However, the flawed reception limits this notable performance, as the status of the line of sight channel may not always persist in practice. An SDN-assisted VLC model is described and validated, combined with WiFi access technology to enhance the reliability of the VLC model, reassures the reception quality of null packet loss owing to misalignment or route obstructions or when the customer travels between two successive VLC transmitters and encounters "dead coverage zones" [3].

Using SDN, an operator-assisted data offloading platform for 5G mobile networks is provided. By allowing lateral communication between various SDN devices, providers can conduct the method of offloading without the user's interference. In addition, the platform's suggested offloading choice is focused on precise real-time network conditions. The suggested method to check feasibility and performance is incorporated on a test bed [4].

With the evolution towards 5G, the coexistence of heterogeneous networks is increasingly prevalent, rising the volume and price of deploying and handling these networks. Consequently, network providers need to identify efficient methods to build and operate networks flexibly within a heterogeneous network setting to limit operational expenditure (OPEX) and capital expenditure (CAPEX). One approach to satisfy this demand is to accommodate former legacy network facilities in the newly deployed network while progressively decreasing dependence on legacy physical networks. A formidable candidate for attaining this is the software-defined transitional network (SDTN) approach. In the SDTN approach, NFV and SDN play a pivotal role in combining already existing network services into the network that is newly deployed. Architecture of an SDTN is advocated and an illustration of its rollout in a scenario of evolution of the mobile network is portrayed, in which there exists complete integration of mobile services running on 3G network, with that of a 4G network. Unified mobility management is the method in which mobile services running on 3G network are integrated with a 4G access network that is based on SDN/NFV implementations, is described. On the control plane, the network nodes for already existing and older mobility management services are virtualized and integrated into the architecture of the SDTN. Mobility management is therefore interoperable between the functions of the already existing virtualized service by the network and 4G mobile network that is enveloping it. Switches that are scalable are suggested for mapping of protocols between various incoming service traffic that is of a heterogeneous nature and data under 4G conditions to support integration of numerous services which are of heterogeneous nature, into the mobile network running on 4G. The suggested SDTN approach can be enforced in future implementation of 5G networks using the already existing services in new networks [5].

The potential requirements of 5G mobile networks can be considered to be solved by SDN. However, only a few studies have been done so far to tackle the security problems in Software-Defined Mobile Networks (SDMN), and almost all methods suggested exhibit downsides. Thus, a fresh SDN-based security framework presents many avenues in this sense and offers the opportunity for solving the security issue in the mobile core network. The SDS-SC is a software-defined security architecture for the 5G network oriented on SDN, and is therefore being suggested. Network-aware and flexible security solutions could be supplied on demand for subscribers with a security controller which is completely centralized and communicates with SDN network controller. Also described is the simple implementation of security applications in the architecture via an application interface, in addition to the security controller [6].

5G technology also supports mobile cloud computing, which is a new paradigm that works on the principle of provision of resources whenever necessary (on-demand), and excess resources are offloaded to the cloud, thereby saving energy and increasing efficiency of the system. The major drawback here is the performance and scalability. This is compensated by a novel architecture based on SDN/OpenFlow, which works for mobile cloud computing systems [7].

A general study on how SDN is used in 5G is made in [8]. The advanced features, enhanced data rates and data formats are detailed in the study. There is mention of diversity of platforms for 5G and carrier aggregation. Provisioning of bandwidth is also done dynamically.

Furthermore, the mobility report and technical whitepapers of two telecom giants, Huawei and Ericsson, are studied. The high-level perspective of how 5G works and the network architecture of 5G is detailed in the whitepaper submitted by Huawei, whereas the mobility report by Ericsson gives details and statistics about the worldwide mobile subscriptions, the network traffic and the growth of data traffic across all mobile devices [9] [10].

III. Organizations Working on SDN for 5G

The following section describes the organizations that are working on SDN for 5G. It outlines the hardware and software being developed at these organizations over the period of many years, with respect to SDN and 5G technologies [11].

A. Hardware

SDN architectures involve the use of OpenFlow devices, which are used to provide the hardware infrastructure for the deployment of SDN on the network. Some of the hardware built by various organizations are detailed below, in Table I.

B. Software

The SDN architectures also require the use of functional software in order to effectively communicate with the infrastructure and transmit data efficiently over the network. Table II gives the details about software developed by various organizations for SDN.

Table I: Hardware Components For SDN [11]

Product	Type	Maker	Description
8200zl and 5400zl	It is a chassis	Made by Hewlett-Packard	Chassis built to operate in a data center (switch modules).
Arista 7150 Series	It is a switch	Made by Arista Networks	Switches that can be used as hybrid Ethernet/OpenFlow switches in data centers.
BlackDiamond X8	It is a switch	Made by Extreme Networks	Switches that can be used for hybrid Ethernet/OpenFlow switches in cloud environments.
CX600 Series	It is a router	Made by Huawei	Routers that are used for MAN.
EX9200 Ethernet	It is a chassis	Made by Juniper Networks	Switches that are used in cloud data centers.
EZchip NP-4	It is a chip	Made by EZchip Technologies	Processors that are used in 100G networks.
MLX Series	It is a router	Made by Brocade	Routers that are used by service providers.
NoviSwitch 1248	It is a switch	Made by NoviFlow	Switches that are used for OpenFlow and provide high performance.
NetFPGA	It is a card	Made by NetFPGA	Implementations of OpenFlow that are used in 1G and 10G networks.
RackSwitch G8264	It is a switch	Made by IBM	Switches in the data center that can support both OpenFlow and Virtual Fabric.
PF5240 and PF5820	It is a switch	Made by NEC	Switches that are used as hybrid implementations in enterprises.
Pica8 3920	It is a switch	Made by Pica8	Switches that are used as a hybrid variant of both OpenFlow and Ethernet.
Plexxi Switch 1	It is a switch	Made by Plexxi	Switch that is used in data centers to perform optical multiplexing.
330 Series	It is a switch	Made by Centec Networks	Switches that are used as hybrid versions of both Ethernet and OpenFlow.
Z-Series	It is a switch	Made by Cyan	Switches that are used in optical transportation of packets.

Table II: Software for SDN [11]

Product	Type	Maker	Description
Contrail-vrouter	It is a virtual router	Developed by Juniper Networks	Function written for the dataplane which is used to provide a VRF interface.
LINC	It is a switch software	Developed by Flow Forwarding	Switch software that is written in Erlang that provides support for OFConfig 1.1.
Of soft switch13	It is a switch software	Developed by Ericsson and CPqD	Switch software that is written to be compatible with OF 1.3 in the user space.
Open vSwitch	It is a switch software	Developed by the open community	Consists of a platform of switches that are used in virtualized server environments.
Open Flow Reference	It is a switch software	Developed by Stanford	Provides OF switching capability to a Linux PC with multiple NICs.
Open Flow Click	It is a virtual router	Developed by Yogesh Mundada	Consists of a virtual router that is used for switching using OpenFlow.
Switch Light	It is a switch software	Developed by Big Switch	Compilation of software that are used to implement both physical/virtual switches.
Pantou/OpenWRT	It is a switch software	Developed by Stanford	A router can be modified to a switch that can run OpenFlow.
XorPlus	It is a switch software	Developed by Pica8	Consists of software that are used in switches in ASICs of high performance.

IV. Testbeds Available for Experimentation

This section consists of the details about the testbeds that have been developed for the testing and trials of SDN and 5G technologies all around the world. Testbeds are necessary to conduct experiments and trials for upcoming technologies including 5G, SDN, Mobile Edge Computing (MEC) and NFV. These testbeds contain running deployments of the technologies and trials can be conducted on all the required parameters. Table III gives details about the testbeds all over the world.

Table III: Details of Testbeds

Title	Organization and Location	Description
5G Playground	Hosted by Fraunhofer FOKUS in Berlin, Germany	5G Playground encompasses a comprehensive, highly customizable and re-configurable network environment, based on commercially available components and the Fraunhofer own toolkits.
5G haus	Hosted by Deutsche Telekom in Germany	Deutsche Telekom has established a comprehensive program throughout Europe to coordinate, plan and carry out experiments, tests and field trials related to 5G.
5G Center for Innovative Networks	Hosted by NETAS in Turkey, and is based out of Istanbul	5GNET depends on wireless communication techniques and combines functionality with a large-scale laboratory supplied with venture capital.
5G-EmPOWER	Hosted by Create-Net in Italy	5G-EmPOWER built by Create-Net is a distinctive and free toolkit for wireless and mobile network study and testing using SDN/NFV.
KU Leuven Networked Systems	Hosted by KU Leuven in Belgium	The test facility comprises of 45 software radios (consists of 90 antennas) enabled with FPGA, which is programmed in different methods to explore the advantages of several 5G-appropriate networking architectures.
SICS ICE	SICS North, Sweden	The test lab consists of a data center that is still under construction, planned to undergo 2 stages. It exists in the campus of Lulea University of Technology, Sweden. Phase 1 is currently working fine. There are machines with high specifications such as RAM of 4TB, storage of 7PB, and running up to 3600 cores across 200 servers.
Future Networks Innovation Lab	Italtel, Italy	The purpose of the unit is to apply NFV and SDN principles to improve real-time digital communication and M2M/IoT services.

V. Development of 5G in India

Compared to the remainder of the globe, India has always lagged behind the implementation of wireless technology. 3G services were introduced in India in 2008, almost six years after they were introduced in nations such as the United States and Japan. India started adoption of 4G pretty quickly; mobile 4G operations were introduced in India in 2014, around four years since it was started in nations such as the United States. The widespread availability of 4G metro facilities made it possible for mass smartphone adoption and service emergence like Ola, Swiggy and PayTM. Around 5G use cases, there are many expectations worldwide, and India is no exception.

The Government of India has made public its National Digital Communications Policy 2018 and has also apportioned INR 500 crore (USD 77 million) to 5G implementation – sections of this grant will be aimed at establishing laboratories across the nation, involving scientists, learners and educators. Ericsson has partnered with IIT Delhi to set up a Center of Excellence (CoE), which houses a 5G testbed and incubation center. Building the infrastructure and procuring the spectrum would require several billion dollars of investment to launch 5G in India. After the introduction of Reliance Jio facilities in 2016, the telecommunications industry has been under pressure – debts are rising and Jio's low-cost Internet facilities have caused an enormous impact on the profitability of other service providers. In its annual report for FY18, the Cellular Operators' Association of India (COAI) observed that telecommunications operators are in major financial crisis with INR 7.7 lakh crore worth of total debt.

Furthermore, enormous reorganization is taking place in the telecom sector – Aircel turned dormant; Reliance Communications transferred its mobile technology holdings to Reliance Jio; Tata Teleservices and Telenor donated their shares to Airtel; Vodafone and Idea Cellular combined into Vodafone Idea Limited. The fight is now between BSNL, Vodafone Idea, Bharti Airtel and Reliance Jio. Alongside network equipment vendors including Nokia, Ericsson, Huawei and Samsung, these service providers approached the Telecommunications Department (DOT) in December 2018 to conduct 5G experiments in various regions of the nation. There have been some claims regarding the status of 5G trials by telecom giants in India. These are given as follows:

- The Chief General Manager of BSNL, Anil Jain, said that BSNL is studying and experimenting on 5G technology on the surface by negotiating deals with several carriers such as NTT Advanced Technology and Nokia.
- Bharti Airtel, one of India's largest service providers, conducted some 5G experiments with Huawei hardware in 2018 at its Gurugram Network Experience Center. Airtel claims that the 5G experiment had attained rates of 3 Gbps.
- In the recent India Mobile Congress event that took place during October 2018, Reliance Jio teamed up with Ericsson to unveil some 5G demonstrations – together they demonstrated 5G connected car and Virtual Reality (VR)-enabled 5G navigation for driving.
- Vodafone Idea is retrofitting its existing communications infrastructure for preparation to launch 5G. The CTO of Vodafone said the company is evolving its 4G network based on 5G architecture components as well as 60% of all network traffic is presently functioning on the cloud core.

Though 5G technology is not considered as part of the initial launch to power mobile devices, several vendors are competing to add 5G support to their mobile phones. Qualcomm announced that 5G support will be available for its Snapdragon 855 chipset. Qualcomm is working in collaboration with companies such as Motorola, ASUS, Google, Oppo, OnePlus, Samsung, HMD Global, Xiaomi and Vivo to launch 5G handsets in 2019. The Qualcomm Snapdragon 855 chipset will be present in mobiles such as ASUS Zenfone 6, Samsung Galaxy S10, OnePlus 7 and Google Pixel 4, with 5G support. Apple depends on the 5G launch hardware of Intel. During the second half of 2019, Intel is expected to make its XMM 8160 5G modem available. And, this may delay Apple's iPhone support for 5G through 2020.

In India, the launch of 5G will greatly contribute to the deployment/adoption of Enhanced Mobile Broadband (eMBB) facilities in public areas like those of railway stations, buses, airports and trains. Launching fixed wireless services would assist service providers minimize their operating costs in offering broadband services. Virtual Reality or Augmented Reality related use cases may gain popularity among youth. Use cases like Smart Cars for implementation in India are quite far away. That being said, some of the IoT-related use cases would benefit from the 5G release with the government's venture on Smart Cities. Several service providers all over the globe are actively deploying commercial services based on 5G. According to the Telecom Regulatory Authority of India (TRAI), 5G services will be introduced in India as early as 2021 or 2022.

VI. Conclusion

5G technology is a futuristic technology that is expected to provide higher data rates, cross-layer optimization, radio-aware adaptations and dynamic creation or updation. SDN enacts a major role in faster development and adoption of 5G technology, due to its flexible and optimized resource allocation schemes, along with efficient management of cloud-based networks.

The use of SDN and NFV for 5G will aid in tackling complex issues and even improve upon existing solution schemes. However, due to difficulty in practical deployment, there are no 5G operations running as of now; but, it is expected to be successful in the near future, due to fast-changing and adapting technology. This has led the industry and academia to research more on 5G and its related technologies and come up with innovative ideas for its development and enhancement. Several testbeds have already been set up across the world in order to carry out experiments and simulations for SDN/NFV for 5G technology, among many other technologies such as MEC, mmWave and VLC communication for 5G networks.

The future scope for SDN in 5G would be a successful deployment of the technology in the current scenario as a short-term goal and improve it further in the long term. The technology should also be affordable to the general public, in order to enable faster, better and more efficient communication. Additionally, complex security measures should also be taken in order to prevent leak of data during transmission.

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