Original scientific paper

https://doi.org/10.33180/InfMIDEM2024.205

Informacije MIDEM
Journal of Microelectronics,
Electronic Components and Materials
Vol. 54, No. 2(2024), XX – XX

Software Defined Network Architecture Based Network Slicing in Fifth Generation Networks

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Abstract: Network slicing is a promising approach that can cater to the need for differential services. It can be employed to improve the performance of users. In Fifth Generation (5G) networks, it is adopted to enhance the Quality of Experience (QoE) of the clients of differential services. In this research, 5G clients of five distinct services in different combinations in two scenarios are considered. They are Enhanced Mobile Broadband (eMBB), Massive Machine Type Communication (mMTC), Ultra Reliable Low Latency Communication (URLLC), voice, and Enhanced Mobile Broadband Prioritized (eMBB_p) clients. This study develops Software Defined Networks (SDN) architecture-based network slicing in a 5G network. It is simulated using Python 3.7. Whenever the bandwidth available on the client-associated Base Stations is not sufficient to meet their service requirements, the process of network slicing is invoked. It consists of slice creation and slice allocation. Both of these modules are governed by Network slicing management. The amount of slice depends on the service requirements of the active clients. In scenario 1, the active clients are assumed to be 96. There are some combinations: 70 eMBB, 10 mMTC, 10 URLLC, 2 voice, and 4 eMBB_p. while in scenario 2, it is 52 eMBB, 21 mMTC, 15 URLLC, 24 voice, and 5 eMBB_p. As per the 3GPP standard, the bandwidth required for eMBB_p is 10 G bit/s. The bandwidth available per Base Station is 6 G bit/s; however, 1 G bit/s is assigned for signaling, and hence only 5 G bit/s are available per Base Station to serve the clients. From the simulation results, it is found that scenarios 1 and 2 achieve bandwidth utilization of 24% and 38%, respectively.

Keywords: Network Slicing; 5G; SDN; QoE

Programsko definirana omrežna arhitektura, ki temelji na rezinjenju omrežja v omrežjih pete generacije

Izvleček: Rezinjenje omrežja je obetaven pristop, ki lahko zadovolji potrebe po različnih storitvah. Uporablja se lahko za izboljšanje zmogljivosti uporabnikov. V omrežjih pete generacije (5G) se uporablja za izboljšanje kakovosti izkušenj (QoE) odjemalcev različnih storitev. V tej raziskavi so obravnavani odjemalci petih različnih storitev 5G v različnih kombinacijah v dveh scenarijih. To so izboljšani mobilni širokopasovni odjemalci (eMBB), masivna komunikacija strojnega tipa (mMTC), zelo zanesljiva komunikacija z nizko zakasnitvijo (URLLC), glas in izboljšani mobilni širokopasovni prednostni odjemalci (eMBB_p). Študija razvija na arhitekturi SDN (Software Defined Networks) temelječe rezinjenje omrežja v omrežju 5G. Simulirana je z uporabo programa Python 3.7. Kadar pasovna širina, ki je na voljo na baznih postajah z odjemalci, ne zadostuje za izpolnitev njihovih zahtev po storitvah, se sproži postopek delitve omrežja. Sestavljen je iz ustvarjanja in dodeljevanja rezin. Oba modula ureja upravljanje rezinjenje omrežja. Količina rezine je odvisna od storitvenih zahtev aktivnih odjemalcev. V scenariju 1 se predpostavlja, da je aktivnih odjemalcev 96. Obstaja nekaj kombinacij: 70 eMBB, 10 mMTC, 10 URLLC, 2 glas in 4 eMBB_p. V scenariju 2 je to 52 eMBB, 21 mMTC, 15 URLLC, 24 glas in 5 eMBB_p. V skladu s standardom 3GPP je pasovna širina, potrebna za eMBB_p, 10 G bit/s. Pasovna širina, ki je na voljo na bazno postajo, je 6 G bit/s; vendar je 1 G bit/s dodeljen za signalizacijo, zato je na voljo le 5 G bit/s za servisiranje odjemalcev. Iz rezultatov simulacije je razvidno, da scenarija 1 in 2 dosegata 24-odstotno oziroma 38-odstotno izkoriščenost pasovne širine.

Ključne besede: rezinjenje omrežja; 5G; SDN; QoE

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1 Introduction

In general, public networks [1] provide ease of usage and a wider range of coverage with limited resources as the number of users availing of the resources increases. It suffers from latency and bandwidth constraints, which in turn influence the Quality of Service (QoS) experienced by the customers. On the other hand, a standalone private network [2] ensures services to limited customers with assured QoS. The private network can be considered a logical or virtual network. One of the primary factors contributing to the emergence of future fifth generation (5G) networks is the imperative to efficiently support a wide range of novel use cases on a shared network infrastructure.

5G of wireless communication is envisioned to provide a higher data rate, lesser latency, and enhanced capacity when compared to existing Fourth Generation (4G) networks. Various industries that are moving towards complete automation have slowly started to adopt 5G since the connectivity services offered by 5G are more promising. The connectivity services can be classified into three categories: enhanced mobile broadband (eMBB), massive Machine Type Communication (mMTC), and ultra-reliable low latency communication (URLLC) [3]. Due to the enhanced features supported by 5G, the QoS experienced by applications also gets enhanced.

In order to increase revenue, the service providers of 5G are exploring the business model through the concept of network slicing. Network slicing [4] is fundamentally overlaying a private or virtual network onto the existing infrastructure network. The flexibility is introduced so that each slice of the network can have its own logical structure, security protocol, performance requirements, etc.

The concept of network slicing introduced in 4G [5] confined its operations within the same infrastructure. Access Point Name Routing, Multi-Operator Core Network (MOCN), and Dedicated Core Network [6] are used for this realization. The concept of virtualization [7] is introduced in 5G along with the existing Radio Access Networks (RANs) [8] to realize network slicing. Through network slicing, the service providers make meaningful commitments to the customers by ensuring their expected QoS.

A network slice possesses self-contained characteristics, meaning that it may function independently after deployment, without requiring human involvement, by relying on the provided customizable governance model. This characteristic renders slices as customized virtual networks that provide self-contained functionality. In this context, it is possible for each network slice to possess distinct network architecture, engineering methods, and dynamic resource provisioning algorithms. With these features in place, the network slice may function as a smart platform that can automatically adjust its settings to meet the requirements of any given use case.

Network slicing allows a mobile operator to create virtual networks tailored to individual customers and use cases. 5G envisions support for applications such as mobile broadband, machine-to-machine communications, connected cars, etc. These applications need faster, lower-latency, and edge computing resources. A 5G operator may tailor solutions to individual enterprises by prioritizing resources in distinct slices. Slicing can tremendously assist Mobile Virtual Network operators (MVNOs) [9]. Slicing may also improve service continuity by constructing a virtual network that spans numerous local or national networks or by enabling a host network to create an optimal virtual network that matches the devices available in the existing network [10].

As mentioned earlier, all the applications that are driven by 5G can be classified under various categories, namely eMBB, mMTC, and URLLC. The QoS requirements of each of the above vary with respect to latency, bandwidth, and connectivity.

eMBB [3] is used in Smart offices and large-scale event applications. They are driven by voluminous data and, hence, are in need of higher data rates over a wider area. The applications of URLLC [3] are remote surgery, autonomous cars, and Tactile Internet. They have rigorous standards to deal with latency and dependability. The requirement of mMTC [3] is to handle a higher number of devices in a limited area that may only transmit data intermittently. The Internet of Things (IoT) is one of the use cases in this category. Hence, to satisfy the above application-specific QoS, portioning in the logical network is made by the service providers through the concept of network slicing.

The rest of the Article is organized as follows: Section II discusses the state of the art related to existing work. Section III describes the proposed work in detail. Section IV describes the observations made based on the findings. Section V culminates by detailing the importance of the outcome of the study and highlighting the prospects of future work.

2 Literature Survey

The author of [11] has presented a comprehensive review of the advancement of wireless technology solutions, namely 5G cellular network designs. The author elaborated on the following concepts, which will include a subset of the technical components: Device to Device Communication (D2D), Massive Machine Communication (MMC), and Ultra-reliable Networks (URN). The primary propagation challenges associated with mm wave propagation for 5G wireless communications are route loss, blocking, atmospheric effects, and absorption.

The author of [12] examined 5G wireless mobile technologies that are made up of two logical layers: namely, a radio network and a network cloud. In terms of data throughput, spectrum efficiency, latency, capacity, energy efficiency, and QoS, the essential criteria of 5th generation wireless communication have been examined.

In [13], the author discusses the taxonomy developed for network slicing on the basis of various characteristics, namely core design concepts, enablers, slicing resource categories, customer-centric supply chaining schemes, basic infrastructure, and privacy. The author also explained the enabled smart applications, namely intelligent transport systems, smart industries, smart homes, health care, and smart grids.

In [14], the author developed an architecture of network slicing in 5G communications for heterogeneous wireless domains. The architecture is developed using cutting-edge technologies such as Long-Term Evolution-Advanced (LTE-A), Software Defined Network (SDN), etc. The author has presented the performance enhancements that could be achieved through the new architecture in various scenarios.

The author of [15] presented the benefits of incorporating network slicing concepts by integrating the physical 5G Infrastructure with SDN and Network Function Virtualization (NFV). From the studies carried out by introducing the dynamic architecture, it was found that a wide range of applications with expected performance were achieved.

The author of [16] examined the impact made by network slicing on the layered architecture of 5G. The layers considered for analysis are the infrastructure layer, network function layer, service layer, and Management and Orchestration (MANO). The functionalities of each layer were studied in context with network lifetime enhancement and the security of the network.

The authors of [17] investigated the performance of 5G by incorporating Network Slicing. A priority-driven, entry-controlled strategy is adopted for allocating resources to the incoming 5G traffic. This strategy consists of both inter- and intra-slice priorities. The traffic pertaining to mMTC and eMBB is being investigated. The performance of NS3 simulator in reducing network congestion is analyzed.

From the above literature, it is observed that not much work has been carried out to investigate the impact of network slicing in 5G. The authors [17] have investigated the performance of the 5G incorporated in network slicing pertaining to traffic mMTC and eMBB.

In a realistic environment, the 5G network can have the composition of all services, namely eMBB, mMTC, URLLC, voice, and Enhanced Mobile Broadband Prioritized (eMBB_p). Hence, to explore the importance of network slicing with respect to bandwidth utilization.

This research considers different scenarios, and the results obtained for the best scenario are detailed in this article, which is claimed to be the novelty behind this research.

The investigation into QoS achieved by each service and different scenarios under the bandwidth utilization strategy adopted above is in progress.

3 Proposed Methodology

In this research, two scenarios are investigated in order to allocate bandwidth to customers. By creating network slices on demand, mobile operators may effortlessly and dynamically serve new use cases. The services offered by 5G will create demand based on user requirements and by incorporating the SDN network to maintain QoS.

3.1 System Model

The system model of network slicing in 5G is presented in Figure 1. In this, the 5G network is layered with SDN to provide efficient bandwidth to the user.

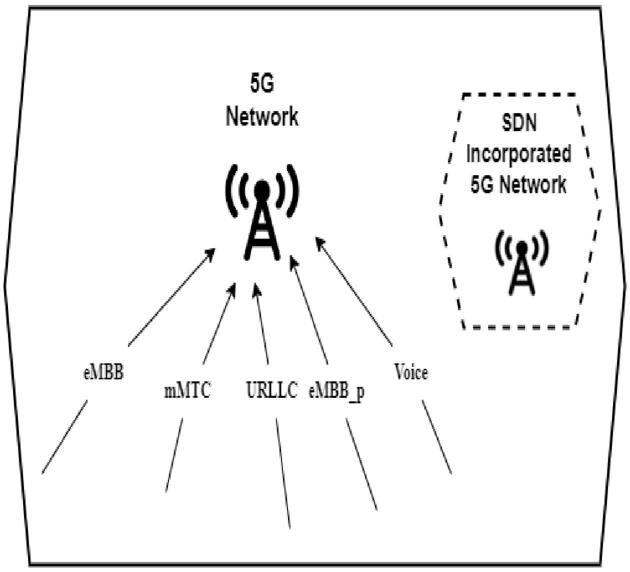

Figure 1: System model of network slicing in 5G Network

In this investigation, the services that are supported by the concept of network slicing are eMBB, mMTC, URLLC, voice, and eMBB_p. In cases where the bandwidth is not sufficient for the transmission of data offered by these services, they are regulated by using the SDN-incorporated 5G network to maintain the QoS.

3.2 Network Slicing in 5G

Let $\beta_{€i}$ be the total bandwidth required for the differential services associated with the Base station. Let β_{5G} be the bandwidth available in the associated Base Station (BS) and β_{SDN} be the bandwidth offered through network slicing. Let €i be the service class of the clients dwelling in the network at any particular instant. Such that i varies from 1 to N. As mentioned earlier, each class of €i exhibits different service requirements as given in Table 1. Let ϕj be the number of BS present in the considered 5G scenario. Let δj be their serving capacity. Let α be the number of clients falling under €i service class being served by ϕj BS at any particular instant. Let $¥_{\alpha}$ be the QoS requirements of each of these clients. The degradation in ¥ is generally realized whenever the clients are not well connected with the BS. It also depends on their allocated resources. Whenever any of this reasoning is observed, the process of Network slicing is invoked. When β5G exceeds its full capacity, a slice of resources pertaining to β_{SDN} is assigned to these clients. Thereby, the ¥ offered to them is strengthened.

Table 1: 5G Services and its Bandwidth

Services	Bandwidth	Class
eMBB_p	10 G bit/s	5
eMBB	100 M bit/s	4
Voice	100 M bit/s	3
mMTC	10 M bit/s	2
URLLC	1 M bit/s	1

The SDN architecture-based network slicing in the 5G Network is shown in Figure 2. It consists of five different services, namely eMBB, mMTC, URLLC, Voice, and eMBB_p, which request Bandwidth from the serving BS and its class is shown in the Table 1. The BS initially checks whether the bandwidth available is sufficient to provide service-specific QoS to the requested client. If sufficient, services will be provided, and performance will be analyzed. Otherwise, the BS request from SDN Serving BS to provide slices to accommodate the requirements of the clients Thus, SDN allows different virtual networks to be overlaid on the same physical infrastructure.

eMBB_p traffic might be expressed mathematically as a function of user traffic. The mean arrival of λi of a single user may be determined using the number of users (αi) as follows:

$$\lambda eMBB\_p = \alpha i * \lambda i \quad (1)$$

In this research, Network slicing is considered the primary component of the system model. This component assists in the generation of slices to meet the resource requirements of the client services considered in the scenario. Its generation depends on the features of the core network, RAN, and UE. It is further broken down into its subcomponents, namely, Slice creation, Slice allocation, and Slice management. Slice creation does the slicing of the 5G network with the aid of SDN. Slice allocation separates the entire type of slices, while slice management controls the entire process involved in the above two.

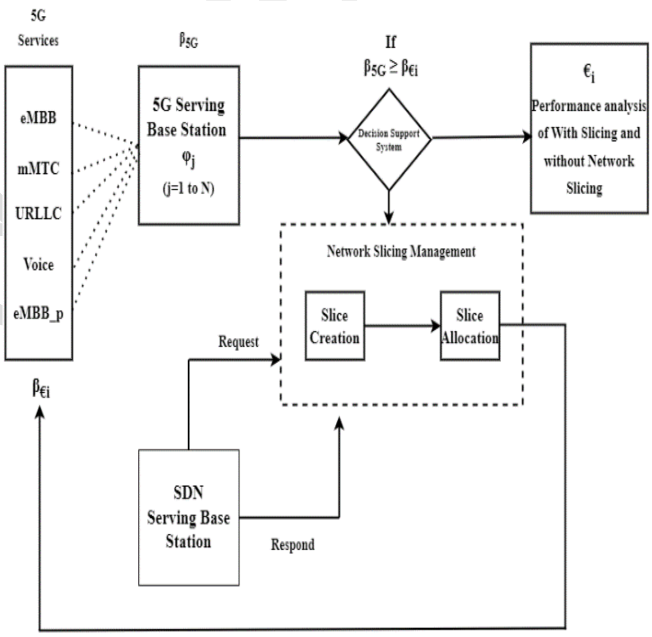

Figure 2: Proposed SDN Architecture Based Network Slicing in 5G network

After slicing, using the feedback mechanism, it provides bandwidth to all the services.

3.3 5G Networks

Slices of the 5G network [18] may be constructed in random areas. The region of the networks that are sliced is a crucial consideration when implementing network slicing. The main parts of the 5G network are the RAN and the Core Network. User devices are linked to the central node of the network through RAN. The RAN is provided by connected BSs and controllers. The core network is connected to other networks through the Internet. A network node is the segment of the 5G network where network slicing can be applied.

Flexible network slicing allows slices to be constructed on top of a shared infrastructure, each delivering customized network services to meet the demands of the use case.

3.4 Software Defined Networks

Sectioning the connection to implement the concept of Network slicing is realized through SDN architecture, as shown in Figure 3.

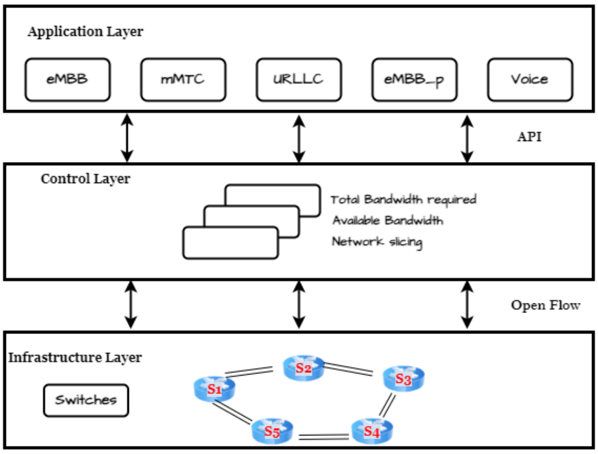

Figure 3: SDN Architecture

It is used to regulate traffic flows via the Application Programming Interface (APIs) of a central control plane. Using the application layer, the control plane configures Bandwidth resources so as to meet the requirements of individual clients.

On the basis of their service category, the infrastructure layer of SDN takes responsibility for data forwarding and rule processing needed for the control plane. It also governs essential tasks required for networking. The network slice controller maps and monitors the inter-layer functionality of the network. In the proposed research, the developed methodology is emulated using Python 3.7. It uses various packages, namely: simpy, matplotlib, KDTree, shapely, ski learn, random, Kiwi Solver, numpy, pillow, pyparsing, random color, and python-dateutil, to create the SDN architecture. YAML (Aint Markup Language) is used for reading input configuration. The operations of the clients are asynchronous as they use discrete event simulation. Matplotlib is used for data visualization. It is accomplished through a 2D plot. KDTree is used to determine the nearest-neighbor lookup. Shapely is used for the manipulation and analysis of planar geometric objects. The various classes of services used in this research are eMBB, mMTC, URLLC, and voice.

4 Results and Discussion

4.1 Simulation Parameters

In this research, the proposed system is constructed using the network slicing notion of services offered. Two distinct cases are analyzed. The simulation parameters considered are represented in Table 2.

Table 2: 5G Simulation Parameters

S. No	Parameters with Notations	Value
1.	$€_i$ (Serving Class)	5
2.	ϕ_j (Base Station)	20
3.	δ_j (Serving Capacity)	6 G bit/s (Payload: 5 G bit/s)
4.	α (Total number of Clients)	100
5.	$\beta_{€i}$ (Total Bandwidth)	120 G bit/s
6.	β_{5G} (Bandwidth available in the Base Station)	40 G bit/s
7.	β_{SDN} (Bandwidth offered through Network Slicing)	20 G bit/s
8.	α_1-No. of active Clients scenario 1 α_2-No. of active Clients scenario 2	96 97
9.	$\phi 1$-No. of BS Scenario 1 $\phi 2$ -No. of BS Scenario 2	10 15

4.2 Simulation Scenarios

The simulation scenario is shown in Figure 4. This scenario is created using the Python IDE, and the number of clients considered is 100.

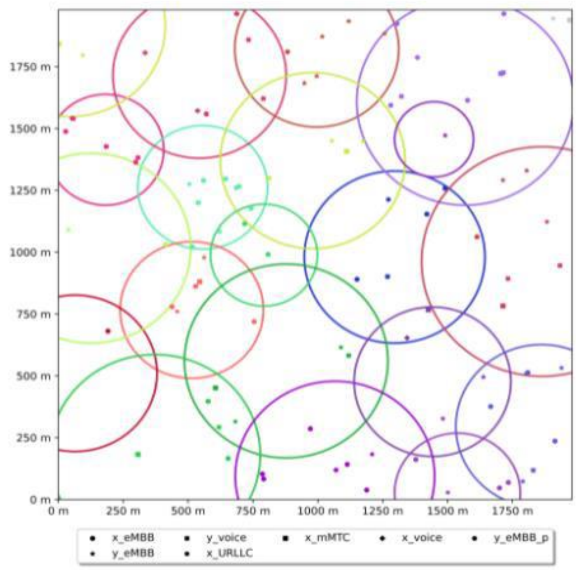

Figure 4: Simulation Scenario for network slicing

4.3 Performance Analysis

In the proposed research, two scenarios with the adoption of network slicing are considered.

To understand the impact of network slicing when the 5G network is accommodated with all five kinds of services, distributed in different ratios, it needs to be investigated. Several scenarios meeting the above requirement have been constructed and investigated. The results obtained from two scenarios with a wide range of variations with respect to the types of services are presented here.

4.3.1 Scenario 1

The performance evaluation of scenario 1 with and without network slicing is shown in Figure 5. Out of the total 100 clients considered, 96 were linked to five different services and assumed to be active clients. The service distribution among the clients is: 70 eMBB clients, 10 mMTC clients, 10 URLLC clients, 2 voice clients, and 4 eMBB_p clients. From Table 1, 47.31 G bit/s is found to be the total bandwidth requirement of these 96 Clients. In this scenario, 10 BSs are required to provide the above bandwidth requirement. Each BS can serve up to 5 G bit/s. Thus, the total offered bandwidth is 50 G bit/s (5 x 10). The required additional bandwidth is provided by network slicing techniques. According to the simulation findings, it is observed that the associated BS offers 35.789 G bit/s while the Network Slicing offers 11.521 G bit/s.

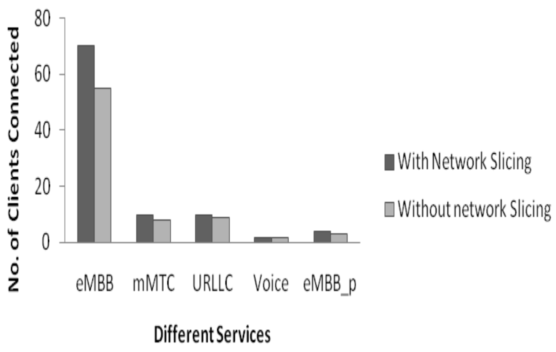

Figure 5: Clients Connected ratio for Scenario 1

The network slice for eMBB_p is shown in Figure 6. BS 1, BS 5, BS 7, and BS 10 have eMBB_p services with a bandwidth of 10 G bit/s. In such a scenario, a single BS cannot provide the needed bandwidth; network slicing is used to obtain the bandwidth available from the nearby BS. The additional bandwidth of 5.521 G bit/s required by BS 1 is sliced between BS 2 and BS 3. Each slice is assumed to have 1 G bit/s. Consequently, BS2 provides 4 slices, while BS2 provides 2 Slices to BS 1. In a similar manner, the allocation of slices is regulated based on the requirements of the BS.

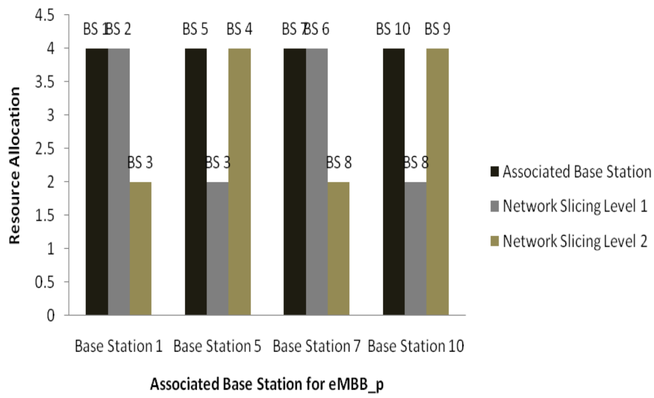

Figure 6: Network slicing for eMBB_p in Scenario 1

4.3.2 Scenario 2

The performance evaluation of scenario 2 with and without network slicing is shown in Figure 7. Out of the total 100 clients considered, 97 were linked to five different services and assumed to be active clients. The service distribution among the clients is: 52 eMBB clients, 21 mMTC clients, 15 URLLC clients, 24 voice clients, and 5 eMBB_p clients. From Table 1, 47.31 G bit/s is found to be the total bandwidth requirement of these 97 Clients. In this scenario, 15 BSs are required to provide the above bandwidth requirement. Each BS can serve up to 5 G bit/s. Thus, the total offered bandwidth is 75 G bit/s. However, G bit/s is required to maintain QoS. The required additional bandwidth is provided by network slicing techniques. According to the simulation findings, it is observed that the associated BS offers 34.372 G bit/s while the Network Slicing offers 21.453 G bit/s.

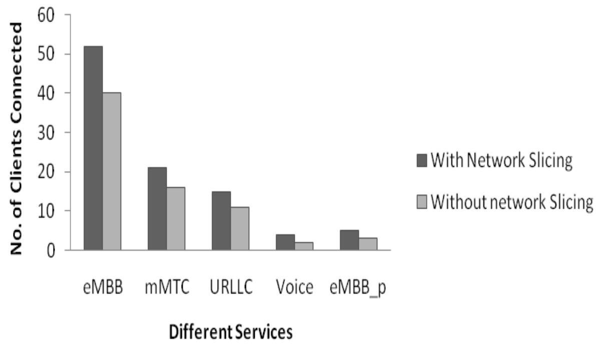

Figure 7: Clients Connected ratio for Scenario 2

The network slice for eMBB_p is shown in Figure 8. BS 1, BS 4, BS 7, BS 12, and BS 14 have eMBB_p services with a bandwidth of 10 G bit/s. In such a scenario, a single BS cannot provide the needed bandwidth; network slicing is used to obtain the bandwidth available from the nearby BS. The additional bandwidth of 5.332 G bit/s required by BS 4 is sliced between BS 5 and BS 6. Each slice is assumed to have 1 G bit/s. Consequently, BS2 provides 3 slices, while BS2 provides 3 Slices to BS 4. In a similar manner, the allocation of slices is regulated based on the requirements of the BS.

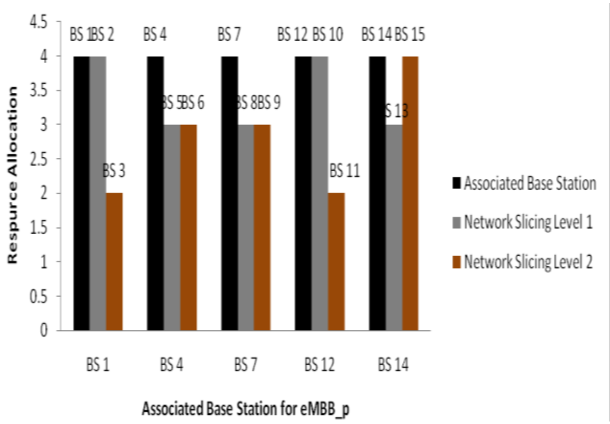

Figure 8: Network slicing for eMBB_p in Scenario 2

4.3.3 Bandwidth Utilization

The consumption of bandwidth in both scenarios is depicted in Figures 9 and 10. In Scenario 1, the utilization of bandwidth without network slicing is 76%, while it is 24% in scenario 2 to achieve application-specific QoS by the clients.

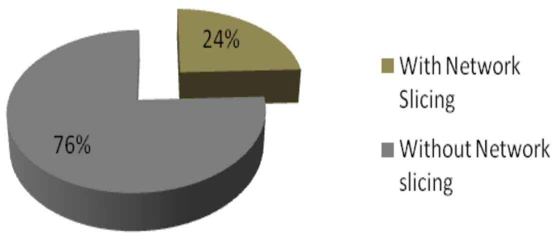

Figure 9: Bandwidth Utilization for Scenario 1

In Scenario 2, the utilization of bandwidth without network slicing is 62%. Through network slicing, 38% of the bandwidth has been utilized to serve the clients and achieve QoS.

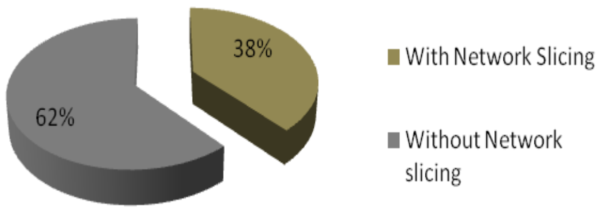

Figure 10: Bandwidth Utilization for Scenario 2

5 Conclusions

In this research, the concept of network slicing is investigated. SDN-based architecture-based network slicing in the 5G network is being developed. 5G clients of five different types of services, namely: eMBB, mMTC, URLLC, voice, and eMBB_p, are considered. The ratio of them is varied, and two different scenarios are constructed. Their performance with and without network slicing is analyzed. The developed SDN architecture is simulated using Python 3.7. From the simulation results, it is found that scenarios 1 and 2 achieve bandwidth utilization of 24% and 38%, respectively. Further, through network slicing, the clients of differential services are assured of the required bandwidth. The developed work is assumed to have static clients; hence, the BS associated with it and network slices will remain constant. However, to understand a more realistic scenario, the clients can be subjected to mobility, which is considered the future of work.

6 Acknowledgments

The authors are grateful to the Centre for Internet of Things (CIoT), Madras Institute of Technology Campus, Anna University, for providing the resources needed to complete the research.

7 Conflict of Interest

The authors declare that there is no conflict of interest.

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Arrived: 05.09.2024
Accepted: 24.04.2024