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CSI Transactions on ICT

ISSN 2277-9078
Volume 8
Number 1

CSIT (2020) 8:57-60
DOI 10.1007/s40012-020-00269-5

Springer

CSIT (March 2020) 8(1):57–60
https://doi.org/10.1007/s40012-020-00269-5

SPECIAL ISSUE ON SDN

SDN Journey: How SDN brings versatility to 5G networks?

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Published online: 29 April 2020

1 1. Introduction to 5G

A 5G network has three basic subsystems—user devices and equipment, radio access network and core network. The user equipment can be any of the communication devices such as those in a car, in industrial equipments, utility meters, phones, wearables and so on. The Access Network for 5G networks has a gNodeB as the base station similar to the eNodeB for 4G. The gNodeB can be an individual node or can be a distributed setup or a cloud covering larger areas. The core network has the common network and operator related functionalities which enable the user devices to connect to any network. The core network can also be in a cloud setup. 5G networks are going to be much more complex than the earlier generations and has many dimensions to manage and control. For this, the concept of Software Defined Networks (SDN) has been brought into 5G mobile networks which is revolutionizing the way 5G is being designed and deployed in terms of architecture, topology, functionalities and how the various control aspects are managed. This paper gives an introduction to SDN in 5G and an overview of the versatility it brings to the 5G networks.

2 Virtualized 5G

Virtualization is an important aspect of SDN. In fact, SDN and virtualization go hand in hand. In order to enable SDN, many of the network functions need to run in software rather than in custom-built hardware. Virtualization has already been happening in the cellular world for the past few years. It was initially tried for the Core network functions and then exprimented in some of the RAN functions.

NG RAN is a radio access network for the next generation (5G RAN). It can have distributed units and centralized units. The distributed units include the baseband, antenna and radio. The higher layers of the base station such as Layer 2 and Layer 3 can run on the centralized unit. The 3G or the 4G networks had dedicated hardware for base stations, while in 5G, quite a bit of virtualization is brought into the RAN. Now, part of the RAN hardware is based on generic computing systems and can run software built for a specific technology, especially the higher layers of the radio access network.

5G Core has the core functionalities such as access management, mobility management, session management and so on. In 5G all these functions are getting virtualized. In the near future, almost all 5G networks in the world will be having virtualized network functions, with accelerators for specific functionalities, all of them running on standard servers. Beyond virtualization, it can also be seen that the networks are getting cloudified. When 5G Core is built using the service based architecture, it will enable micro services and cloudification, that can give tremendous flexibility to the architecture of the network.

3 SDN concepts in 5G

Following the SDN principles, the user/data plane and control plane are separated in 5G too. There are control nodes for signalling and data nodes for traffic. It is true for Radio functions as well as Core network functions. Separating the control functionalities from the user plane or

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the forwarding functionalities enables logical centralization and management of the control aspects. This provides versatility in management, orchestration, and application of artificial intelligence in 5G networks. In a SDN based 5G network, more functionalities, features and intelligence can be added to the control plane while the user plane is more or less standardized.

4 SDN in 5G core networks

In the core network, all the control plane functions are separated from the user plane function (UPF). 5G has a specific network function called UPF, which does forwarding, routing and handling the QoS aspects of the data plane. The user traffic such as the internet data, voice over 5G or data from any app in the mobile phone go through the data plane. Background activities such as registration, authentication, session management and resource allocation for the data plane are done through the control plane functions.

There are several control plane functions such as the Access and Mobility Function (AMF), Session Management Function (SMF), Authentication function (AUSF), Unified database functions (UDM, UDR), policy function (PCF) and few others. The Session Management Function enables the user devices to create a session and connect to internet. The data goes through the user plane connection created during the session establishment. In effect, the SMF is equivalent to controller of a switch and UPF is similar to the switch itself. The SMF gives routing rules to the UPF which in turn routes the traffic between the user devices and the external networks. The major function of the UPF is thus the forwarding functionality. 5G network provides a lot of flexibility in the architecture by allowing a number of UPFs to be deployed at appropriate locations in the network.

Bringing in SDN in the core of 5G networks gives a lot of advantages. The architectures and topologies are flexible as the control plane and the data plane are separated. Evolution of control and user plane functions can thus become independent. For example, if throughput needs to be increased, the user plane nodes alone are scaled/added without any changes to the control plane. Another advantage is that it can cater to the specific application traffic requirement. For applications such as manufacturing automation, connected cars, and remote surgeries, latency is a very critical factor. Latency can be reduced in 5G networks by selecting user plane functions closer to the RAN. We can also see that the centralization of the control plane enables AI/Machine learning aspects to be brought into networks.

5 Enabling mobile edge computing

In a typical 5G network user equipment are connected through a base station (NG RAN) and a UPF to the data network. The data network can be an internet, operator's network or a network of an application domain like conneted cars, utilities, healthcare or an industry.

In 3G or 4G networks the packet gateway functionality of routing to the data networks is centralized and there could be only one gateway for several telecom circles. This centralized gateway has to be used even by users located far away to break out to the internet. If latency is critical, it is however important to have a gateway in close proximity to the users. This can be achieved in 5G by adding a UPF next to a base station or the local application server. It can reduce the latency drastically, say, up to say few milliseconds. It is even possible for the same session of the same user to communicate to the internet through different UPFs. The traffic is distributed through multiple break outs for same user session, and this provides greater flexibility and enables the concept of mobile edge platform. As the mobile moves, the controllers can switch the UPF from one edge to the other.

6 Routing influenced by application functions

5G allows external application functions to control the routing of traffic, which can bring a lot of flexibility and control to the domain applications that will use 5G in future. Applications can be internal (owned by the operator) or external (operator lending services to the client). The UPF used for routing can be changed dynamically as and when the application wants to, based on its requirements. Dynamicity is enabled through SDN and orchestration. Thus, it is seen that a lot of flexibility has been brought into the 5G networks using the concepts of SDN and virtualization. This flexibility has given a tremendous scope for orchestration of the network by the applications from various domains that deploy 5G.

7 SDN in 5G RAN

Similar to the 5G core, there is separation of user and control plane in RAN too, though it is not as straight forward as in the 5G core. There is limitation to the extent to which the user plane can be separated from the control plane in the lower layers (Physical layer, Radio layer and Layer 2). The seperation is possible in the higher substack/functions of Layer 2 and Layer 3 present in the centralized units. The centralized unit control plane functions can control the different user plane functions in the RAN.

Most of the Radio Access Networks will have RAN Controllers, which acts like a brain of the Radio network. The control aspects at different time dimensions—real time, near real time and non-real time are all handled by the RAN Controller. The near real time and real time control aspects are controlled through the radio resource management and control modules present within the centralized unit. This provides a lot of flexibility in terms of managing the traffic in various network conditions and handling different types of traffic.

There are basically three types of 5G traffic—a) eMBB—evolved mobile broad band wherein throughput is the crucial factor, b) IoT where the number of units connected is the most important factor compared to throughput or latency, c) URLLC (Ultra Reliable Low Latency Communication) where latency is the most critical factor. In order to meet these disparate requirements, the user plane functions need to be configured appropriately to meet the characteristics of the traffic. For example, certain user plane units can avoid ciphering to make the processing faster and thus the latency lower while others can do ciphering for higher protection.

The Layer 2 protocol stack of 5G RAN has the Media Access Control (MAC), the Radio Link Control (RLC) and the Packet Data Convergence Protocol (PDCP) functions as in 4G. A new function called Service Data Adaptation Protocol (SDAP) has been introduced in 5G. SDAP in RAN is connected to UPF in the 5G core. All these Layer 2 functions form part of the data plane layer in RAN. The control plane function—Radio Resource Control (RRC), which was there in 4G is also available in 5G, with enhanced functionalities. The various configurations of all of the above modules can be set by the SDN Controller in RAN. When orchestration is planned across the network, a lot can be done on how the radio connectivity is defined and how Layer 2 module functionalities are configured.

As in the earlier mobile networks, a radio bearer carries the user traffic in 5G as well. The radio bearer is established from the user equipment to the base station. Multiple bearers or flows are established based on different QoS requirements and slices. Multiple slices can be created to carry different types of traffic for various sets of customers. Different or same instances of the network functions have to handle all these different types of traffic. This means that the individual sub modules or functions have to be configured appropriately so that the various requirements of the traffic like QoS, latency, scalability, reliability, security are fully met.

Scaling of data functions is much easier now using SDN, as the data and control plane are separated. When networks are evolving, the required changes can be optimally done due to this separation. Latency reduction is also achieved by isolating and optimizing the data plane. 5G supports a common 5G core for any kind of access making it a totally converged network. The access network can be new radio (NR) of 5G, enhanced LTE WiFi or DSL. All of these can be connected to the same 5G core and can be orchestrated using the same orchestration platform. An operator who owns multiple access networks can choose the appropriate access and network topology to service a specific set of customers. 5G will support a larger number of cells compared to that of 4G due to high frequency spectrum/millimeter wave functionality being brought in. As higher throughput can be achieved through higher bandwidth and proximity to the base station, there will be several small cells near a hot spot, which can be managed by the right placement of user plane functions and also orchestrating at system level which can optimize both the resources and the energy requirements.

8 Network slicing and orchestration

Slicing is a powerful feature in 5G networks, which helps in creating and dynamically managing virtual end to end networks over a common infrastructure. This is done by creating virtual resources and functions across the system. For example, one slice can be created for a government department like Police, another one for manufacturing, another for broadband wireless for public and so on. In effect, a virtual network is created by chaining a set of network functions right from the user equipment up to the UPF that breaks out into the appropriate data network. There are a lot of functionalities in the RAN, transport and core subsystems, which are to be configured to meet the requirements of a slice. SDN facilitates this by providing the levers of control throughout the network. Slice Management is an active area of research to find better ways to create, manage, and analyze how slicing can be orchestrated across various subsystems.

Orchestration is another powerful feature that makes best use of the resources to ensure that services are rendered as expected. It can also help in automating the networks. Orchestration can help in managing complex networks, by reducing manual intervention and taking decisions automatically, which is where data analytics and AI can be employed. Much of the orcehstration is achieved through the SDN controllers of various subsystems.

9 SDN based end-to-end 5G test bed

In a collaborative project taken up by eight institutes in India and supported by the Department of telecom of the Government of India, an end-to-end indigenous 5G test bed is being built using the latest technological advancements. The hardware and software IPs built in the test bed project, will be useful to startups, companies, academic users and research labs. The algorithms and techniques developed in the project will also be available for research and deployment purposes. The test bed itself will be opened up to the potential users once it is integrated and tested end to end.

The end to end test bed is consisted of user devices, base stations, core and the management orchestration layer. The core, management and orchestration subsystems and part of RAN are all SDN based. The orchestration subsystem is using ONAP which is an open source platform.

All the hardware and software components are built by the eight institutes, ensuring complete control over the test bed design and ownership. It is a white box implementation that can be shared, as required, with companies and institutes that plan to work in 5G, in the coming years.

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