Quality of Service for IoT in 5G LTE

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Abstract

As the demand for a faster and more reliable mobile telecommunications network grows, so do the capital and operating expenditures to expand the network. The current standard for mobile telecommunications is to provide 4G capabilities to customers, while the next step is to reach 5G capabilities. 5G has yet to be standardized and aims for increased capacity and lower latency. One of the driving influences for 5G is the rapid increase of connected devices and the bandwidth demand due to the Internet of Things. In addition, there is a growing urgency to decrease the time for network innovations by closing the time gap it takes to develop, integrate, and scale networks. As it stands, developing, managing, and upgrading networks is extremely expensive for networking companies. Software Defined Networking is the solution to alleviate these issues. Software Defined Networking provides abstraction to efficiently manage Long Term Evolution networks. It aims to reduce the operating expenditure for network management and to reduce the capital expenditure through programmability. This solution translates to easing scalability of networks. Software Defined Networking separates the control plane from the data plane and introduces the ability to effectively program the network. This separation enables capability to offload computational responsibilities from individual specialized hardware to the lower cost general hardware running virtualized omniscient software. Integrating Software Defined Networking into the Long Term Evolution architecture will be essential to attain 5G capabilities as well as to adequately support the increasing demands from the Internet of Things. It will enable a high quality of service that can dynamically adjust in a programmatic fashion.

Table of Contents

1 Introduction

2 Software Defined Networking

2.1 Software Defined Networking Architecture

3 Fifth Generation Long Term Evolution

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4 Use Cases

4.1 Mobility Management

4.2 Ubiquitous Connectivity

4.3 Mobile Clouds

4.4 Quality of Service Provisioning

4.5 Cognitive Network Management and Operation

5 Current Developments

6 Quality of Service for IoT

6.1 Development and Simulation

6.2 Traditional LTE Simulation

6.3 SDN LTE Simulation

6.4 Performance Evaluation

7 Conclusion and Future Work

Acronyms

4G	Fourth Generation of Wireless Mobile Telecommunications Technology
5G	Fifth Generation of Wireless Mobile Telecommunications Technology
EPC	Evolved Packet Core
E-UTRA	Evolved Universal Mobile Telecommunication System Terrestrial Radio Access
IoT	Internet of Things
LTE	Long Term Evolution
QoS	Quality of Service
SDN	Software Defined Networking
QoS	Quality of Service

1 INTRODUCTION

The rapidly increasing popularity of smart mobile devices has led to an escalated demand for high speed reliable networks. According to Cisco Systems, the number of smart mobile devices is expected to increase nearly threefold from 2015 to 2020 [1]. This increase is expected to result in an eightfold growth of global mobile data traffic. Mobile connection speeds have increased in the past few years to meet current demands, however mobile networks have a limited capacity that can be overwhelmed by the increasingly larger and dynamic behaviors of mobile traffic [2]. As a result, network operators are forced to deploy an increasing number of base stations to handle dynamic and large data traffic [3]. Current mobile telecommunications use Fourth Generation Wireless Mobile Telecommunications Technology (4G), which can be built using Long Term Evolution (LTE) or Worldwide Interoperability for Microwave Access [4]. 4G will be unable to adequately scale with the quick growth of mobile devices. As a result, the Fifth Generation of Wireless Mobile Telecommunications Technology (5G) is meant to address the increasing number of connections and traffic. It aims to have greater capacity with lower latency and higher speed compared to 4G. Though no current standards for 5G exist, the International Telecommunications Union and the 3rd Generation Partnership Project aim to have to the mobile standards set by 2020 [5].

Networking companies typically have high fixed costs in capital and operational expenditures. Expanding or upgrading a network can become costly. One solution that can help networking companies ease network upgrades is the integration of Software Defined Networking (SDN) into the LTE network architecture. The integration of SDN leads to abstracting networks, which would allow for faster delivery of upgrades, performance improvements, and a more flexible management system.

The remaining report is organized as follows: Section 2 provides a background for SDN, Section 3 provides a background on 5G LTE, Section 4 presents use cases for both technologies, Section 5 examines the current developments of SDN in the commercial environments, Section 6 describes shows the simulation and performance evaluation of QoS in SDN for IoT devices, and finally this paper is concluded in Section 7.

2 Software Defined Networking

Software Defined Networking is an emerging programmable technology [6]. It was originally thought of as centralized control with the Openflow protocol for communications between the control plane and the data plane. Its definition has now changed and can be defined by three features. It is abstracted from the hardware thus having no dependency on physical hardware restrictions. It maintains centralized control to manage forwarding tables and policy delegation. It is programmable to dynamically configure networks based on policy and demand.

SDN provides benefits of configuration, performance, and innovation through its programmability [6]. Since the SDN requires instantaneous network status, it can configure for real-time centralized control. This centralized control can enable optimizing network configurations to improve network performance. With programmable centralized control, SDN allows experimentation of network configurations.

2.1 Software Defined Networking Architecture

The SDN architecture consists of three planes and two interfaces for communication between the planes. The components include the application plane, the control plane, and the data plane. The two interfaces include the northbound and southbound interfaces. The SDN architecture is shown in Figure 1.

The data layer is the bottom most layer of the SDN architecture. It consists of network devices that forwards data based on control tables. Although the data layer contains control tables it does not create the table. The table comes from the controller.

The southbound interface is used for communication between the data layer and the control layer. This interface is used to transmit the type and amount of traffic from the data layer to the control layer. It is also used to transmit the flow tables from the controller to the data layer. OpenFlow was the original southbound protocol, however many other open protocols have been used.

The controller layer is in charge of enforcing policies from the business applications. It creates forwarding tables and prioritizes Quality of Service based on business policies. The control layer sends forwarding tables to the data layer to carry out the transmission of data.

The northbound interface is used for communication between the controller layer and the application layer. It provides abstract network views and enables network requirements. This interface is expected to be implemented through application protocol interface.

The application layer is the top most layer of the SDN architecture. It consists of business applications. These applications programmatically communicate business policies to the network. They determine Quality of Service and network behavior through Service Level Agreements for the controller to carry out.

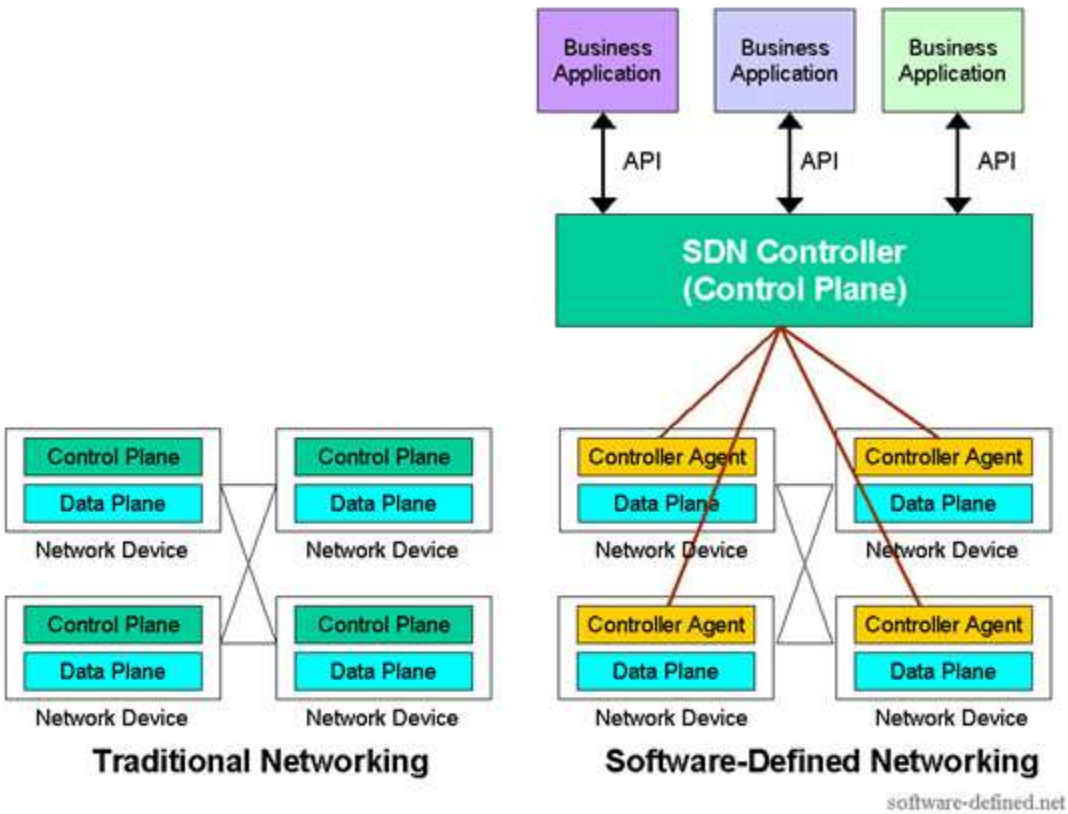

Figure 1: Traditional Network vs. SDN [7]

3 FIFTH GENERATION OF WIRELESS MOBILE TELECOMMUNICATIONS TECHNOLOGY LTE

The future of telecommunications is 5G because it is the next major step towards ubiquitous computing. Unlike 4G, 5G does not intend to focus on faster peak speeds. Instead, 5G is pushing to obtain higher capacity and lower latency for IoT devices. At this time there are no standards for 5G, however the standards for 5G are expected to be set by 2020 [8]. 5G is the fifth generation technology based on the IEEE 802.11ac standard that aims to provide faster speed and increase coverage compared to 4G. The 5G standard will be created by the International Telecommunications Union Radiocommunications Sector in addition to the 3rd Generation Partnership Project. It is anticipated that users of 5G will achieve data rates greater than 10 megabits per second, with a potential for a 20 gigabit per second peak data rate [8]. 5G is expected to be achieved through various technologies. One technology is SDN.

3.1 LTE ARCHITECTURE

Long Term Evolution is a communications standard for telecommunications. It is located in the access portion of the Evolved Packet System to transmit data. 5G is expected to use orthogonal frequency division multiplexing in LTE. LTE uses the architecture [9] where the user equipment communicates with the Evolved Universal Mobile Telecommunication System Terrestrial Radio Access (E-UTRA). The E-UTRA then transmits data to the Evolved Packet Core (EPC) in order to communicate with the Internet. Figure 2 shows the architecture.

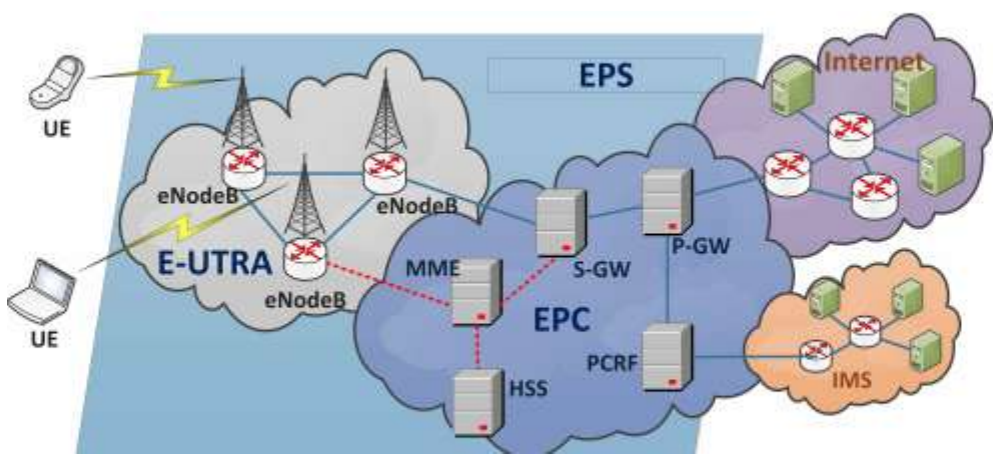

Figure 2: Telecommunications Architecture [10]

User equipment includes items such as computers, mobile phone, tablets, and IoT devices. It consists of devices that start the initial transmittal of data. User equipment transmits data through radio waves to towers. These towers have hardware attached to them called eNodeB. The eNodeB is the physical equipment that takes the radio waves from the user equipment. Multiple eNodeBs are combined to form an E-UTRA. ENodeBs can communicate with one another as well as the EPC.

The EPC is the core network for LTE communications. It is a framework that provides data on an internet protocol network. The EPC consists of five major components: Mobility Management Entity, Serving Gateway, Packet Data Network Gateway, the Home Subscriber Server, and the Policy Control and Charging Rules Function. The Serving Gateway serves as the interface between the EPC and the E-UTRA. In addition, the Serving Gateway routes data between the components in the EPC. The Mobility Management Entity serves as a controller. It keeps track of the users as well as manages and authenticates each session. The Home Subscriber Server is connected in the EPC through the Mobility Management Entity. The Home Subscriber Server is responsible for carrying information such as metadata on users. The Packet Data Network Gateway is the connection between the EPC and external IP networks such as the rest of the internet. The last component is the Policy Control and Charging Rules Function [11]. This component is a controller that makes decisions about flow control based on policies and charging.

4 USE CASES

Today's mobile telecommunications network is in need to evolve for the future. As there becomes an increase in devices from the trend of IoT, there becomes an increasing strain on telecommunications. Traffic increase will require new services and applications. 5G is in its adolescence but must overcome the challenges presented in mobile telecommunications [12].

4.1 MOBILITY MANAGEMENT

IoT is a trend that is currently growing. As more devices become connected through telecommunications it becomes difficult manage them. The plethora of devices will require connectivity to a variety of interconnected services and applications while in motion. This idea questions the current network design and what steps should be taken to provide management of mobile devices.

SDN in mobile networks would be a technology to provide programmable resources for mobility management. SDN controllers would be able to maintain session continuity and network connectivity from dynamic channel configuration. Furthermore, they should have rapid re-association and policy management.

4.2 UBIQUITOUS CONNECTIVITY

The future increase in devices will cause an increase in the communication between devices. It is believed the future will hold connectivity for all devices to connect to one another. Telecommunications will be required to make the connections from user devices to networks as well as other devices. It will also require an establishment for machine to machine connections. All of these new interactions will require a new network infrastructure. IoT devices will change the requirements for the network. They will require an increase in multimedia capabilities for control and monitoring.

SDN controllers should be able to manage all connections. It should be flexible enough to create true peer to peer connections while adjusting for link reliability. The controller will deal with topology discovery, self-configuration, and self-organization so network devices and user devices can save energy.

4.3 Mobile Clouds

Mobile Cloud Computing is a technology in rapid development. It promises a low latency environment in which mobile devices look attached locally to a cloud. It provides access to backend cloud resources at high speeds. Mobile cloud computing requires resource sharing, session management, and low latency.

The implementation of SDN will enable the new capabilities required to create a mobile cloud. Some of these new capabilities include initiating and adjusting network connectivity, tunneling, and monitoring network conditions. SDN in 5G will allow dynamic supply of network resources to connect to the cloud while maintaining low power for user devices.

4.4 Quality of Service Provisioning

The landscape of Quality of Service (QoS) is changing as the IoT is currently is expanding among consumers. The increase of devices and software creates a change in the traffic pattern of telecommunications. Each device or software will require different QoS requirements. These devices must interconnect with a variety of services and applications. Fast changing traffic patterns create havoc for network operators who need to predict various traffic patterns.

To provide a flexible network, SDN should be implemented. SDNs are programmable to address automatic provisioning for various layouts of QoS. They can be dynamically programmed to adjust as traffic requirements change. They will cope with large demands of services and applications to provide a network slice to each user device. QoS can be manually configured through the northbound interface. This will allow service providers to develop efficient algorithms for dynamic network adjustment.

4.5 Cognitive Network Management and Operation

Network management and operational controls are an important role in telecommunications. They address the policies for performance, failure recovery, self-organization and configuration, and changes in network load. Current tools provide little or no mechanism for auto responding to changes. They require individual configuration for every device by a human operator.

SDN introduces a new era in network management. It enables monitoring capabilities to improve performance and reduce bottlenecks to a multitude of network devices. In order to accomplish this SDN must have an open interface to simultaneously connect to a plethora of vendor specific devices for management and operations. This will enable an elastic network that can conform to operational demands.

5 Current Developments

Currently, commercial versions of SDN for wireless networks are scarce as there is still much research being done with how SDN features can be integrated into the LTE architecture. One early example of SDN for wireless networks in industry is the Agile Controller 3.0, recently released by Huawei in September 2016 [13].

The wireless nature of LTE largely differs from the standard wired networks, having greater overhead with managerial and operational issues with heterogenetic networks, inter-cell interference, accelerated network scaling, and traffic routing [14]. SDN can help LTE in three ways: simplifying the already complex management in wireless networks through the logical centralization of the control plane, easing network upgrades and adapting to dynamic network behaviors through network programmability.

It should still be noted that a number of commercial SDN controller implementations exist for wired networks. Table 1 lists some of the different SDN controller implementations as examples [15].

Company	SDN	Brief Description
Cisco	Application Policy Infrastructure Controller (APIC)	Focuses on application level policy management
Cisco	Open SDN Controller (OSC)	Commercial distribution of OpenDaylight that improves service delivery and reduce operating costs
Blue Planet	SDN/NFV Orchestration Platform	Simplifies creation, automation, and delivery of services
Brocade	SDN Controller	Quality assured edition of OpenDaylight that is still an open source SDN controller
Ericsson	SDN Controller	Domain specific commercial version of OpenDaylight SDN
Huawei	Agile Controller	Focuses upon on-demand network resource allocation, configuration, and optimization
IBM	Programmable Network Controller	Platform using OpenFlow
PLUMgrid	OpenStack Networking Suite	Focuses on secure and scalable SDN through containers and OpenStack
Hewlett Packard Enterprise	Virtual Application Networks (VAN) SDN Controller Software	HPE Carrier SDN that connects to various NFV components for real time responsive elasticity in cloud based VNF

Table 1: Brief, Non-comprehensive Overview of SDN Controller Implementations [15]

6 QUALITY OF SERVICE FOR IOT

The rapidly increasing popularity of smart devices has led to an escalated demand for high speed reliable networks. In order to accommodate the escalation of devices, SDN needs to be incorporated into 5G telecommunications. This new architecture will enable scalability and reduce latency. It will enable QoS for smart devices such as Internet of Thing (IoT) devices. Implementing SDN into 5G LTE is an expensive and timely task. In order to research this solution in a timely cost effective manner, this paper implemented SDN for LTE in a simulator. Various simulators were evaluated to determine their functionality and ease of use.

6.1 DEVELOPMENT AND SIMULATION

Simulating the integration of a SDN controller into the 5G LTE network requires a number of steps. Omnet++ was investigated to simulate a LTE network and an OpenFlow controller using the SimULTE and OpenFlow libraries. However, the simulation was developed in Java because the two libraries were architected in very different ways. OpenFlow was created with a wired network in mind, while SimULTE was created with 5G in mind. To make the two libraries work together would require a large amount of code modification outside the scope of this project. As a result, a simplified simulation was developed in Java. It should be noted that only the functionality implemented is dynamic reallocation of bandwidth based on demand.

In order to prove the concept two simulations were developed. The initial simulation consisted of the existing LTE backhaul entities. This simulation showed smart devices running in a typical 4G LTE network. The smart devices include both IoT devices and mobile phones. The smart devices send data with variety of service types. The second simulation incorporated a SDN incorporated into the LTE backhaul. For this simulation the SDN varied the bandwidth for the different types of services.

6.2 TRADITIONAL LTE SIMULATION

In the simulation, a number of classes that were deemed relevant to the scope of this project were created. Specifically, the program modeled UE as User Equipment, EPC as the simplified evolved packet core, Internet as the internet or place where messages are received, eNodeB as the tower responsible, QoS as the various enumerations of services for conversations, streaming, interactive, and background data for both IoT and mobile. Message as the messages sent between User Equipment. For purposes of this simulation, various components were simplified focus of this experiment was to demonstrate flexibility for the bandwidth provisioning for quality of service in LTE. The SGW, PGW, MME, and other components were simplified and aggregated as the EPC. It is also assumed that the messages are sent and received by the UEs and that the simulation shows only one direction of flow for the messages. The simulation consisted of 1 EPC, 1 Internet, 50 UEs, 1 eNodeB with a bandwidth of 27,000 Kbits per second, and 1400 Messages with different QoS weights that were sent from the pool of UEs. The overall procedural flow of the simulation is as follows: (1) Initialize the EPC, Internet, eNodeB, UEs, (2) Connect the EPC to the Internet, then connect the eNodeB to the EPC, and then connect the UEs to the eNodeB, (3) Run the simulation in units of seconds where it is assumed that all UEs run at the same point of time and that the destination of messages are sent to other UEs randomly. The interaction in the simulation is shown in Figure 3 below:

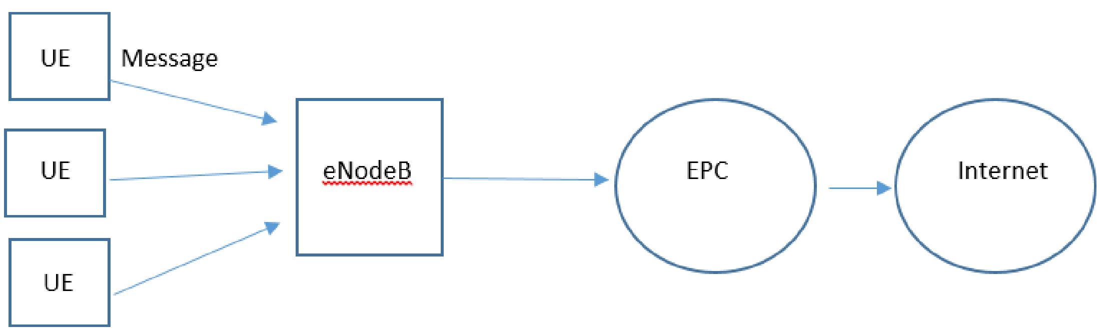

Figure 3: Simulation Architecture

6.3 SDN LTE SIMULATION

In this simulation incorporates a way to dynamically reallocate the bandwidth for each type of service provided. This project has asserted a prioritization on increasing the Quality of Service in terms of throughput for all messages. Thus, the bandwidth allocated for each service is based on the required total size of bandwidth needed so there is even distribution of weights between the services. This is done with each round of message processing in the total 1400 messages done in the simulation.

6.4 PERFORMANCE EVALUATION

The traditional LTE simulation shows that the average throughput time of messages with higher need for bandwidth usage was significantly greater than the average throughput time of messages with smaller bandwidth usage. After incorporating a partial SDN controller into the architecture, which prioritizes throughput of all messages, the SDN LTE simulation showed that average throughput time for all messages could be stabilized to provide equal Quality of Service. As a result, the time for services that had a longer throughput time significantly improved at the expense of services that had a shorter throughput time. This is because the bandwidth for each type of QoS was dynamically re-allocated during runtime to ensure better quality of service for messages that had longer throughput times.

Consequently, the dynamic reallocation in the SDN LTE simulation allowed for a better total average throughput time than the Traditional LTE simulation. This shows that the service for different types of IoT and Mobile data could be dynamically adjusted to provide a certain quality depending on the prioritization that is asserted. Table 2 below shows the results of the simulation. One of the biggest improvements can be seen in Table 3 where the total time it took to receive messages significantly reduced when using the dynamic bandwidth re-allocation. A comparison utilized bandwidth of the first ten seconds of the simulation are shown in Figure 4. The flexibility provided in the simulation shows that the bandwidth usage can be utilized much more efficiently in the SDN LTE scenario and that bandwidths would be able to provide more stable QoS when there are large surges of incoming traffic.

Services	Bandwidth Needed for Each Type of Message (Kbps)	Traditional LTE: Average Throughput Time (Seconds)	SDN LTE: Average Throughput Time (Seconds)
MConversational	3000	30.7	36.99
MStreaming	1500	21.5	31.44375
MInteractive	100	1	36.78
MBackground	8	1	31.82143
IConversational	3000	181	29.4775
IStreaming	1500	61	29.67333
IInteractive	100	1	28.89
IBackground	8	1	28.89
Total	1152	69.75	30.95286

Table 2: Average Results of Traditional LTE vs SDN LTE Simulation

	Traditional LTE	SDN LTE
Number of Messages	1400	1400
Total Time to Send (Seconds)	400	98

Table 3: Overall Results of Traditional LTE vs SDN LTE Simulation

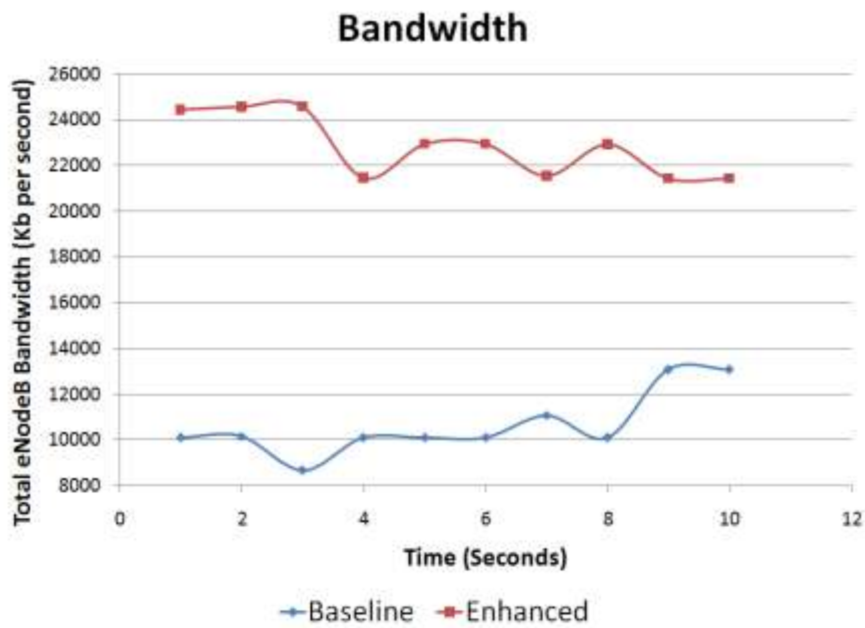

Figure 4: Comparison of first ten seconds of utilized eNodeB bandwidth

7 Conclusion and Future Work

To bridge the gap from 4G to 5G, SDN must be incorporated in a LTE architecture. This will enable telecommunications to reach the speeds that 5G requires. SDN in the LTE network will enable higher packet transfer rates through a centralized controller and automatic QoS provisioning.

The research completed with this architecture has shown great potential to increase capacity and reduce latency for telecommunications by increasing throughput by dynamic QoS adjustments. They show there are various configurations for SDN in LTE that can be employed.

There are many options for the future of SDN and 5G. The next step will be determining the placement and style in which the controller should be located. To do this, research must be completed on containerizing the controller. Controller containerization will enable a way to quickly create multiple controllers. Multiple controllers will follow in this research path to remove SDNs weakness of central point of failure.

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