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Enhancing Service Classification for Network Slicing in 5G Using Machine Learning Algorithms

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Abstract
In a virtualization aspect, Network Function Virtualization (NFV) has a role in implementing network slicing. Using NFV to slice the network, make the network more flexible, but very complicated in term of management. A slice is a set of services that the network needs based on the user requirements. Moreover, each slice has a set of services called sub-slice, or one type of service. This research aims to improve the availability and scalability of the services in network slicing by managing the performance of the inter/intra slice in real-time. Also, this research will enhance the Quality of Service (QoS) for the network resources and services and the Quality of Experience (QoE) for the users within the slice when we applied machine learning algorithms to classify and predicate accurate service to the user. With this research, we implemented the slices based on the principles of NFV to deliver flexibility in the 5G network by creating multiple slices on top of the physical network. When the implementation of the prototype is completed, traffic generated tool was used to send traffic over the slices. After data collection, we classified different services using machine learning algorithms. The optimizable tree model had almost high accuracy among other algorithms which was 99.3%.

Keywords: 5G · Network Slicing · NSSF · Traffic-Classification · QoS · inter-slice · NFV · E2E · Machine Learning

1 Introduction
Next-generation networks will be configured with softwarization techniques based on a Software-Defined Network (SDN) and NFV. The implementation of the network elements will be started from the core layer to the access layer. The key benefits of using the SDN are to reduce time configuration for complex networks, reconfigure them easily and optimize the resources using a programmable interface [1]. In addition, there are different aspects that lead the future network using NFV because it is bringing a great effect on the network especially when it is optimizing the Network Functions (NFs), while the SDN optimises the fundamental system [2].

The NF is a functional block built on top of the physical or virtual infrastructure to create a network service and define the functional behaviour of the networks. With future systems, all NFs and resources will be virtualized and reconfigured in the core network to provide scalability and flexibility to the networks [3]. The network resources such as storage, computing and radio access network will be virtualized and dynamically managed to scale up/down the resources in the network. A network slice considered a logical network contains a set of resources [4] These resources will be provided in the slice by the service provider based on the requirements that have been agreed upon in the service level agreement (SLA) between the service provider and customers (slice owner).

The 3G Partnership Project (3GPP) in their TS 28.801 explained the concept of network slicing, the network functions and the connection between them. Also, 3GPP explained and standardised the QoS and QoE for future mobile networks. In this survey [5], the 3GPP TS 23.501 and 23.502 reviewed in terms of the mobility management in 5G with inter-slice handover in a service level. In their research directions, authors mentioned that the continuity between the slices is not given in the 3GPP TS. Furthermore, the creative concept of the Network Slice Subnet Instance (NSSI) is explained within the 3GPP TR 28.801. Network Slice Management Function (NSMF) send a request to the Network Slice Subnet Management Function (NSSMF) to create the NSSI. The NSSI depends on the availability and reliability of the physical and logical resources, and it is work on the run-time operations. The 3GPP TR 23.799 discussed all that in their technical specification document.

The QoS set of policies needs to be considered in real-time traffic with a group of functions and services to guarantee the required bandwidth for each application. With the QoE, the performance of the service needs to be improved to bring an efficient service to cover the demands of the end-user. However, there are three types of verticals that will be considered in this work: eMBB (enhanced Mobile Broadband), URLLC (ultra-Reliable Low Latency Communications) and MIoT (Massive IoT) [6]. Furthermore, managing the priority of the slice and the QoS flow during the session setup of the service are still open issues. In addition, slice and mobility management at the service level in real time is discussed in a state-of-the-art paper in [7].

In Sect. 2, we summarize the related research to implement the slice approach on 5G systems. In Sect. 3, we propose our slicing prototype and classification model using our dataset. In Sect. 4, we explain and evaluate the performance of the model. Finally, in Sect. 5, we conclude this paper.

2 Related Works

By increasing the number of user requirements, the future network was invented to be flexible as possible. Network slicing is used to provide the flexibility needed in the new radio network. The programmability of network service is realized in slice selection. Vertical slice, radio access slice and air interface slice mentioned in [1]. With vertical slicing, they could slice one network into multiple vertical networks. Each slice could have its own core network and architecture for End- to-End network slicing in the 5G network. In addition, this architecture gives flexibility, scalability and efficiency for air interface network slicing [8].

Vassilaras et al. [9] reviewed all the network slice problems. In addition, their concentration on controlling and managing the resource allocation in the virtual network using a real-time management algorithm.

Yousaf et al. in [10] proposed a network slicing with flexible mobility and QoS/QoE support for 5G networks represented an open research problem. They mention many issues that need to be considered, such as packet filter for 5G services. Zhang et al. in [11] presented a network slicing architecture, the concept and the management of the network slicing and the handover management scheme for handover between different access networks.

Many issues and challenges discussed in network slicing for the future network. The new approach to mobility management needs to be developed to support seamless handover for 5G new radio in network slicing to improve the continuity and scalability of the user experience [12].

Oladejo and Falowo demonstrated the network capacity of Mobile Virtual Network Operators (MVNOs) in a multi-Tenancy. In their work, the resource allocation is realized based on the hierarchal model by setting a priority to different slices to solve the resources allocation problem. Moreover, SLA between infrastructure providers and MVNOs was taken into consideration [13]. Zhang et al. in [14], proposed flexible rescheduling network services over multi Virtual Network Function (VNF) within different orders in runtime process. Their sharing and preemption model was developed using the Integer Linear Programming algorithm to increase the number of legal resources. Also, the result showed that this model beats the other models in terms of resource sharing acceptance in the virtual network.

Mobility management architecture based on a network slicing explained in which means each slice manages its users across heterogeneous radio access technologies. In this architecture, each slice has the slice configuration and service characteristics control different requirements such as latency and speed [15]. Mobility [16] is one of the key issues in a service level for future networks because the management in the mobility is in two levels of mode: idle mode for the user reachability and connected mode for the handover. Sattar and Matrawy in [17] mentioned two key challenges in network slicing for 5G core Networks in terms of isolation and End-to-End delay. The End-to-End slice means creating a connection between the core network and RAN.
The relationship between this connection could be one-to-one or one-to-many with a real-time application. They applied Mixed-Linear Integer Programming (MILP) as a formulation for a model optimization algorithm. In the end, they simulated the 5G core network and slice request and their simulation result met the minimum requirement, but it need more enhancement.

A slice management schema proposed in [18] to reduce the interference in a wireless network by defining different policies within their routing protocol. A virtual function is used to satisfy the QoS requirement when the resources isolated between slices are done based on their priority. In this paper, traffic policy flows based on two types of priority: high and low priority. So, the highest weight gets through the shortest path to provide a better QoS and lower interference to VIP slices. Their proposed solution is based on brute-force search to find the shortest path and k-hop distance interference algorithm because it is used with different types of wireless networks. Besides, they evaluated the routing algorithm performance for the wireless network environment. In the end, a comparison between their result and the naive slice management method showed that their method defeated NSM in terms of the QoS, throughput and delay performance.

Shurman et al. in [19] designed network slicing over a mmwave bands with a frequency range between (30–300) GHz to prove that their work supports the 5G channel. Their scenario has two types of priorities based on the reserved value. Moreover, this value is set as a tag on the frame, which corresponds to a slice priority after sending the packet to the switch. The Work in [20] proposed a set of policies that work with network slicing and sub-network slicing in a dynamic way. Their ontologies managed the lifecycle for the slices dynamically based on two types of policies: inter-slice policy and intra-slice policy. In their model, the resources and the services came from remote health scenarios to support eHealth and Ultra HD video to support multimedia services. Virtual resources allocation within slice priority identified in [21] to change the traffic dynamically without affecting the QoE for the users. The inter and intra-slice priority will depend on the QoS requirement for various users and services in the future network.

A dynamic management resource approach applied a reinforcement learning algorithm to meet the end-users requirement [22]. In this approach, the authors managed the resources using a Markov Decision Process (MDP). Then, they utilized Q-learning for managing the resources dynamically. In the end, they compared their result with different algorithms using an inelastic flow to demonstrate that the number of the resources increase, the amount of profit increase and the satisfaction rate for the QoS increase in the dynamic resource allocation.

Kim et al. in [23] addressed the complexities of the 5G network, where each user within the slice has two service function chains (SFCs). The first SFC handles the traffic in the control plane and the second one is used to carry the traffic in the data plane. Both of the SFCs work on the physical and virtual layers to reduce the traffic cost according to the users’ requirements in different verticals in terms of latency and bandwidth. Supervised learning algorithm is used to classify and predict slice traffic over the 5G network [24]. 5G services are allocated dynamically in real-time. Their work is done based on open-source code to program the slice decisions.

Based on the authors’ knowledge, none of the above research paper deal with the 5G function to solve the open research issues, such as resource allocation, mobility and slice management. For that reason, we will build a set of slices on top of the 5G core using open-source code to send traffic, collect the slice traffic and predict the 5G services using the best machine learning model that’s fit our dataset. This solution will enhance the QoS and QoE for the user when applying more services to future networks and let the users connect to multiple slices at the same time.

3 The Proposed Model

This system will be developed using softwarization approaches based on SDN and NFV. All NFs will be implemented according to the 5G functions. The 5G means a wireless network standard by a group of telecommunications companies to increase the speed of data communication, capacity and coverage in logical networks instead of the traditional networks. The compensation between SDN, NFV and 5G functions introduced real-time dynamic programming services to the network based on the use cases demand. From the diagram below in Fig. 1, the infrastructure layer will be represented as a user plane which contains all the slices that will be implemented as virtual Tenants. The 5G core will work as the brain of the network to control the top layer of the network (application plane) and the lower layer (user plane). The Proposed slice model builds on top of Free5gc open-source code for the 5G core [25] and UERANSIM open source code is used for the users and radio access network [26].

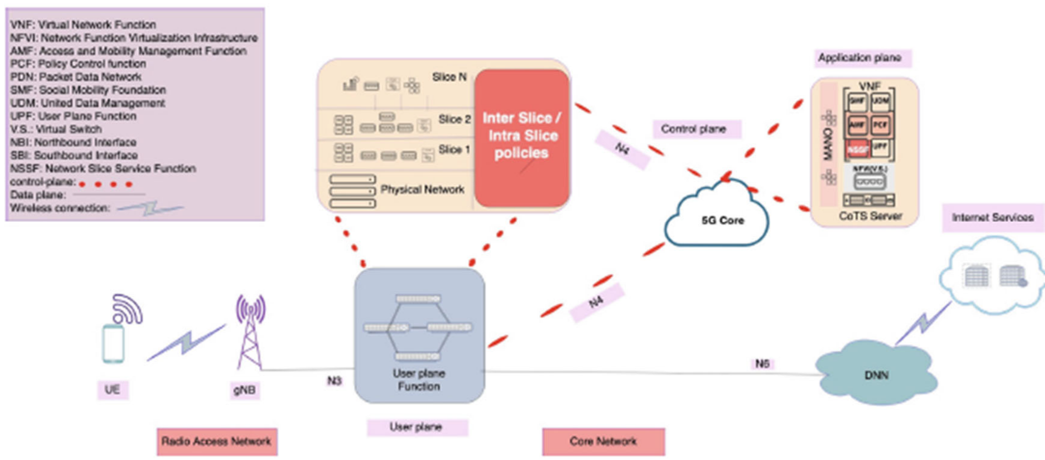

Figure 1 System prototype

All the slice resources and services will be reconfigured by the 5G core using the N4 interface. In addition, the application plane will contain all the functions and services. The 5G core needs to manage the slices in the data plane such as slice policy, data flow and slice management. All the future networks will need to implement the slice in the core network to control the users in the data plane. The slice implementation will use Access and Mobility Function (AMF) for controlling the user data, mobility state and authentication, Police Control Function (PCF) for policy rules and authorization and Network Slice Service Function (NSNF) to manage the policies for the network slicing. According to the 3GPP specifications, all functions will be implemented at the core layer and will run through different types of interfaces based on the function. All these functions will be connected using a specific interface named Service-Based Interface (SBI) through the SBI Message Bus. In this system, many functions will be configured, such as mobility, policy control, and priority with different functional requirements such as latency, mobility, availability, reliability and data rates to serve the specific users. Furthermore, all 5G functions will be configured in the core network and then will be run in the user plane depending on the requirement of the slice management in the future network as listed below:

- Adding/scaling a set of services and resources that support the slice.
- Moving the users from one slice to another and assigning the users for more than eight slices at the same time for a specific purpose based on the user demands or in emergency cases.

- Isolating the slices from each other to prevent any interference between the slices.

In slice management, flexibility is one of the features required in the future network, which means that scale the slice up and down. Specifically, the network slice priority will be changed based on the network situation, such as an emergency state or disaster. Moreover, the priority of the user per service needs to be changed depending on the service regulations.

Network policies will be divided into two types: inter-slice and intra-slice policies. The inter-slice priority deal with the devices inside the slice. On the other hand, the intra-slice policy deals with devices within different types of slices. The 5G core in this system will be responsible for managing the mobility as a service, managing slice policies, the QoS flow and the life cycle for the slice. Furthermore, each Tenant has a different type of service such as Tenant 1 for emergency services and Tenant 2 for video live stream. In the end, this system needs to use management optimization techniques to support a users. Indeed, network slicing faced many challenges such as:

- Guaranteeing that the SLAs will be available on each slice over the 5G networks at
- the same time and increase the QoS and the QoE for the user based on the requirement.
- Combining the main keys for the future networks: flexibility, efficiency and lightness. Slicing is used to combine multiple applications on a single network.
- Minimising the Operating Expenditure (OPEX) and improving the revenue of the
- networks.
- Time increases for the network services in two cases Time-to-Market (TTM) and Time-to-Customer (TTC).

4 Result and Discussion

In this section, we will explain our prototype and how we generated the traffic over the 5G networks. Free5gc is required for the 5G core on the core layer, and it is run on the Ubuntu server. For the access layer, the User Plan Function (UPF) is run on the Ubuntu server and connects to another server containing UERANSIM, which is used for the Radio Access Layer (RAN) and the user device. Inter and intra slice were configured over the 5G core, UPF and RAN. Each user can connect to more than eight slices and generate traffic over them based on the user requirements.

Traffic is generated over the slices and over the 5G core. The traffic was collected from the core and user plane using Wireshark. From the Wireshark file, we checked the performance of the network in terms of delay, throughput and window size on different streams.

TCP stream sent over slice number five with 60.64.0.1 as the IP address for the slice to show the throughput of the connection from the online server with IP address 140.110.240.80. The number of the packets plotted over time in steven's graph as is shown in Fig. 2. The number of the TCP packets increased regularly until 26 s then the TCP packets become stable until 36 s when the TCP packets start increase. The number of the TCP packets in our work is better than the result for the TCP protocol in [27].

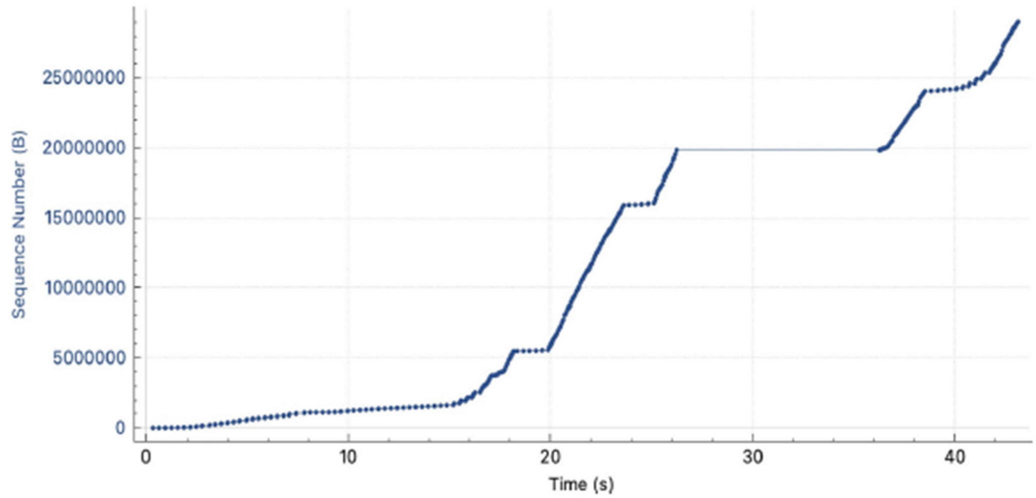

Figure 2 Steven's graph for TCP traffic

The throughput average for six streams is shown in Fig. 3. This traffic was sent from the online server using a traffic-generated tool to slice number six that the user connected to using 60.65.0.1 as IP for slice number six. On the other hand, the throughput average for 44 streams is shown in Fig. 4. This traffic was sent from the online server using a traffic-generated tool to slice number five that the user connected to using 60.64.0.1 as IP for a slice. The connection dropped between 28 s–38 s as is shown in the graph. TCP packets length in the blue line, the throughput stream in yellow and the goodput in the green line. The average throughput for the 5G slices is important with and without the user mobility. The average packets arrival on the system is better than the result in [28].

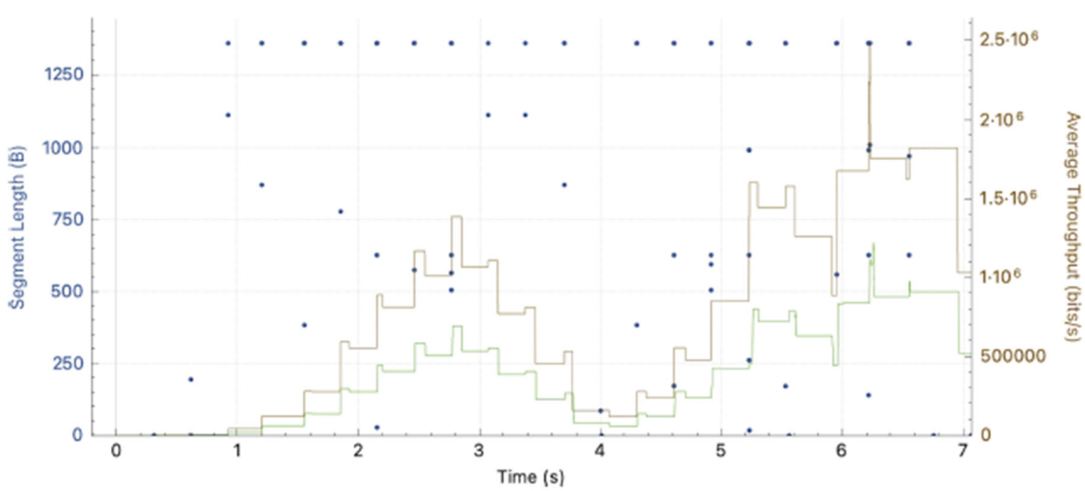

Figure 3 Throughput for the 5G network after sending 6 streams

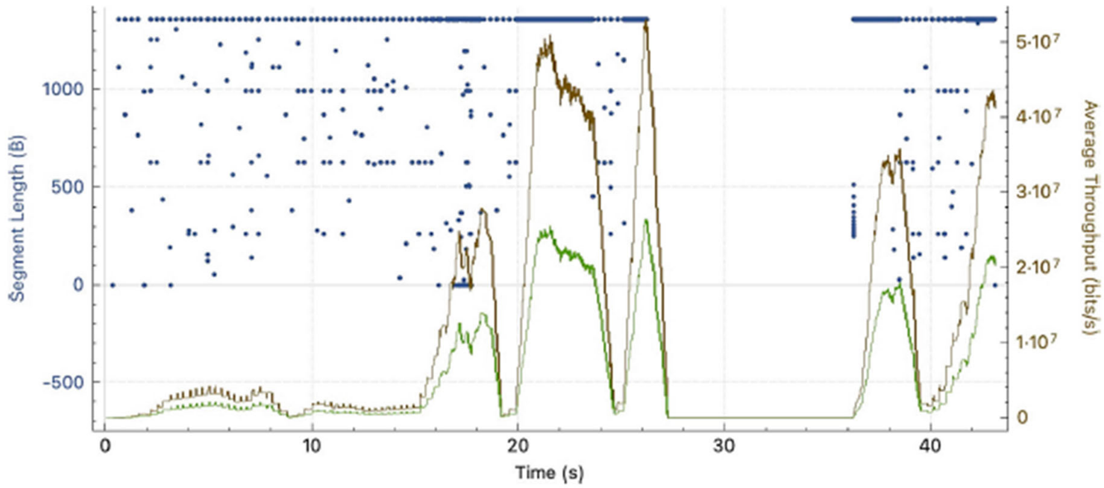

Figure 4 Throughput for the 5G network after sending 44 streams

After sending the traffic over slice number five, we calculated the duration for the packet when it is sent and received from the server to the slice using TCP protocol. In this case, Round-trip time (RTT) determines the successful delivery of the packet as is shown in Fig. 5.

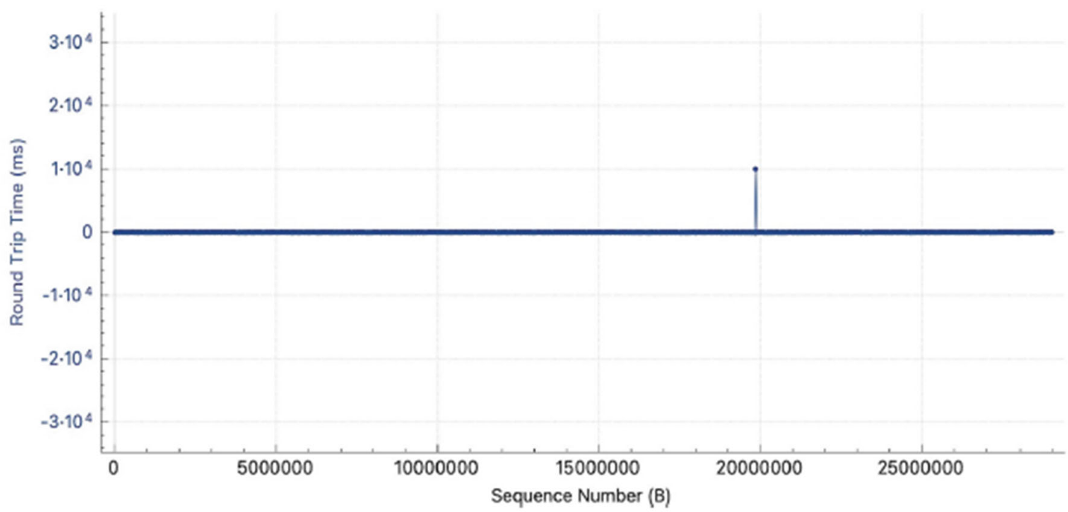

Figure 5 Round-trip time

Window scaling for 44 streams over slice number five as is shown in Fig. 6. After generated the traffic over the 5G network, we calculated the delay as is shown in Fig. 7.

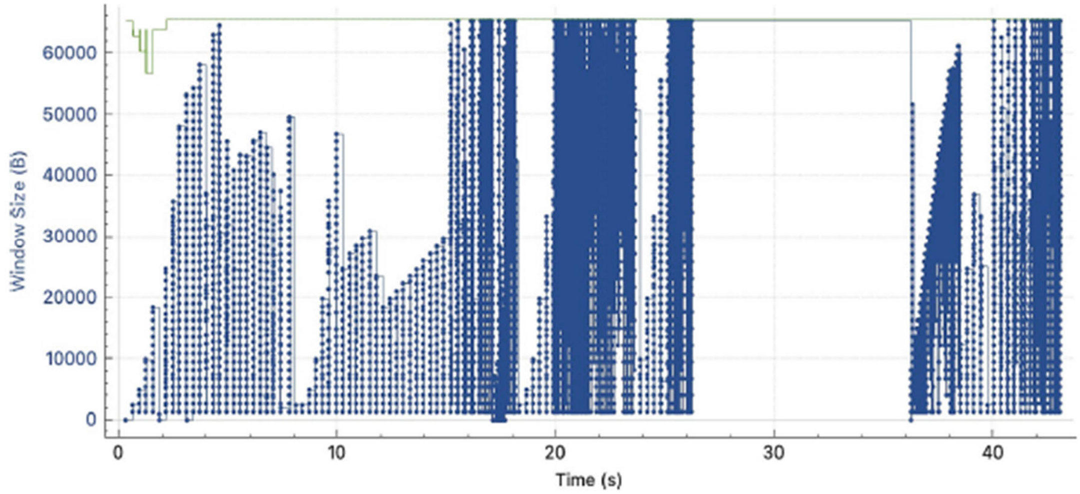

Figure 6 Window scaling

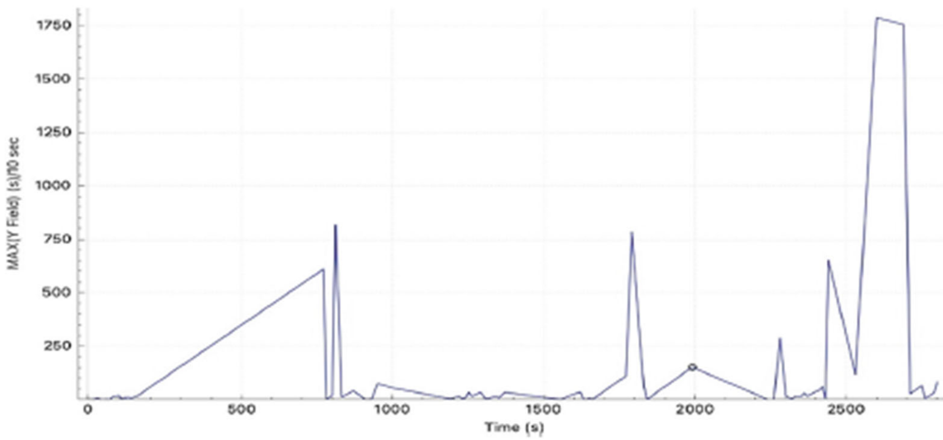

Figure 7 Delay

In this research, we will classify the 5G traffic for different services using machine learning in Matlab. The idea of using different machine learning algorithms is to choose the best model that's fitted our purpose. We need to apply an algorithm that has good accuracy and less training time to make the decision of choosing the services faster to reduce the energy. We didn't look at the computation power in this paper, but it will be investigated more about it in our future work.

The classification model will help us to identify the best algorithms for our dataset. Our dataset contains: Traffic time, source and destination address, protocol name, the length of the packets and the packet information. Different types of protocols are generated over the 5G systems such as: TCP, UDP, ICMP and HTTP. In MATLAB, we will identify all columns as input features except the service name will be the output. Machine Learning Model Classification for the prototype is shown in Table 1. Our prediction accuracy values are enhanced in many models and get higher accuracy compared with the work in [29]. In our system, different types of traffic are classified over the End-to-End 5G slice network. The accuracy is not only our concern, but we need to predicate future services in less time. For this reason, the medium tree model has less training prediction time compared with other models.

After the classification model, the Confusion matrix for the best algorithm that's fitted our model is shown in Fig. 8. The optimizable tree model trained with high accuracy which is 99.3% as shown in Table 1. With our model, the maximum number of splits was 258 and the split criterion was twoing rule. The optimization result for this model is shown in Fig. 9 for the minimum classification error.

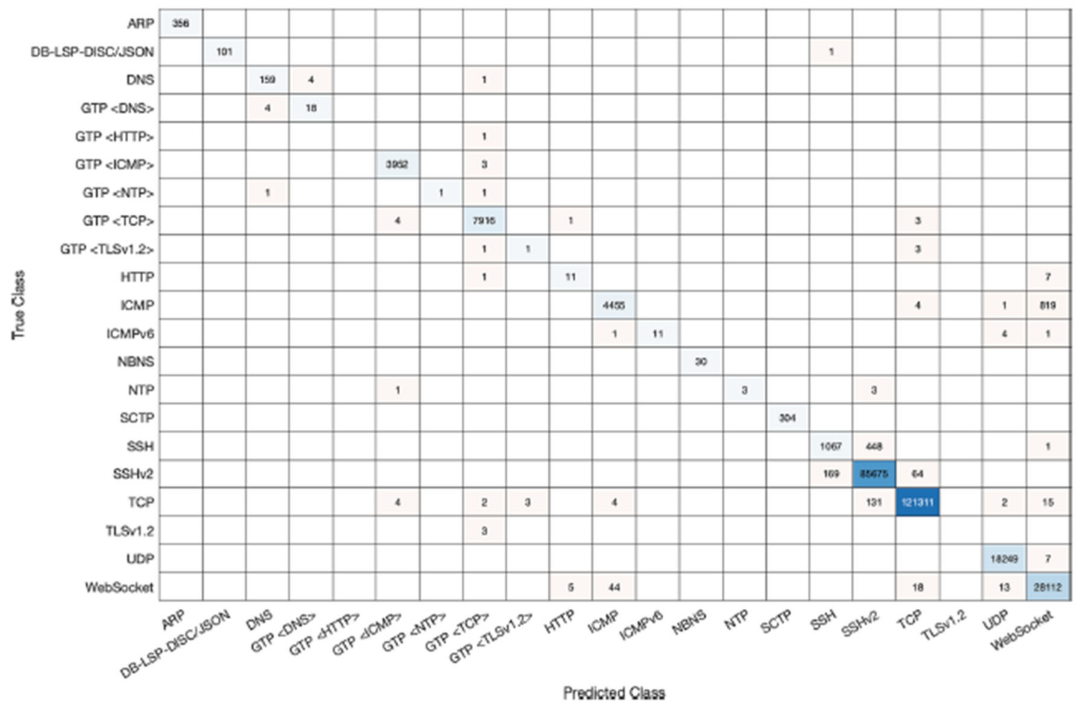

Figure 8 Confusion matrix for the Optimizable model

Table 1 Model classification

Class	Classification Model	Accuracy (%)	Prediction Speed (obs/sec)	Train Time (sec)
Trees	Fine	**99.2**	810000	13.029
	Medium	**97.0**	900000	**11.633**
	Coarse	89.3	820000	18.956
	Optimizable	**99.3**	1300000	719.5
SVM	Linear	80.1	7600	48116
	Quadratic	86.6	400	72551
	Boosted Trees	**98.8**	42000	4441.5
Ensemble	Bagged Trees	**98.8**	34000	4880.1
	RUSBoosted Trees	33.4	37000	5687.6

Class	Classification Model	Accuracy (%)	Prediction Speed (obs/sec)	Train Time (sec)
	Narrow	94.0	350000	5562
Neural Network	Medium	**95.2**	390000	6120.7
	Wide	**95.9**	250000	19540
	Bilayered	91.6	320000	11392
	Trilayered	89.5	310000	17352

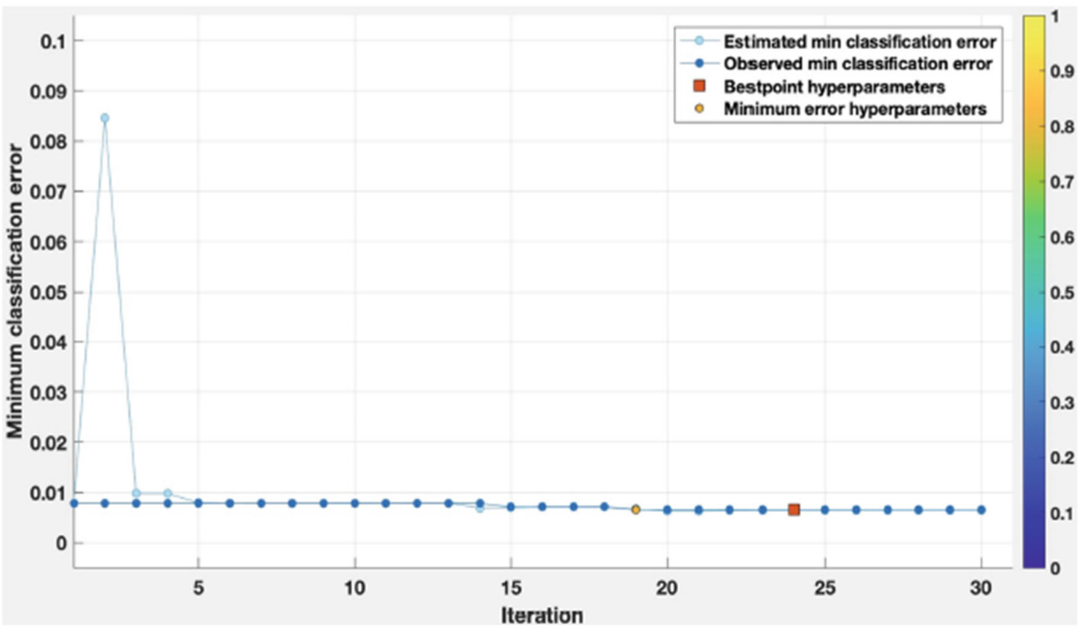

Figure 9 Minimum classification error

5 Conclusions and Future Work

Several techniques need to be implemented to make the 5G core takes the right decision with the upcoming request to choose the slice and service within the slice. For example, when the user is on a video call, then at the same time, this user receives a phone call. So, the 5G core needs to make sure that the user will be available in both slices without any interference or cut in a call. But if the user decides to leave the video slice and move to another one, the 5G core will be able to forward the traffic based on the users' demands. Based on the authors' research resource allocation, slice and mobility management is still an open issue and under investigation by telecommunication companies and researchers especially at a service level for real-time application. In this research, we implemented the slices over the core and user plane layer and generated traffic over the slices and the core to see the performance of the traffic when we sent different types of services. After training our model with multi-machine learning algorithms. We will identify the best algorithm to fit our model to deal with real-time traffic to predict the services based on the requirements. For future work, we will implement a machine learning algorithm with an SDN controller to connect it with the 5G core to manage the mobility for inter/intra slice without effects the QoS in real-time when it is delivered to the users based on their demands and this system needs to specify the mobility types to support the 5G users.

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