Performance Evaluation for End-to-End Slice Management in 5G/B5G Cellular Networks

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***Abstract*—End-to-End (E2E) virtual networks represent a key technology in future cellular networks. Generally, the E2E connection means each slice has an independent part of the RAN, User Plane Function (UPF) and the 5G Core. Within each slice, a subscriber may have one or more Quality of Service (QoS) flows. These flows only exist within the slices. According to the 3G Partnership Project (3GPP) Technical Specification (TS), it could be at most eight Single Network Slice Selection Assistance Informations (S-NSSAIs) in the Allowed list. Requested NSSAIs sent in signalling messages; registration request, accept and respectively; between the user and the network. These messages allow the network to select the serving Access and Mobility Management Function (AMF), network slices and Network Slice Instances (NSIs)for the user. The research idea is to improve the Quality of Service (QoS) and the Quality of Experience (QoE) for the user when connecting to different slices on the 5G systems. The slice performance for one slice should not be affected by other slice traffic. This paper evaluates the performance of E2E 5G slicing in terms of throughput, jitter, reliability, transmission rate and mobility under different circumstances. In the proposed system, the performance of the slice is checked when the user connects to eight slices or more at the same time. In addition, we propose a slice termination and connection algorithm that allows the user to register new slices. Moreover, the algorithm allows users who are already registered to be released after using slices, enabling more effective use of the network resources.**

***Index Terms*—5G Slicing, Future Network, Inter-Slice, Intra-Slice, Sub-Slices, Network Services, isolation, NSSF, NS, MaaS**

I. INTRODUCTION

Network slicing aims to create virtual networks on top of the physical network [1]. Graph theory and slice queuing are proposed in [2] for Inter-slice management and according to their probability event, the QoS will improve in the future networks. Inter and intra slice management mentioned in [3] and highlight the significant efforts that the network slicing needs to be used in the next-generation networks.

Each virtual service is isolated from other services and it has its own QoS flow for the uplink and the downlink over a specific virtual tunnel. Each virtual tunnel will get an IP address, with a maximum data rate transfer across a given slice. The proposed system aims to manage the performance of 5G services when the user connects to these services virtually. This system will evaluate the performance of the users when the users connect on several slices with multiple QoS levels to get better QoE. A Free5gc [4] an open-source code will be used to evaluate and enhance the performance of these slices after implementing different scenarios.

5G core includes AMF, Session Management Function (SMF), Policy Control Function (PCF), Network Slice Selection Function (NSSF), Authenticate Server Function (AUSF), Unified Data Management (UDM), and Unified Data Repository (UDR) [5]. In addition, S-NSSAI is managed by the NSSF in the 5G Core. Moreover, it contains Slice/Service Type (SST) and Slice Differentiator (SD) are identified by the 3GPP TS 29.571 version 16.6.0 Release 16. The main 5G service types are [6]:

1) enhanced mobile broadband (eMBB) requires High speed, high capacity and allocates bandwidth dynamically. Examples are virtual reality (VR), Augmented Reality (AR), ultra-high-definition (UHD) video and Audio.
2) ultra-reliable and low-latency communications (uRLLC) require low latency, high reliability and high availability. For example, autonomous cars, remote-controlled and remote surgery.
3) massive Internet of Things (mIoT) requires dynamic bandwidth allocation, high capacity and speed. For example, IoT devices and smart cities.
4) Vehicle-to-Everything (V2X) requires high capacity, speed and low latency with high-speed vehicles.

In the 3GPP TS 23.501, the 5G QoS parameters for each QoS Flow are defined as follows: 1- 5G QoS Identifier (5QI), 2- Allocation and Retention Priority (ARP), 3- Reflective QoS Attribute (RQA) for Non-GBR QoS Flow, 4- Notification

Control for GBR QoS Flow, 5- Maximum Packet Loss Rate in the Uplink and Downlink for GBR QoS Flow, 6- Guaranteed Flow Bit Rate (GFBR) and Maximum Flow Bit Rate (MFBR) in the Uplink and Downlink these two for GBR QoS Flow, 7- Default Values and Aggregate Maximum Bit Rate (AMBR) includes Session-AMBR and UE-AMBR for Non-GBR QoS Flows [5].

All 5G functions are positioned in the Core Plane of the proposed system on Virtual Machine (VM1). On the other hand, the UPF is placed on a separate Virtual Machine (VM2) and connect to the Data Network Name (DNN). UE subscription information added to the 5G core and saved in a MongoDB database. UE and RAN configured on Virtual Machine (VM3). Each of the UPF, UE and RAN are allocated on the User Plane. To deal with Network Slicing over 5G will identify the slice information for each UE as a set of the S-NSSAI

To get a comprehensive view of the 5G network slicing performance will monitor the bandwidth and the throughput for the allocated slice and make sure that the bandwidth is being used efficiently by inter and intra slices in the 5G networks as suggested in [7].

In the Free5gc [8], each Packet Data Unit (PDU) session will have AMBR for Uplink and Downlink to limit the aggregate bit rate for each UE across Non-GBR QoS flows. Each slice in the proposed system will have a different value for the AMBR for the Uplink and the Downlink.

The proposed system has different service types: eMBB, URLLC, MIoT and V2X. Each slice has its own Sub-Slice, UE could register to all slices, but connect to no more than ten slices simultaneously. In addition, bandwidth transmission demands is classified as high, medium and low based on user superscription.

This paper is a continue work for our overview in [9], we have surveyed all softwarization and virtualization techniques that could be used to implement the network slicing in the future networks. Furthermore, we considered the traffic classification for inter/intra slice depending on the use cases. In addition, the QoS is evaluated in terms of throughput, delay, jitter, and packet loss to characterize the target performance level.

In Section II, we summarize the related work to develop E2E slice management. In Section III, we propose the existing 5G test-bed and implement the E2E Slice model on the current system. In Section IV, we generate traffic over slices to evaluate the performance of the model. Finally, in Section V, we conclude this paper.

II. RELATED WORK

Based on 3GPP TS each slice type has its own SST and SD. When we look inside the NSSF will see SST and SD. In addition, each SST has a sub-slice as in Figure 1, inside the eMBB slice, there are many services. We can define each one of them for different applications such as one for video, audio, chat and email [7]. The 3GPP TS specified the slice types but TS did not mention How the system can choose the SD for each user or service? is it based on the Service Level Agreement (SLA) between the user and the ISP or done dynamically based on the future network configuration.

The E2E packet duplication techniques for 5G services are proposed with two different scenarios in [10] to satisfy the URLLC demands. In [11], the E2E slice model connected the satellite with the 5G networks, but the interaction between them is limited due to the life-cycle of the slice in terms of management. On the other hand, the E2E service migration algorithm designed in [12] for real-time application to guarantee the QoS. In addition, reinforcement learning is proposed to optimize the bandwidth allocation for low latency slice migration.

This state of the art is designed to work on different slices according to the user's subscription. The connection will be done after checking the subscription to the slice first and then connecting the user to the requested slice. For example, if the user has a mobile device, the user will connect to eMBB, and URLLC slices. On the other hand, if the user has a car, the car will connect to the V2X slice. Furthermore, if the UE has an IoT device, the device will connect to the mIoT slice.

III. THE PROPOSED E2E SLICE MODEL USING THE CURRENT 5G TEST-BED

The Proposed E2E slice model builds on top of Free5gc open-source code for the 5G core and another open-source code called UERANSIM for the UE and RAN [13]. The implementation of the S-NSSAI was done based on the 3GPP TS standard and as explained in [9].

The Free5gc [8] added default slice to each of their functions. For example: DNN1 is fixed to the Internet and S-NSSAI of UE1 is fixed as SST=1 and SD=010203 and DNN2 is fixed to IMS and S-NSSAI of UE2 is fixed as SST=1 and SD=112233.

A. Network Configuration

Researchers contribution done on top of the Free5gc to create an E2E Slice model for the 5G system to evaluate the slices' performance:

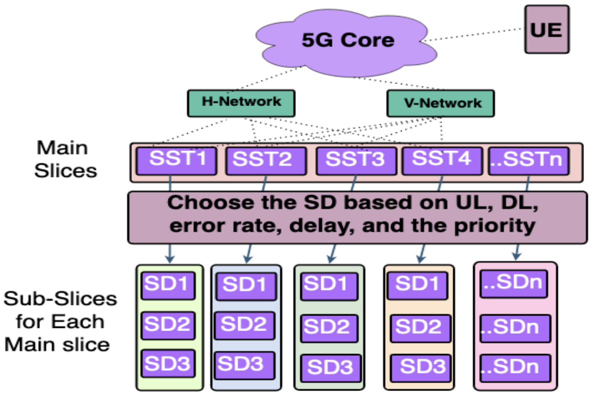

Fig. 1. Each SST contains multiple SD

1) Using the Free5gc code for the 5G core and the UERANSIM code to connect the UE/RAN with the 5G core.
2) Update some of the 5G core files (AMF, SMF, UPF and NSSF) to add slice configurations. For example, adding multiple slice types (SST) with Multi sub-slice for each main slice (SD) to 5G core as in the Figure 1.
3) Adding NSI list for the slice to identify the slice service which includes S-NSSAI, NSI information list (NRF ID and NSIID). Moreover, adding the slices detail to the allowed list. In this case, the UE can connect only to the allowed list after the registration stage complete [14].
4) UE can connect to multiple slices simultaneously. In our solution, UE could connect to ten slices. In 3GPP TS the UE is allowed to connect to eight slices at the same time. In this case, if the UE want to connect to more than eight slices needs to disconnect to any one of these eight slices and add the new slice to the allowed list. The final number of these slices should be eight only.

   It is not just a device limitation, it's time segmentation as well. More than eight slices will move to 16 bps which is related to 6G which will be between (2025 to 2030) [15].
5) Classify the Slices based on the Type (eMBB, URLLC, mIoT and V2X) and the Sub-Slices that are related to each type. The benefit of this classification is to view the main slice type and the sub-slice type that the UE connect to.

B. Equipment

For the deployment, Ubuntu server 20.04 is used as main operating system for the 5G core with 7.797GB RAM, 2vCPU and 200 GB hard. In addition, same operating system is used for the UE, RAN and UPF with 7.052GB RAM, 1vCPU and 10 GB hard. Slices' details added to three configuration files (AMF, SMF, and NSSF) in red rectangle in 5G core as in the Figure 2. The details of each file are listed below:

1) In the AMF file, each PLMN-Id has supported a list of slices with the list of the DNN. The AMF File has been updated with all S-NSSAI lists associated with specific PLMN, and the DNN list that is supported by AMF.

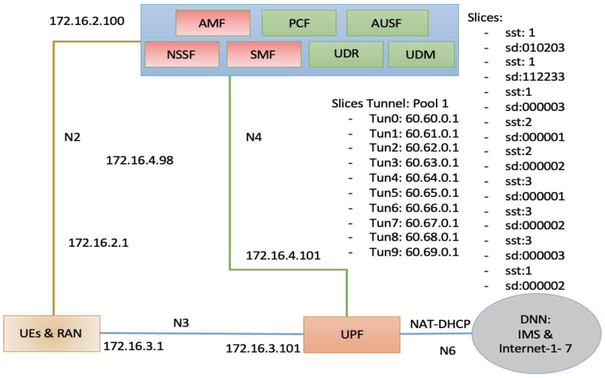

Fig. 2. 5G E2E Lab Setup

2) The SMF file has supported a list of slices which link with UPF that are supported these slices including the DNS and the DNN for each slice. Each slice had an SST, SD, specific IP for the tunnel and DNN. The SMF File has been updated with all S-NSSAI associated with specific PLMN, and DNN with specific IP for each DNN. Also, the type of interface that is related to UPF.
3) The NSSF file supported a list of slices and each one of them had NSI which includes an ID and URL link with the slice service. The NSSF file has been updated with all S-NSSAI for each PLMN that the core network is associated with and specifies the NSI list for specific S-NSSAI.
4) The UPF file has been updated with the DNN list. This list contains the DNN name and the IP address that link with S-NSSAI in the core layer.
5) The UE details including all the S-NSSAI added to the MongoDB after this stage the UE can connect to the 5G core. All the required files are expanded to work properly with the proposed system.

C. Apply Different Scenarios

After creating a set of slices and the sub-slices on top of the 5G core to see the performance of the system will propose a set of seniors to check the QoS when the UE connect to the

TABLE I
APPLY DIFFERENT SCENARIOS TO CHECK THE SLICES' PERFORMANCE

Scenarios	Users	Number of the Slices	Slices	Packets	Average TR	GTP Streams	Add Slices	Terminate Slices
Scenarios 1	1	9 slices for UE1	9 Slices	1000	45.98762342 Mbps	24	2 Slices	5 Slices
Scenarios 2	3	UE1: 4, UE2: 2, UE3: 2	7 Slices	10000	63.1267305 Mbps	40	4 Slices	8 Slices
Scenarios 3	4	UE1: 4, UE2: 2, UE3: 2, UE4: 4	11 Slices	10000	64.55263382 Mbps	33	3 Slices	4 Slices
Scenarios 4	3	9 Slices each UE	27 Slices	140000	65.203378 Mbps	78	2 Slices	7 Slices
Scenarios 5	6	UE1,2,3,4: 9 , UE5,6: 4	44 Slices	10000	7 69.946225 Mbps	132	5 Slices	17 Slices
Scenarios 6	7	9 Slices each UE	63 Slices	10000	71.416840 Mbps	189	4 Slices	30 Slices
Scenarios 7	11	UE1: 6, UE2: 10, UE3,6,7: 9, UE4,5,9,10: 4, UE8,11: 5	69 Slices	10000	57.03236434 Mbps	207	30 Slices	11 Slices
Scenarios 8	100	8 Slices each UE	800 Slices	10000	135.9415505 Mbps	2400	50 Slices	126 Slices

slice and send a traffic over the virtual tunnel to the DNN that related to each slice. Table I list all the seniors that are used in our system. These scenarios will contribute to use different types of 5G services: eMBB, URLLC and mIoT with required bandwidth for each slice. Heterogeneous traffic is applied to ensure a high reliability and better isolation for the E2E slicing especial for the critical data when it is send over the network.

D. Slice Connection and Termination Algorithm

Inter-slice connection and release in this done based on the 3GPP TS and the new review in [16]. The user can connect to a new slice after sending a registration request which contains NSSAI information to AMF then after the verification response, the requested slice will be added to the allowed NSSAI for this user. On the other hand, the PDU session will be triggered randomly to release the slice.

Our algorithm will manage the slices based on the user demands. When the user connects to the 5G core will get a list of the slices that the user does not connect to. So, the user could choose one of new the slices. Moreover, the user could access to all his subscript's slices. The slices will be saved in a database for the user if the user wants to delete a slice will choose one of the saved slices and release it. The user could add the released slice again if needed. Number of the slices added and terminated using our algorithm is shown in Table I.

Algorithm 1 5G Slice Management Algorithm

```
Ensure: Run the 5G Core, UPF, RAN and UEs
Ensure: $SConRe \neq 0$ & $U_i \neq 0$
  for $U_i = 1$ to $Un$ do
    for $SConRe = 1$ to $SConRe_n$ do
      if $s \in S_n$ then
        $rand_S \leftarrow s$
        Establish a Slice Connection $EC \leftarrow U_i \; -e \; rand_S$
      end if
      $pdus \leftarrow$ List all the PDU Sessions for selected $U_i$
      $PS \leftarrow U_i \; -e \; pdus$
      $pl.yaml \leftarrow PS$
      $Conpdu = 1$ & $re_s = 0$
      while $line \neq 0$ do
        if $line \in pl.yaml$ then
          $re_s \leftarrow Conpdu$
          $Conpdu = Conpdu + 1$
        else
          $break$
        end if
      end while
      $sliceSes \leftarrow re_s$
      $RS \leftarrow U_i \; -e \; releasesliceSes$
    end for
  end for
```

IV. RESULT & DISCUSSION

After the system is running, Traffic Generators (TG) tools will be used to send traffic from the slices to the DNNs over the virtual tunnels. TG tools will send packets using ICMP, TCP and UDP protocols to perform network diagnostics.

GTP traffic generator tool will be used to measure the transmission data rate (TR) from the slices to the DNNs. The GTP packets send 1000, 10000, 100000 and 140000 packets send from the UE using a particular slice tunnel to the DNN for that slice. The average TR for each scenario is shown in the Table I.

The GTP is used the UDP protocol to send a number of packets over the slice virtual tunnel to measure the TR. 10000 packets were sent over three streams using the GTP tool to measure the TR for 11 UEs connected to 69 slices as shown in Figure 3. The date rate average is 57.03236434 Mbps after sending 207 streams over 69 slices to the DNNs. The number of slices and streams for each UE is shown in the Table I.

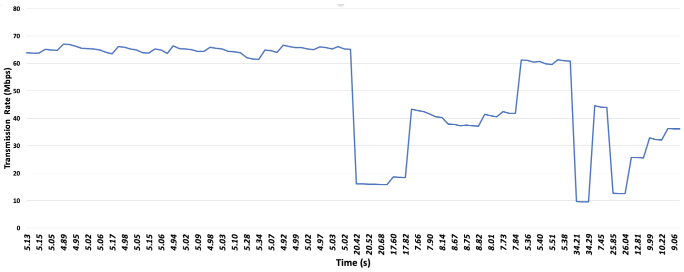

Fig. 3. Transmission Rate send from 69 slices to DNNs

The GTP is sent 10000 packets in one stream over the slice virtual tunnel for 100 UEs connected to 800 slices. The date rate average is 135.94155049125 Mbps. After sending the traffic on the virtual tunnels to the DNNs, TR drops four times because of the network congestion as shown in Figure 4.

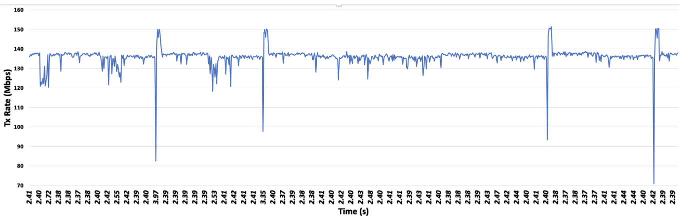

Fig. 4. Transmission Rate send from 800 slices to DNN

The average response time using ICMP protocol for 3 slices was 148.6μs is batter than the work in [17]. In addition, the average response time for each Slice through the 60s with TCP protocol for limited bandwidth for each slice was 48.708 ms as shown in Figure 5.

Ipref tool is used to measure the network throughput by establishing a spatial E2E throughput between the UE and the data network [18]. Ipref tool will be used to measure the performance of the Virtual link for each slice by sending TCP packets with different data rates from the UE slices to the DNNs.

At the beginning of the simulation, we had all the 63 slices ON; which is related to Scenario 6; then after the traffic load

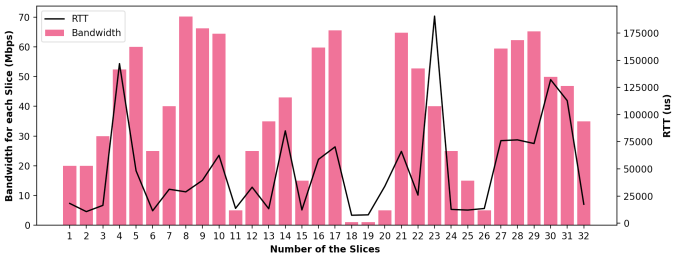

Fig. 5. Bandwidth and RTT through 60s

only 42 slices were ON and 21 slices turn OFF. At the end of the simulation time, only 32 slices were ON. For that reason, TCP traffic is sent over 32 slices only with bandwidth ranging from 1 Mbps to 80 Mbps) on each slice.

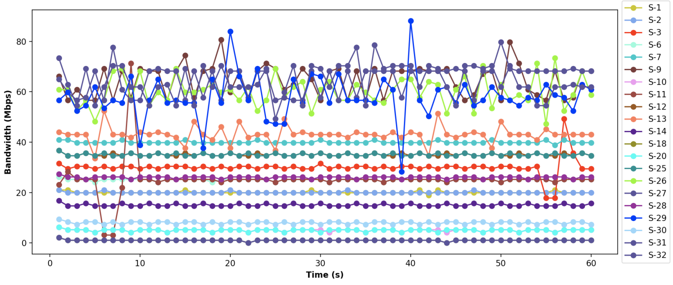

Fig. 6. Throughput for 21 slices through 60s

Throughput for the 21 slices through the 60s is shown in Figure 6. From this Figure, the throughput in some slices within the link capacity for each slice without congestion in their virtual tunnel and the bandwidth range from 1 Mbps to 40 Mbps. On the over hand, when the bandwidth between 55 Mbps to 80 Mbps congestion happened on their virtual tunnels.

Iperf tool is used to measure the time delay in the sending of data packets from the UE slices to the UPF using a UDP protocol. To see the variation in the time between slice packets arriving, the Jitter values for each slice are shown in Figure 7 when the traffic load over 35 slices.

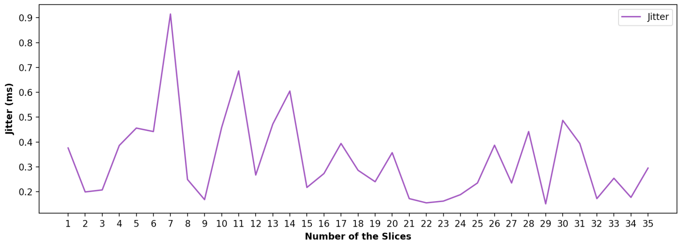

Fig. 7. Jitter values for 35 slices through 60s.

On the other hand, when the traffic load is over 63 slices the jitter values shown in Figure 8.

In our prototype, the average of the latency decreased when the number of the slices increase to 63 slices as shown in Figure 9. Furthermore, it is batter than the result in [4] when their latency increase when they added two slices to their system.

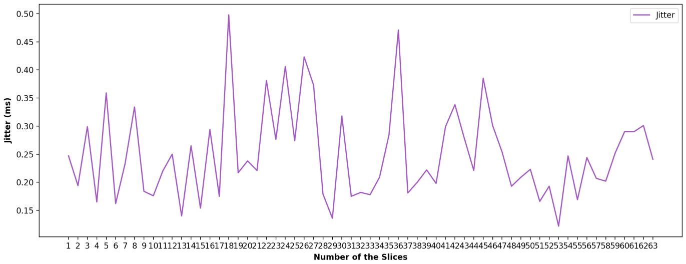

Fig. 8. Jitter values for 63 slices through 60s.

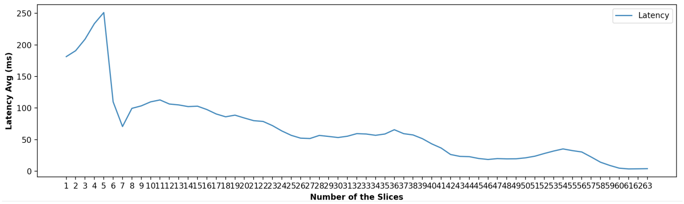

Fig. 9. Latency for each Slice through 60s.

The average of the network power was measured to check the use of the energy after sending traffic over 63 slices. The network power increase when the number of the slices increase as shown in Figure 10.

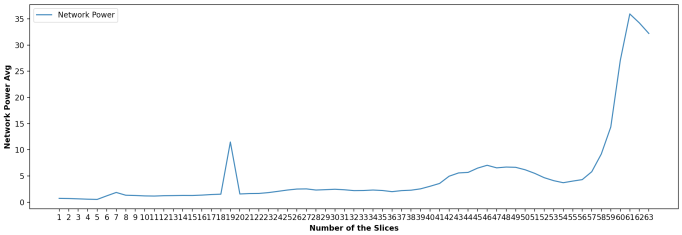

Fig. 10. Network power for 63 slices.

In scenario 8, 100 UEs connected to the 5G core and UPF. each UE had 8 slices with different bandwidth ranges (5, 15, 10, 25, 30, 27, 50, 37 and 40 Mbps). In this case, the total number of slices was 800 slices. For testing purposes will activate 800 virtual tunnels. Ipref is used to send traffic using a TCP protocol with a different bandwidth ranges from 5 Mbps to 50 Mbps to measure the average throughput for 674 slices through the 60s as shown in Figure 11.

Comparing with contribution in [19], in our prototype, user connected to three V2X slices to meet the demands. The traffic classified based on the SST and SD for each slice to create intra slice scenario with low-latency.

The UDP traffic is sent from the user (client-side) to the UPF (server-side) using iperf to get the variation in the time between slice packets arriving, the Jitter values for each slice are shown in Figure 12 when the traffic load over 784 slices for 100 UEs. In our prototype, the total duration to run the TCP and UDP traffic over 800 slice was 30 hours.

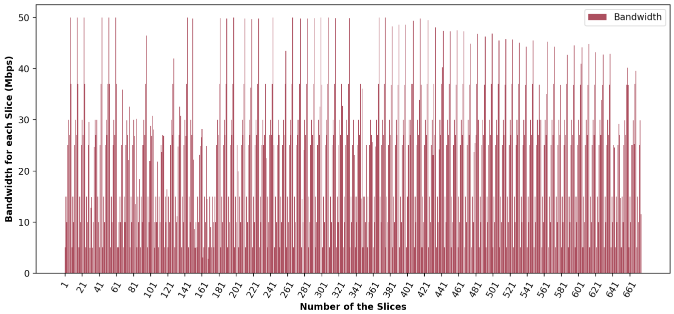

Fig. 11. Throughput for the 674 slices with different Bandwidth ranges through 60s

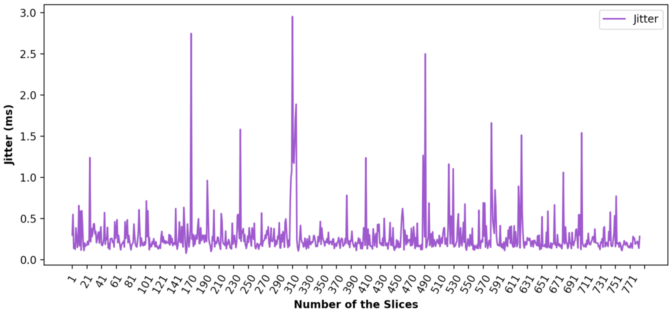

Fig. 12. Jitter for the 784 slices through 60s

The quality of the application such as video and call in 5G services will affect if the jitter value is high. These services will be dropped or glaciated. In this case, we need to find a way to reduce the jitter values for each slice based on the slice requirement.

The Researchers note that after adding another UPF for this model, the pool of the IP address for UPF1 is different from the pool for the UPF2. Note that generate traffic over Multi-UPFs will be in the future work to deal with different slices on different UPF pools. For example: When the UE subscript to the slice if the premium is high the traffic will forward to pool1. Otherwise, the traffic will forward to pool2 and each pool will contain 20 slices to deal with mobility as a service.

V. CONCLUSIONS & FUTURE WORK

In this research, we proposed the E2E slices model to evaluate the performance of the 5G system when the user connects to more than 8 slices at the same time. The main advantages of using a slicing technique for a resource management system are reducing the cost and enhancing the performance. In our work, we applied inter/intra slices using a real 5G core based on the 3GPP TS Release 15 to check the evaluate the performance of the slicing without using a software-defined network. All data have been collected from this system are saved in the dataset. In addition, we will continue saving all the traffic to enhance the performance of the current system. For future work, a deep learning algorithm will be proposed to train the data and predict accurate resources for inter/intra slice in real-time for the users based on the demands. The QoS was investigated in this paper, it will be used in the future to build a deep learning model to control and manage all the slices efficiently. The future framework will be more efficient and work with 6G parameters.

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