5G Network Slicing: Application to Use Cases

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***Abstract*—Network Slicing (NS) and network configuration are essential for remote AI autonomous industrial applications aimed at engineering efficiency and economic consideration. In this paper, we test the capability and performance of 5G network slicing based on the video streaming network topology. Test results clearly show that 5G network slicing can guarantee QoS to the application. The experience gained from the results could be applied to use cases such as network efficiency improvements, cost savings, and healthcare improvement of the site workers in a remote autonomous industry.**

***Keywords*— Index terms, Network Slicing, AI Remote Automation, Cost Performance Efficiency, Working Friendly Environment, Health Hazard, Working Environment, Video Streaming**

I. Introduction

5G network slicing is an end-to-end logical network that runs on a shared physical infrastructure, capable of providing a guaranteed service quality. 5G network slicing can span across multiple parts of the network, e.g., RAN (Radio Access Network), transport network, and 5G core network, as shown in Figure 1. This allows 5G network operators to accommodate different business use case requirements for security, reliability, and performance on the same network. 5G network slicing uses virtualization technology to create multiple networks or slices on top of a single shared network. Each slice contains its own unique QoS, e.g., latency, throughput. These two parameters are the key QoS parameters that we can manage using 5G network slicing.

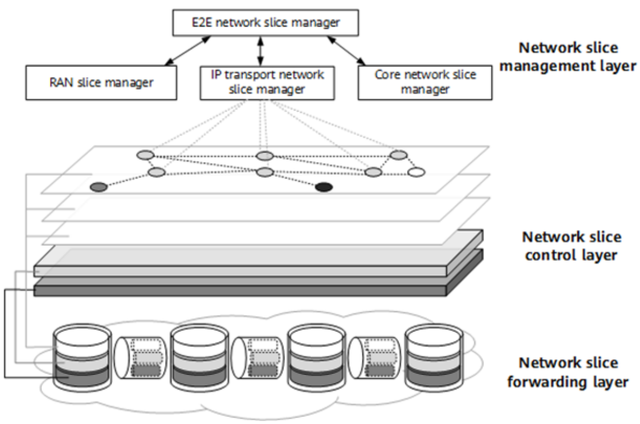

Fig 1. 5G network slicing architecture [1]

For end-to-end latency, the two main components are air interface latency and propagation latency. From our experience in a live network, two-way air interface latency in mid-band TDD (Time Division Duplex) 5G is typically around 8 msec (eMBB – enhanced Mobile Broadband services). This air interface latency could be reduced to 1–3 msec with the mini-slot concept defined in uRLLC (ultra-Reliable and Low Latency Communication) service type. However, under the current circumstances, devices that support uRLLC are rarely found in the market, but the network site already supports 3GPP uRLLC Rel 17. For propagation latency, it depends on the distance between the client and the destination server. To reduce this latency, MEC (Multi-access Edge Computing) was introduced. The key idea is to move the destination as close to the end user as much as possible. This kind of concept is currently used when we deploy a 5G private network for enterprise use cases or factories.

To uniquely identify a network slice, 3GPP defines the S-NSSAI (Single – Network Slice Selection Assistance Information). N-SSAI is a mandatory user profile defined in UDM (Unstructured Data Management) in 5GC (5G Core network). S-NSSAI is made up of two fields: SST (Slice/Service Type) and SD (Service Differentiator). SST has an 8-bit field length, implying that it can indicate a total of 255 different slice types. SD is an optional field. The format of N-SSAI is shown in Figure 2.

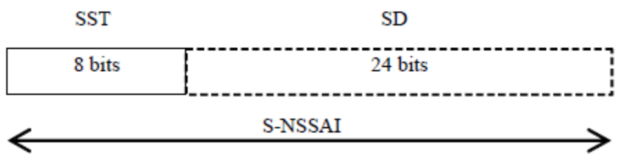

Fig 2. N-SSAI format [9]

Definition of SST and SD are defined below:

1. SST (Slice/Service Type) ***defines*** the expected ***behavior*** of the Network Slice in terms of specific features and services. The standard SST values are shown in Figure 3.

Slice/Service Type	SST Value	Characteristics
eMBB	1	Slice suitable for the handling of 5G enhanced mobile broadband
uRLLC	2	Slice suitable for the handling of ultra-reliable and low latency communications
MIoT	3	Slice suitable for the handling of massive IoT
V2X	4	Slice suitable for the handling of V2X services
HMTC	5	Slice suitable for the handling of High-Performance Machine-Type Communications

Fig 3. Standard SST values [9]

2. SD (Slice Differentiator) – this is optional information that complements the SST and is used as an additional

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differentiator if multiple network slices carry the same SST value.

During the PDU setup process, the UE will receive the N-SSAI value from UDM. The UE will send the N-SSAI value to the network, so the RAN and 5GC can select the particular network slice resource corresponding to the N-SSAI.

For upload/download throughput guarantee, to eliminate the bottleneck in the air interface, the concept of "PRB (Physical Resource Block) reservation" was introduced in 5G network slicing. A PRB is a fundamental resource allocation unit used in the time-frequency domain to schedule and allocate resources for data transmission. The scheduler in a 5G base station allocates/reserves a number of PRBs to users based on users' N-SSAI. The network administrator has to calculate how many PRBs need to be allocated/reserved in both the upload and download direction for the required throughput of specific use cases (N-SSAI). 5G base station will allocate the reserved PRB to every UE that has a corresponding N-SSAI first; for UEs whose N-SSAI does not match (including consumer UE), the remaining PRBs will be allocated. This scheduling will be recalculated every 10 msec in the 5G network. Generally, the threshold value mainly depends on the required throughput as well as the network condition (e.g., RSRP – Received Signal Reference Point). The number of PRBs depends on bandwidth and SCS (Sub-Carrier Spacing) value, as shown in Table 1 [2].

SCS (kHz)	5 MHz	10 MHz	15 MHz	20 MHz	25 MHz	30 MHz	35 MHz
	N_{RB}	N_{RB}	N_{RB}	N_{RB}	N_{RB}	N_{RB}	N_{RB}
15	25	52	79	106	133	160	188
30	11	24	38	51	65	78	92
60	N/A	11	18	24	31	38	44

Continue From Top

40 MHz	45 MHz	50 MHz	60 MHz	70 MHz	80 MHz	90 MHz	100 MHz
N_{RB}	N_{RB}	N_{RB}	N_{RB}	N_{RB}	N_{RB}	N_{RB}	N_{RB}
216	242	270	N/A	N/A	N/A	N/A	N/A
106	119	133	162	189	217	245	273
51	58	65	79	93	107	121	135

TABLE 1: NUMBER OF PRB PER BANDWIDTH AND SCS [9]

PRB reservation is a radio resource partitioning technique; part of the overall PRB will be reserved for the UE that has a corresponding N-SSAI configured in the particular 5G cell site. The simplest way that most 5G RAN vendors implement currently uses the concept of a "Dedicated slice" technique. When we set a certain percentage value of reserved PRB, only the target UEs with the particular N-SSAI value can use the reserved PRB, while the rest of the UEs in that cell site will share the remaining PRB. As a result, groups of the target UEs shall get the desired UL/DL throughput as expected.

3GPP has defined RAN slicing, which enables dynamic allocation of PRBs to different N-SSAIs based on their required QoS, current network condition, and traffic load. 3GPP defined 3 levels of RAN slicing: Dedicated slice, Priority slice, and Shared slice. Details of each RAN slice are as follows:

- Dedicated slices: These slices are isolated and dedicated to the specific N-SSAI, ensuring guaranteed performance and resources. The limitation is that a dedicated slice may cause low utilization of overall PRB in case the specific N-SSAI does not send, or sends at a low traffic rate compared to the dedicated PRB.
- Priority slices: These slices allow for prioritization of traffic within different slices, ensuring that critical services receive the necessary resources. PRBs in the priority slice will not be reserved for the particular N-SSAI; if there are available PRBs, other N-SSAIs can also utilize them. As a result, RAN network utilization is higher than with the dedicated slice.
- Shared slices: These slices allow multiple services/slices to share resources, offering flexibility and cost-effectiveness. Generally, the PRB will be shared based on the configured weight value for each 5QI.

Hence, Network Slicing (NS) is a flexible and scalable solution for enabling the fifth generation (5G) cellular network to support multiple heterogeneous services, which include mobile broadband, mission-critical services, and massive Internet of Things (IoT) connections, guaranteeing Service Level Agreement (SLA) as well as meeting the requirements of a commercial agreement [3].

Following developments such as Smart Grids, Smart Cities, intelligent transportation, Internet of Things (IoT), and Industry 4.0, NS in a 5G shared network with SDN has become popular [4], and the isolation of NS is proposed [5]. NS architecture is enhanced with machine learning, security, sustainability, and experimental network integration for efficiency [6][7]. NS supports 5G to provide a wide range of services and requirements, including enhanced Mobile Broadband (eMBB), Ultra-Reliable Low-Latency Communication (URLLC), and massive Machine Type Communication (mMTC). It also supports 5G-Advanced and evolves into 6G networks to allow MNOs to launch novel and unprecedented applications. Moreover, the feature of Multi-Access Edge Computing (MEC) in NS provides connectivity between RAN and CN possible [10].

The structure of this paper is as follows: Section II shows the experimental testing for network slicing in a 5G standalone network, as shown in Figure 2 [8]. In Section III, discussion and suggestions for network slicing use cases are described. Section IV provides the conclusion.

II. EXPERIMENTAL TESTING SETUP

In Figure 4, a test in a 5G standalone production network is set up using streaming servers A and B. Sim card A has a special network slicing profile (N-SSAI = 1-003001), while Sim card B has the default network slicing profile (N-SSAI = 1-FFFFFF). It should be noted that both streaming servers A and B can stream 4K video content. In the encoding program, average throughput is set to around 10 Mbps. Meanwhile, the available upload throughput is 50 Mbps.

Fig 4. Scenario of 5G network slicing testing in production network

There are also two monitoring laptops, C and D; both C and D have a normal network slicing profile (N-SSAI = 1-FFFFFF). It should be noted that both C and D consume download traffic because both laptops keep monitoring the streaming content from Servers A and B, respectively. The available download throughput is around 400 Mbps during testing.

At the same time 2 mobile phones E and F are set to generate background traffic using OOKLA speed test traffic.

As for the RAN part, we use the PRB (Physical Resource Block) reservation technique as standardized in 3GPP TS 38.300 Section 16.3 and configure it to reserve 20% of the upload PRB for N-SSAI = 1-003001 (Dedicated slice). The transport network uses MPLS as the infrastructure; there is no congestion in the transport network part. In testing the latency, we use the user plane of 5GC: traffic of all UEs is routed to the same UPF; therefore, there is no difference in the end-to-end latency, as shown in Figure 5.

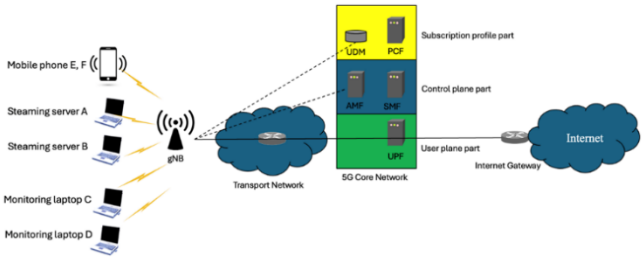

Fig 5. High level network topology of the 5G network slicing test network

In Test Scenario 1, the conditions are as follows:

1. Streaming server A and B stream 4K video content while monitoring laptop C and D continue monitoring the streaming content.

2. No additional background traffic is generated from the mobile phones.

The test result for Test Scenario 1 shows that the monitoring laptop C and D can smoothly monitor the streaming content because there is no upload traffic congestion in the test case.

In Test Scenario 2, the conditions are as follows:

1. Streaming server A and B stream 4K video content while monitoring laptop C and D continue monitoring the streaming content.

2. Background upload traffic is generated from the mobile phone to create congestion in the video streaming traffic of server A and B.

The test result for Test Scenario 2 is as follows:

1. Monitoring laptop C can smoothly monitor the streaming content while the streaming content of monitoring laptop D was interrupted (e.g. image freezing) during the congestion period.

2. After investigation, as expected, streaming video of laptop D was interrupted due to packet loss in the system. The result in Figure 6 shows that the video bit rate, video frame rate and audio frame rate of Streaming server B drop during the congestion period.

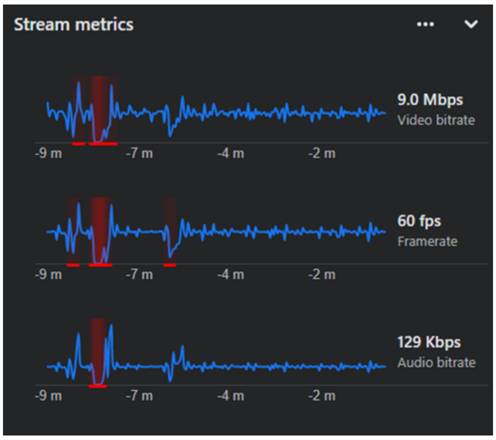

Fig 6. Video bit rate, Frame rate and Audio bit rate of Streaming server B

III. Application to Use Case

The experiences gained from testing Scenario 2 could be applied to a use case in the remote autonomous industry. This involves access to a rural mountainous area where onsite workers face several health problems, such as fine dust exceeding PM 2.5 and dangerous working conditions. Thus, AI automation with remote control of heavy machinery in that hazardous area is shown in Fig. 7. Meanwhile, the server could be located in a nearby vicinity for other users in order to increase efficiency and reduce investment costs, while preserving latency at 20 ms.

Fig 7. Remote Controlled Heavy Machinery

Fig 8. AMR (Automatic Mobile Robot) working with 5G

Another use case of 5G in a smart factory is AMR (Automatic Mobile Robot) control as shown in Fig 8. A 5G private network with network slicing will supplement a high-speed manufacturing environment with greater flexibility supporting the modern factory to manage its production schedule, maintain supply and orchestrate all the activities on the shop floor with an automated system by eliminating the need for wired connectivity.

Fig 9. Smart sea port solution

For the Smart Sea Port solution in Figure 9, a 5G private network with network slicing provides secure, high-speed data transfer with ultra-low latency, which enables remote crane control from a distant place, allowing the operator to move the container to a safer area rather than sitting in a high and risky position. The solution helps improve productivity and safety for the operation.

IV. Conclusion

In a congested network, 5G network slicing shows that it can strongly guarantee QoS to the application. RAN will reserve PRB for the target application for every TTI. As a result, the performance of the target application, especially UL/DL throughput, is as expected.

However, if a 5G network operator would like to deploy the PRB reservation technique of 5G network slicing, one issue that needs to be addressed is that the proper value of the PRB threshold is very significant and affects all UEs' performance, especially for a 5G cell site that is used for both consumer and enterprise use cases.

1. In case a high PRB threshold is reserved for enterprise use cases, the experience of consumer UEs experience will degrade.
2. Setting too low a PRB threshold results in uncontrolled QoS for enterprise use cases.

In addition, security for single-domain NS resource management is of particular concern. Slice isolation could be a security mechanism for different levels of network domain, i.e., TN, CN, RAN, etc. [11] In general, slice isolation ensures that the performance of one active slice does not affect others. However, a balance should be maintained between isolating slices to protect them against attacks and increasing resource usage management [12]. As for security in telecommunication networks, 5G/5.5G networks deploy many security measures, including conventional encryption, authentication, end network control, and more recently, blockchain technology has been employed in 5G/6G communication for Internet of Things (IoT) devices in consumer electronic systems [12]. A unified 5G security standard that defines common 5G security concepts and agreed-upon security bandwidth systems was proposed in [13] to support the Intelligent Connection of Everything (IoE).

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