A NOVEL ARCHITECTURE FOR SDN-BASED CELLULAR NETWORK

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ABSTRACT

In this paper, we propose a novel SDN-based cellular network architecture that will be able to utilize the opportunities of centralized administration of today's emerging mobile network. Our proposed architecture would not depend on a single controller, rather it divides the whole cellular area into clusters, and each cluster is controlled by a separate controller. A number of controller services are provided on top of each controller to manage all the major functionalities of the network and help to make the network programmable and more agile, and create opportunities for policy-driven supervision and more automation.

KEYWORDS

SDN, OpenFlow, LTE.

1. INTRODUCTION

Everyday new technology, policies and smart devices are emerging, todays networking concept is also developing accordingly. The traditional network infrastructure is considered as a single system made by many physical elements, such as routers, switches, and firewalls on which the whole network controlling activities depend for communication and services. A single modification in any part of the network can increase the maintenance effort on the whole network, and sometimes it may cause a miscarriage of the total network. At present, most of the IT related people identify the traditional networking paradigm as very much static and think it require a lot of effort to physically change and laboriously organize and legalize the network [1].

Software Defined Networking (SDN) is a new approach in the networking paradigm that has given the idea to deal efficiently with the emerging network and to better handle the major growth in data traffic, network virtualization, and mobility of user equipment [2] [3]. SDN generally permits network administrators/operators to regulate their network systems programmatically, serving them to improve capabilities and scale without compromising performance, reliability, or user experience [4].

The importance of networking is increasing day-by-day due to the emergent human's need and as a result it has been the key concept in the modern communication system. Now people are very much dependent on advanced technologies and innovative devices that are usually work through various communicating networks. Today's network provides all types communicating services and acts as the common information gateway to the whole world by sending and delivering messages, audios, videos, images and so on. A traditional network layout (shown in Figure 1) as it compares to an SDN network layout (shown in Figure 2) [5] is described in the following.

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Traditional networking devices are composed of an embedded control plane that manages switching, routing and traffic engineering activities while the data plane forwards packet/frames based on traffic [6]. Here control plane is responsible to control the traffic related activities and data plane works as the traffic carrier. The control plane provides information used to build a forwarding table. The data plane consults the forwarding table to make a decision on where to send frames or packets entering the device. The networking device contains both of these planes and these are usually placed as built-in on the device [7].

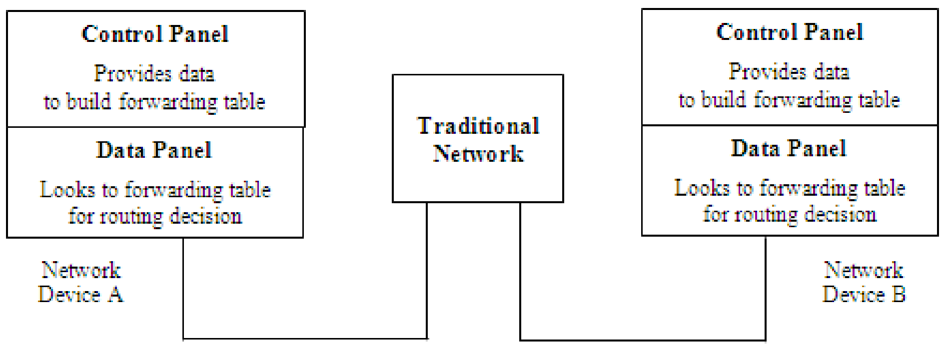

Figure 1. Traditional network layout

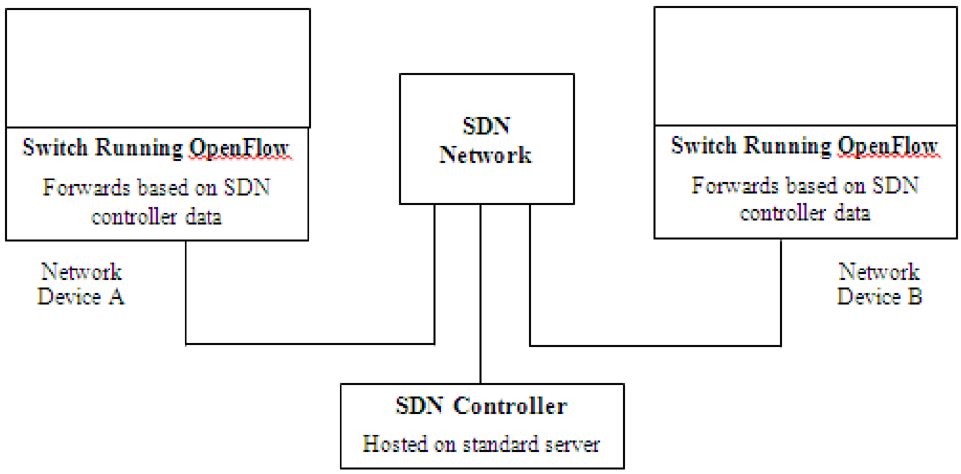

Figure 2. SDN network layout

In SDN architecture, control plane functions are removed from individual networking devices and hosted on a centralized server [8]. The SDN controller usually is an operating system with necessary SDN software. The controller generally communicates with the switch data plane through a protocol that is publicly known as OpenFlow [9]. OpenFlow transmits the instructions and commands to the data plane so that the data plane can forward the data to the right direction. To support the services the network devices must contain and run the OpenFlow protocol.

Mobile and wireless networks are growing rapidly and the technology behind them is changing continuously. As wireless devices become the main or even only option for more and more people to communicate with others, mobile operators must carry much volumes of traffic and at the same time provide a number of facilities or services. New cellular technologies, like Long Term Evolution (LTE) [10], have supported cellular providers/operators to maintain the stability of traffic growth by increasing the radio access volume. However, they now face a number of challenges of keeping up with the increasing demand in their core networks, which carry the User Equipment (UE) traffic between the Base Station (BS) and the Internet and the increasing number of wireless technologies in use simultaneously. Typical devices today support 3G and 4G cellular services as well as Wi-Fi and Bluetooth connectivity. To support these various types of services mobile operators usually have to manage increasing costs and handle operational headaches. In addition, carriers need flexible deployment choices to migrate from older to newer technologies without hampering the customer services.

The cellular and mobile network industry has been fighting to handle the growing data demands of new devices like smartphones and tablets from a number of years [11]. Future cellular networks are faced with the challenge of coping with significant traffic growth without increasing operating costs. SDN is a new networking approach that separates the control and forwarding planes of a networking device in a network [10-12]. This functional separation and the implementation of control plane functions on separate centralized platforms have been of much research interest due to various expected operational benefits [13].

In this article we propose a novel clustering SDN-based cellular network architecture that does not only depend on a single controller, rather it divides the whole cellular area into clusters, and each cluster is controlled by a separate controller. A number of applications or services are kept available on top of the controller that maintains all the controlling functions of the network. The controllers communicate and share information between them through a controller service. Basically, a controlling function is dependent on a number of services. In this way, much of the traffic and single-controller overwhelming could be minimized. To our knowledge, this will be the first work for cellular network that would utilize controller services efficiently by sharing their information rather than depending on only a central controller. The rest of the paper is organized as follows: section 2 briefly describes about the architecture of a generic cellular system, an overview of today's LTE/EPC cellular network architecture is demonstrated in section 3 and the ONF SDN reference model architecture is described in section 4. Related work and background study have been discussed in section 5. We have described our proposed architecture in section 6 and finally section 7 concludes our proposal.

2. CELLULAR NETWORK ARCHITECTURE

The architecture of a generic cellular system [14] is described in Figure 3. The schematic provides an idea of the different components in the traditional mobile network. The radio access subsystem is responsible to locate the position of the mobile station (MS). Sometimes these MSs are also called user equipments (UEs). Base stations (BSs – also called eNodeBs) are fixed transmitters that are points of access to the rest of the network. A MS keeps communication with a BS by sending and receiving information during idle period, cellular phone calls or other data transmission. Base stations are controlled by radio network controllers (RNCs) that are also responsible to manage the radio resources of each BS and MS (frequency channels, time slots, spread spectrum codes, transmit powers, and so on).

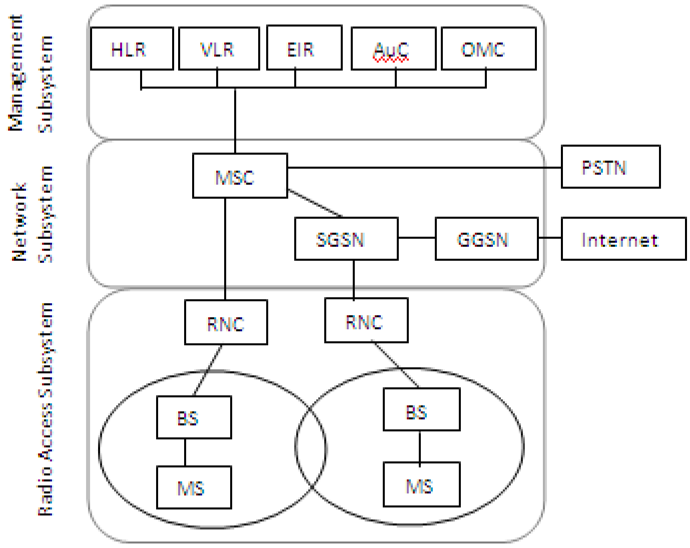

Figure 3. Generic cellular network architecture

The network subsystem is liable to carry voice and data traffic and also handles routing information of voice calls and data packets. The mobile switching center (MSC) and the serving and gateway GPRS (General Packet Radio Service) support nodes (SGSN and GGSNs) are responsible for handling voice and data respectively. These network entities control the mobility management; locate the cell or group of cells where a MS is positioned and update routing information when a MS makes a handoff. They connect to the public switched telephone network (PSTN) or the Internet. Several databases in the management subsystem are used for keeping track of the entities in the network that are currently serving the MS, security issues, accounting and other operations as shown in the upper part of Figure 3.

3. TODAY'S LTE CELLULAR DATA NETWORKS

In Long Term Evolution (LTE) cellular networks, a base station (eNodeB) generally connects to the Internet using an IP networking equipment [15], as shown in Figure 4. The user equipment (UE) directly makes a connection to a base station, which forwards traffic information through a serving gateway (S-GW) over a GPRS Tunneling Protocol (GTP) tunnel. The S-GW acts as a local mobility anchor point that maintains smooth communication when the user travels from one base station to another. The S-GW stores a large amount of state since users retain their IP addresses when they move from one location to another. The S-GW forwards traffic to the packet data network gateway (P-GW). The P-GW enforces quality of service policies and monitors traffic to perform billing. The P-GW also handles the connections to the Internet and other cellular data networks, and works as a firewall that blocks annoying traffic flow. The P-GW can handle different types of policies based on whether the user is travelling, features of the user equipment, usage caps in the service agreement, parental controls, and so on.

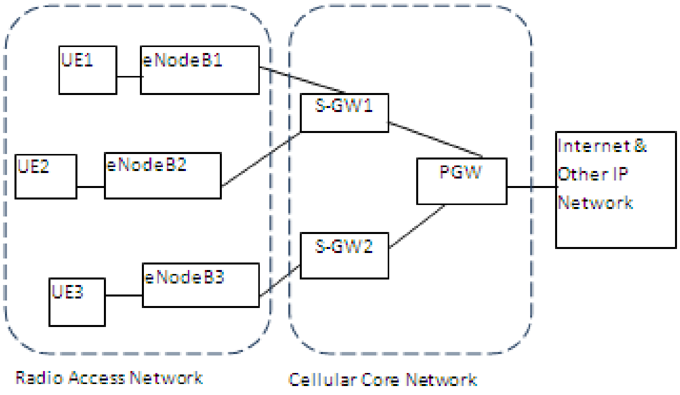

Figure 4. LTE data plane

Besides data-plane functionalities, the base stations, serving gateways, and packet gateways also join in several control-plane protocols, as illustrated in Figure 5. In coordination with the mobility management entity (MME), they handle hop-by-hop signaling to manage session setup, tear-down, and reconfiguration, as well as mobility e.g., location update, paging, and handoff. For example, in reply to a UE's request for dedicated session setup (e.g., for VoIP call), the P-GW forwards QoS and other session information (e.g., the TCP/IP 5-tuple) to the S-GW. The S-GW in turn sends the messages to the MME. The MME then requests the base station to assign radio resources and form the connection to the UE. During handoff of a UE, the source base station directs the handoff request to the target base station. After reception of an acknowledgement, the source base station transfers the UE state (e.g., buffered packets) to the target base station. The target base station also updates the MME that the UE has made new cells, and the previous base station to discharge resources (e.g., eliminate the GTP tunnel).

The S-GW and P-GW are also involved in routing policies by running protocols such as open shortest path first (OSPF). The Policy Control and Charging Function (PCRF) handle flow-based charging rules in the P-GW. The PCRF also offers the QoS authorization (QoS class identifier and bit rates) that chooses how to contact every traffic flow, based on the user's payment options. QoS policies and services can be dynamic, e.g. based on time of day. This must be imposed at the P-GW. The Home Subscriber Server (HSS) holds subscription data for each user, such as the QoS profile, any access constrains for roaming, and the associated MME. In the time of cell overloading, a base station cuts the highest rate allowed for subscribers according to their profiles, in coordination with the P-GW.

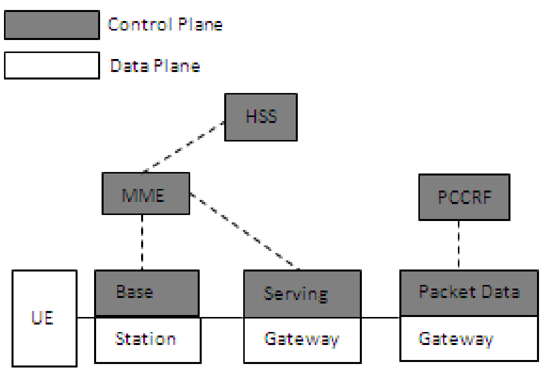

Figure 5. Simplified LTE network architecture

As today's cellular networks provide a number of services but their architectures have numerous major limitations. Centralizing monitoring activities, access control mechanisms, and quality-of-service policies at the packet gateway presents scalability challenges. This makes the networking devices or equipment very expensive (e.g., to purchase a Cisco packet gateway it usually requires more than 6 million dollars). Concentrating data plane activities at the cellular-Internet frontier forces all traffic related data through the P-GW, containing traffic between users on the same cellular network coverage, making it tough to host popular contents inside the cellular network. In addition, the network devices have vendor-specific configuration interfaces, and make communication through complex control-plane protocols, with a huge and increasing number of parameters under more restrictions (e.g., several thousand parameters for base stations). As such, network administrators or operators have limited control over the operation of their networks, with little ability to create innovative policies as well as to provide up-to-date services.

4. SDN OVERVIEW

Software Defined Networking is an innovative architectural approach in the networking arena that has been designed to allow more agile and cost-effective networks to provide network users the recent and future services. The Open Networking Foundation (ONF) is on the top position in SDN standardization, and has defined an SDN architecture model [16] as illustrated in Figure 6.

The ONF/SDN architecture model is comprised of three separate layers that are reachable through a number open APIs:

- The application layer consists of the end-user business applications that provide different communications services. Communications between the application layer and the control layer is managed by the API.
- The control layer controls and supervises the network forwarding functionality through an open interface.
- The physical layer usually contains the physical network devices or components (i.e. router, switch, etc.) that are responsible to handle packet switching and forwarding.

According to this architectural approach, the model is characterized and described by three key features:

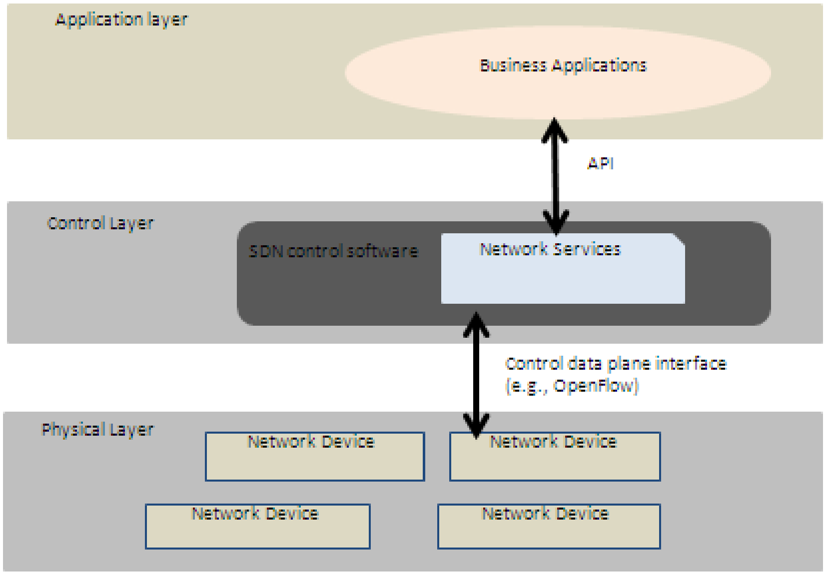

Figure 6. ONF SDN reference model

1. Logically centralized intelligence
   An SDN provides the full network overview from a single point of supervision using the standard interface OpenFlow [17]. By centralizing network functionalities or intelligence, all types of decision-making are performed based on a global (or domain) view where nodes are ignorant of the overall state of the network.
2. Programmability
   An SDN offers programmatic interfaces through different services that can automate and form network fabric configuration. SDN networks can attain revolution and variation from traditional networks by providing open APIs for applications to communicate and interconnect with the networks.
3. Abstraction
   In an SDN network, the business applications and services are abstracted from the underlying network technologies and mechanisms. Network devices are also abstracted from the SDN control layer to support portability for any application or services from any vendor or manufacturer.

5. RELTED WORK AND BACKGROUND STUDY

The ONF has defined an SDN architecture model for cellular network [18]. An SDN provides the overall network functionalities from a single point of administration using the standard interface, OpenFlow. ONF describes two use cases to illustrate the benefit of OpenFlow-based SDN for mobile networks:

- Inter-cell interference management
- Mobile traffic management

As shown in Figure 7, the logically centralized control layer provides radio resource allocation choices to be performed with global visibility through many base stations, which are more efficient than the distributed radio resource management (RRM), mobility management, and routing applications/protocols in use today. By centralizing network intelligence into the SDN controller, RRM decisions can be made based on the dynamic power and subcarrier allocation profile of each base station. In addition, the paper demands that scalability challenges are improved as the required compute capacity at each base station is low because RRM processing is centralized in the SDN controller. The SDN controller makes communications with the base stations through the standard southbound interface (OpenFlow), and any RRM modifications can be accomplished freely from the base station hardware.

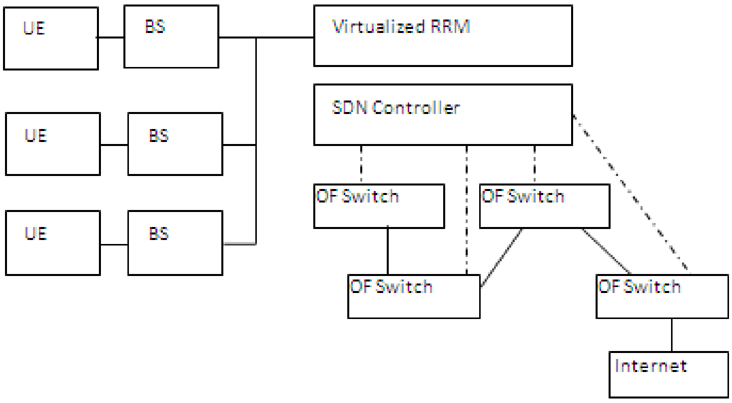

Figure 7. OpenFlow-enabled centralized base station control for interference management

Offloading is the term used in the networking that means moving traffic from a mobile network (cellular, small cells, femtocell) to a Wi-Fi network. It is also known as Wi-Fi roaming. The handover process is the power of software that enables networks with no loss of data/connectivity, preservation of IP address, etc. to maintain the user experience (UX). Offloading can also be applied in the reverse order. The OpenFlow controller (OF controller) will have to communicate with entities such as the ANDSF (access network discovery and selection function) for finding wireless networks close to the mobile user and performing the Wi-Fi offload (Figure 8). The destination selection of the roaming can be on the basis of a QoS metric such as performance, signal strength, or distance in order to maintain the UX.

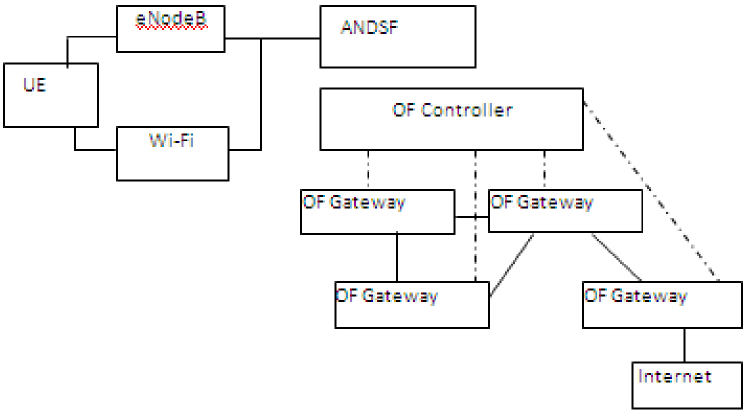

Figure 8. Openflow-based mobile offload

Cellular networks need an SDN architectural mechanism that provides fine-grain, real-time control without losing scalability. The authors in [15] propose four main extensions to SDN as shown in Figure 9, leading to the architecture for cellular network. They uses local controller with switch that communicate with the central controller. The main limitation of this approach is the management of the local and central controller as both may have dissimilar controlling information or data at the same time for a specific switch to forward packets.

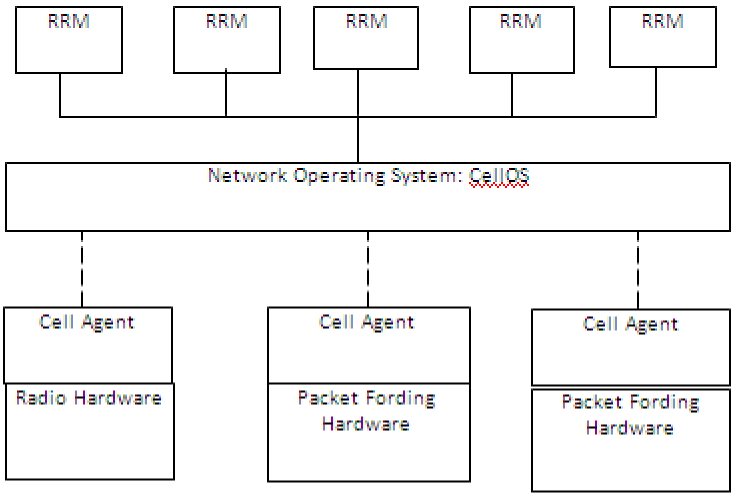

Figure 9. Cellular SDN architecture

SoftCell [19] is an SDN-based cellular network architectural model that demands to support a number of fine-grained services in a scalable manner for cellular core networks (Figure 10). In this article, the authors used local agents and access switch to each base station to communicate with the controller, they also used OpenFlow switches in the core network rather than EPC/LTE switches. It would be very difficult to deploy new software switches to each base station; also it may suffer same limitation as the above approach.

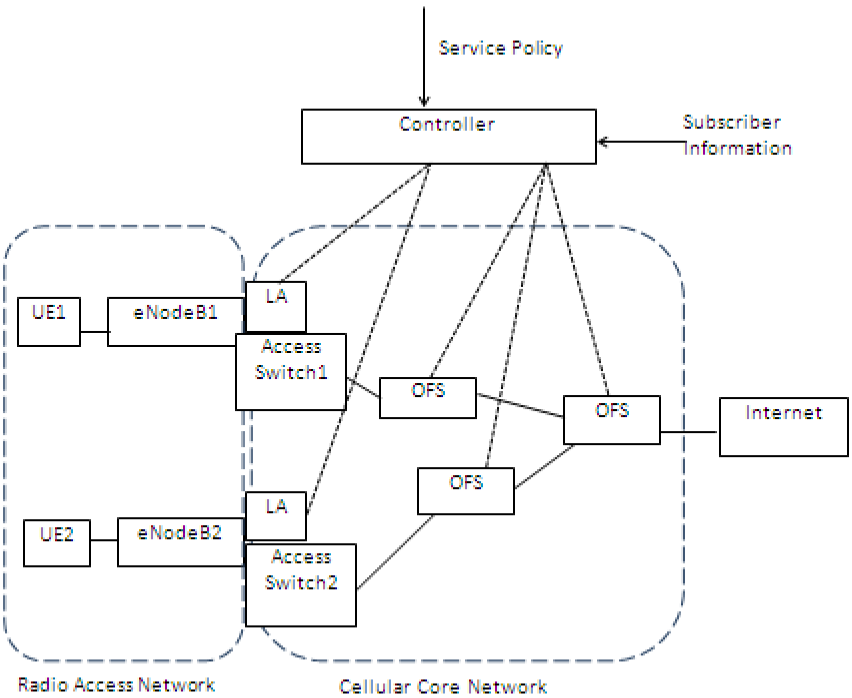

Figure 10. SoftCell Architecture

SoftRAN [20] is a SDN based centralized control plane architecture for radio access networks that localizes all base stations in a particular geographical area as a virtual big-base station comprised of a central controller and radio elements (individual physical base stations), but it does not apply any technique for cellular core network as depicted in Figure 11.

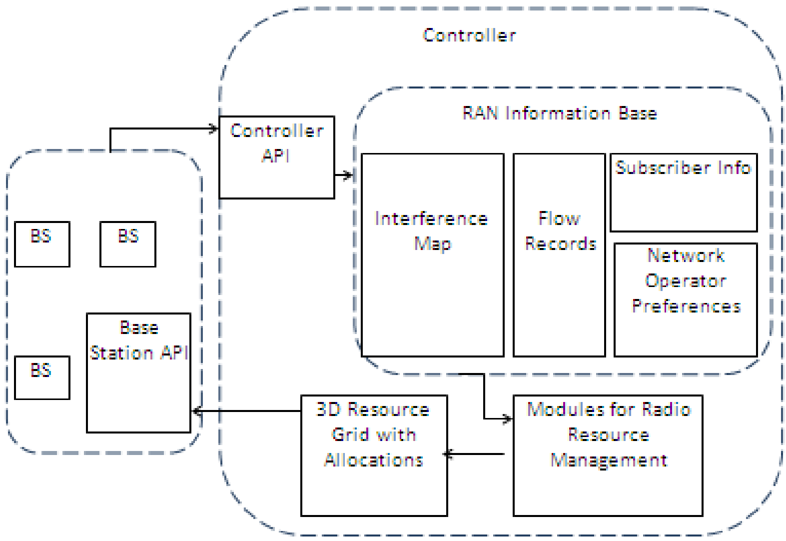

Figure 11. SoftRAN Architecture

In [21], the authors propose an SDN-based mobile networking approach integrated with legacy mobility control plane. They simply call this the partially-separated mobile SDN architecture that is compared to the fully-separated mobile SDN architecture where all the control is dominated by a SDN controller without taking the legacy mobility control plane into consideration (Figure 12). This paper is only for controlling the mobility of the user equipment's and they propose mobility control plane to each switch as like as local controller, and the central mobility controller acts as central controller same in the above techniques.

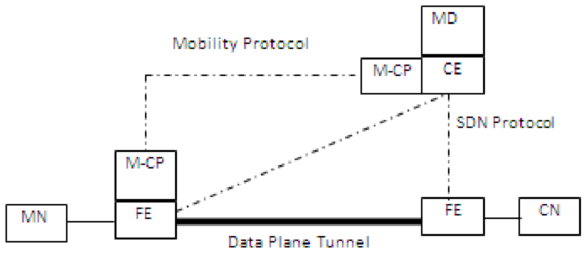

Figure- (a) Partially-distributed

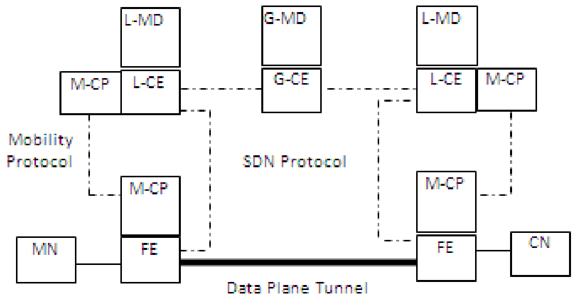

Figure- (b) Fully-distributed

Figure 12. SDN-based mobility management architecture

In the article [22], the authors present a new dynamic tunnel switching technique for SDN-based cellular core networks. This approach is to maximally utilize cloud and implement a virtualized EPC (Evolved Packet Core) serving and packet data network gateway (S/PGW) where control and user plane functions are separated from each other (Figure 13). They demand it would support 5G cellular network. The limitation is that it would not be able to adopt with today's existing network as well as future cellular network.

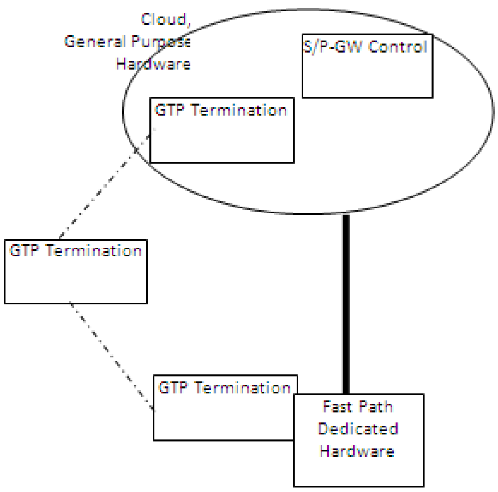

Figure 13. SDN-based virtualized S/P-GW

A new architecture for 3GPP LTE/EPC cellular network for on-demand connectivity service has been proposed in [23]. Their proposal also depends on a single SDN-based controller and used the expensive PGW switch to connect to the internet.

All the above proposals for SDN-based cellular network used only a single controller. As cellular data traffic has exploded in recent years and the rate will also be kept in the coming future, we think it would not be possible for a single controller to handle all the functionalities to manage the network. And hence, we have decided to establish a novel architecture for SDN-based cellular network that would be depended on a number of cluster-based controllers rather than a single controller.

6. PROPOSED ARCHITECTURE

To support the services of today's emerging cellular network and at the same time for future network, we propose a novel architecture for SDN-based cellular network. We change the control protocols on the interfaces of S1 (between MME and eNodeB), S11 (between MME and SGW) and S5 (between SGW-C and PGW-C) of the LTE/EPC architecture by the OpenFlow protocol. The other two interfaces S1 (from eNodeB to SGW-D) and S5 (from SGW-D to PGW-D) are controlled by the existing 3GPP protocol of the LTE/EPC architecture. According to the SDN principle we propose to separate the all controlling activities and place these to the central controller. The central controller is responsible to manage all the controlling functions through its different services that run on top of the OpenFlow controller.

Our proposed architecture needs not any change to the radio hardware at the base station; also it does not want extra support to connect to the Internet. The architecture comprises of the following entities as shown in Figure 14:

Controller: The SDN controller usually involves a network operating system (NOS) that handles a collection of application modules/services. The handling of a single packet may depend on multiple services. The NOS should be able to support the composition of the outcomes of multiple modules into a single set of packet-handling policies in each switch.

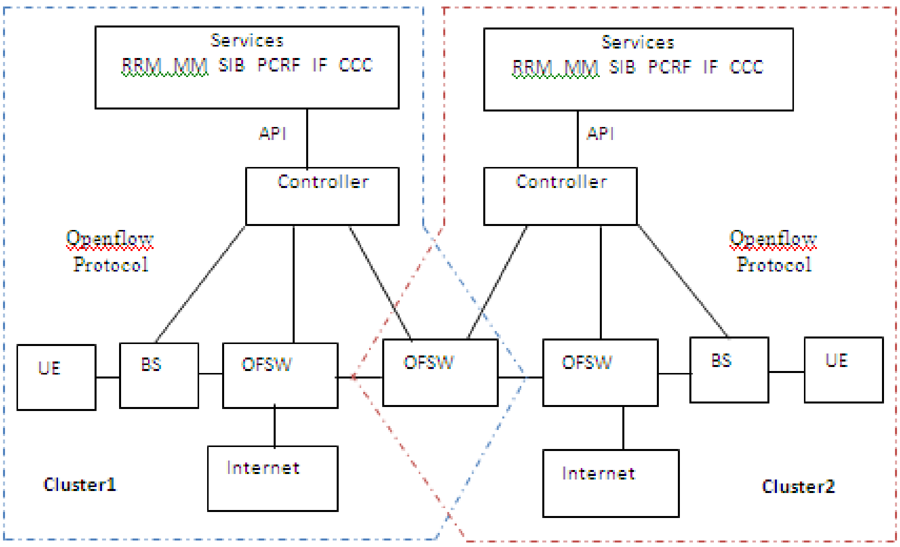

Figure 14. Proposed architecture

It is the key component of our architecture as it handles all controlling activities related to radio access network (RAN), the forwarding plane services of OpenFlow switches as well as gateways to the Internet. It implements high-level service policies by installing switch-level rules that direct traffic through middleboxes as in LTE/EPC network. The OpenFlow controller is responsible for user session establishment and load monitoring at the data plane. It controls all the controlling functions provided to the OpenFlow switches (OFSWs that resemble SGW-D and PGW-D in the LTE/EPC architecture) through different services that reside on top of it. In general, it interconnects with the services through the application programming interface (API) and holds the following modules:

- RRM: It maintains all the radio related functions provided to the base stations through the Openflow protocol rather than GTP tunneling protocol as used in the LTE/EPC architecture. Running radio resource management module (RRM) on top of a logically-centralized controller lets it much simpler to renovate in admission control, radio resource distribution, and interference management.
- MM: It is the service that provides UE authentication and authorization, and supports intra-3GPP mobility management (MM).
- SIB: The controller holds a subscriber information base (SIB) that stores and handles subscriber information, both for relatively static subscriber attributes and dynamic data of the user's current IP address, location, and total traffic consumption.
- IF: The infrastructure routing (IF) is responsible to identify the routes between pairs of network elements and the flow of traffic through the network depending on the subscriber's location (determined by the mobility manager).
- PCRF: The policy and charging rule function (PCRF) is responsible for traffic monitoring and packet scheduling activities.
- CCC: This module is the main part of controlling the clusters of our proposed architecture. When a cluster is heavy loaded, the controller generally sends packet to the switch that is shared between two clusters and search for that cluster which is less loaded by the controller-controller communication (CCC). All cluster that are neighbors, i.e. shared at least one switch, store these information in the CCC service table. Its main function is to update the controller status of the next cluster and share the information between controllers through the shared switch. And it is duty of the visiting cluster controller to forward packets which reached in the shared switch after updating its controller and CCC services. A packet only goes to the shared switch when the controller is extremely overloaded with huge traffic and it ensures only that the traffic is forwarded to another less crowded cluster. So by this way, many traffic as well as controller overwhelming is minimized.

OFSW: Today's OpenFlow switches (OFSW) already support many features needed in cellular networks [10]. These are commodity hardware switches that act like a SGW data plane (SGW-D) and are able to encapsulate/decapsulate GTP packets. This switch applies the rules received from the OpenFlow controller. It is responsible for packet forwarding between the eNodeB and SGW. Our proposed architecture also contains Openflow enabled a few gateway switches connected to the Internet. These gateway switches are much cheaper than PGW switches; they just perform packet forwarding, and relegate sophisticated controlling functions to the Openflow controller.

eNodeB: This is the base station that keeps the same radio functions specified by the 3GPP standard. It is enabled with the Openflow protocol for the data forwarding through the S1 (enodeB to SGW-D) interface. Therefore, the data forwarding is based on instructions received from the OpenFlow controller.
UE: These are mobile devices also called user equipments (UEs) that are today's LTE supported devices and work smart ways.

7. DISCUSSION AND CONCLUSION

Despite the extraordinary success of the cellular mobile telecommunications industry, many of the underlying design strategies and service assumptions that have served us arguably well over the past few decades may benefit from a fresh new look. Certainly, the LTE network architecture can eliminate a few network components, and simplifies some of the cellular network architectural compositions. Although, it was a change in the right direction, the result appears to provide somewhat constrained enhancements in terms of reduction in complexity and improvement in flexibility, as well as to maintain the heavy traffic of the today's popular cellular network.

An innovative SDN-based cellular network architecture has been proposed in this paper that does not only depend on a single controller, rather it splits the whole cellular area into a number of small clusters, and each cluster is managed by a distinct controller. A number of applications are provided on top of the controller that keeps all the controlling activities of the network. The controllers communicate and share information between them through a controller service. Basically, a controlling function is dependent on a number of services. As a result, much of the traffic and single-controller overloading could be minimized.

To design and meet the needs of the future mobile cellular network will be more difficult with a few general observations: there will be far smarter and new devices; the more base stations connecting them, and various numbers of applications - ever changing - running over the network. We believe that our proposed architecture would be able to fulfill the demands for today's and future cellular network and at the same time to support the challenges of this inevitability. Our proposed architecture would be simulated in the mininet emulator for future work to establish it as for practical or real world usage.

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