A Comprehensive Analysis on Network Slicing for Smart Hospital Applications

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***Abstract*—Network slicing (NS) is technology that enables emerging smart applications and use cases in Fifth Generation (5G) and beyond networks. One such application is smart hospitals, which has diverse network requirements for applications ranging from Augmented Reality (AR) and robot assisted surgeries to connecting large numbers of medical wearables and sensors. NS can be performed in smart hospitals under different strategies based on dynamicity, ownership, and application. This paper investigates how these strategies can be utilized in different smart hospital applications. The performance of each slicing strategy in a hospital network is analyzed under three matrices: bandwidth utilization, handover count, and block count.**

***Index Terms*—Network Slicing, Smart Hospitals, IoT, 5G**

I. Introduction

Network slicing (NS) is a technology that is capable of creating multiple distinct logical networks over shared infrastructure in 5G and beyond networks [1]. Therefore, NS is identified to be an enabler of many vertical industries with diverse communication requirements. For instance, a smart hospital environment demonstrates the heterogeneity of Internet of Things (IoT), where the devices are distributed within a confined area. A smart hospital is dispersed with many users, including the medical/non-medical, staff/patients/visitors, and use cases such as remote surgeries, robot-aided medical care, robot-aided surgeries [2]. When slices are offered to cater different requirements (e.g., latency, security, privacy, bandwidth (BW), and scalability), the slice deployment strategies should be carefully considered. We consider different NS classification methods for smart hospital applications that are categorized under dynamic nature, application, and ownership.

In static slice deployment strategy, a pre-defined set of slices with dedicated amounts of network resources are deployed, where the allocated amount of network resources for each slice remains static throughout its entire life-cycle. Resource allocation is done based on the historical traffic data or the requirements presented by the tenant (in this application, hospital authorities) [3]. In case of the dynamic technique, operators can dynamically design, deploy, customize and optimize network slices according to the service requirements or conditions and resource availability in the network [4]. Efficiency in resource utilization can be improved via allocating idle resources in less-congested slices to congested slices. QoS requirements of network slices should be carefully considered in this slicing strategy.

Use-case specific slice allocation is considered in vertical slicing which is categorized under application classification method [5]. Use-case specific configurations can be easily performed under this slicing strategy as there is a clear separation between use-cases achieved through dedicated network slices. However, overlapping traffic classes can be identified in separate slices—for instance, video streaming data in AR slice and robot slice. Horizontal slicing considers the services rather than applications. When considering a particular application, for the optimal operation of that application, several services may require [6]. Since the focus is on the services rather than the use-case, slice arrangement in the hospital is performed based on network services by considering all the use-cases.

The slice ownership can be maintained by the local 5G operator (L5GO) or the MNO. Usually, the resource amount in an L5GO environment is highly specialized. Therefore, more network slices can be allocated for specific applications. Typically NS belongs to MNO based slicing category, where MNO is responsible for slice creation, operation, modification, and termination. MNOs consider the slicing allocation procedure in a high-level manner which can be used by multiple verticals. Due to the large number of users and applications, MNOs create slices based on the types of vertical industries and these slices are spread across large geographical areas [7], [8]. *Figure 1 illustrates the deployment of network slices in a smart hospital environment under different slicing strategies.*

The remainder of the paper is organized as follows. Section II describes the system model and Section III presents the experiment results. Finally, section IV concludes the paper.

II. System Model

The utilization of discussed network slicing strategies is simulated to analyze the performance of each strategy within a smart hospital environment. Slicesim [9] is used as the base open-source NS simulation tool of our experiment. The behaviour of an NS enabled environment within a given geographical area can be modelled by the simulation tool.

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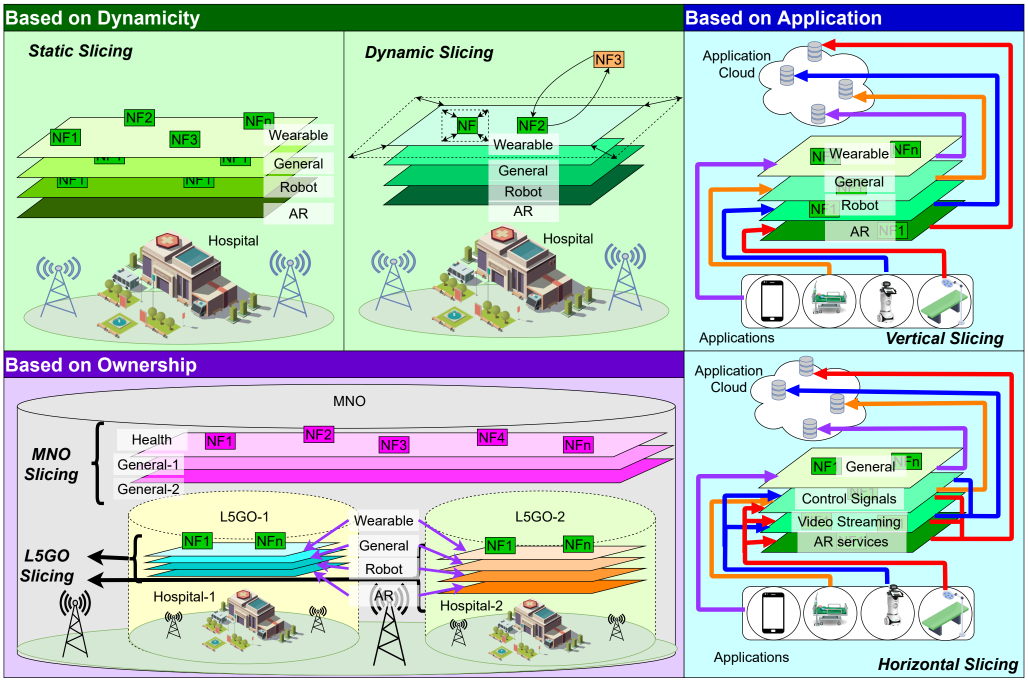
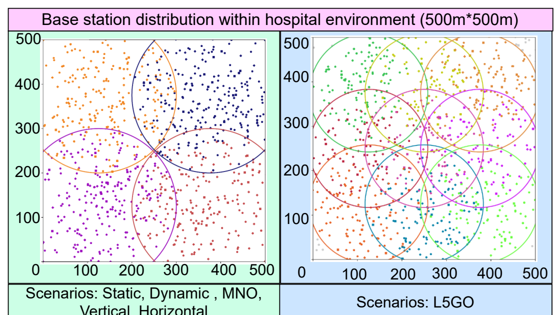


Fig. 1: Slicing strategies in smart hospitals

We modified the code base of the simulation tool to enable different slicing strategies in the modelled environment. A hospital environment that spans over 500m*500m area is used in the experiment. We consider four applications that require connectivity within this environment: AR assisted surgeries, robot-assisted activities, wearable to patient monitoring, and general communications. The configurations used in the experiment are shown in the figure 2. A medium-scale hospital with 200 hospital beds which requires $250m^2$ space per bed, is considered according to [10], [11]. Proportions of client types are decided according to the number of hospital beds. BW allocation from BSs for each slice is performed considering the standard BW requirements of each application and the client proportions in the system [12], [13].

Identical BSs are used in the experiment and only in the L5GO strategy, BS distribution is different from other strategies as the L5GO can manage the network in the hospital environment. Slice allocation is different only in MNO strategy than other strategies. However, the same proportion of resources are allocated to the health-related slice from a BS in MNO strategy to assure resource requirements in hospital applications. A random per second movement is given to each client in the environment according to the intuitive mobility pattern assigned to them [14]. We perform each experiment 100 times with different random number generators and calculated the average values.

Average BW utilization, average block count per second, and average handover (HO) count per second are measured in these experiments. ***Average BW utilization*** is the ratio between total BW used by the clients in the system to total BW in the system. ***Block count*** is the number of clients in the system who are not able to connect to a slice to get resources. The number of active users that moves from one BS to another due to the mobility can be identified as the ***HO count***.



Resource distribution within a base station

Scenarios: Static, Dynamic , L5GO, Vertical, Horizontal		Scenarios: MNO	
AR	0.2	Health	0.5
Robot	0.2		
Wearable	0.1		
General	0.5	General	0.5

Client configurations

User type	Number of users	Mobility pattern
AR users	50	randint, [-1,1]
Connected robots	100	randint, [-5,5]
Wearable devices	500	randint, [-3,3]
General users	350	randint, [-4,4]
Total Users	**1000**	

Fig. 2: Configurations used in the experiment

III. Experimental Results

This section compares the received results of the experiment under each slicing strategy.

A. Performance Comparison of Static vs Dynamic slicing

Figure 3 shows the experiment results for slicing strategies based on the dynamicity.

In both strategies, the same number/type of network slices (i.e.AR, robot, wearable, general) are created. In the static scenario, resource quantity for a slice remains constant for the

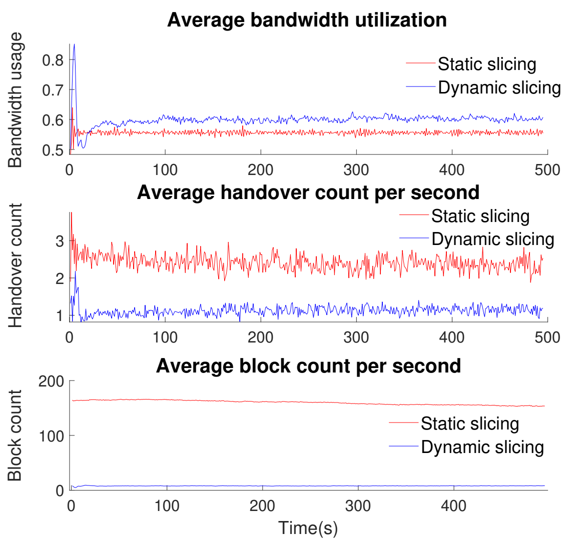


Fig. 3: Bandwidth usage, handover count and block count variation for static and dynamic slicing strategies

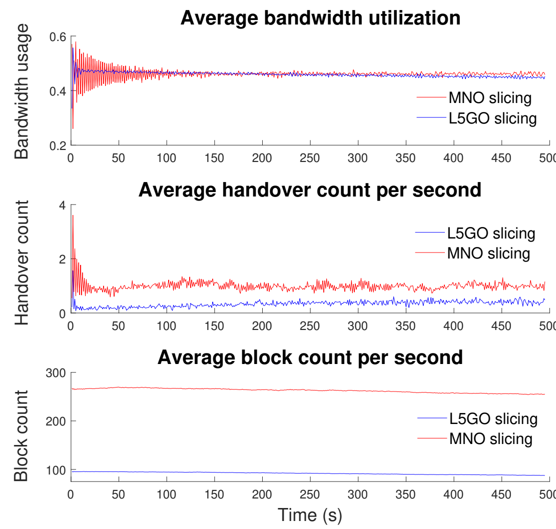


Fig. 4: Bandwidth usage, handover count and block count variation for MNO and L5GO slicing strategies

entire experiment duration. In the dynamic scenario, resource quantify in the slices varies with time by considering the resource requirements presented by clients. However, the total available network resources in the environment remain the same for both strategies.

Here, average BW utilization is a higher value in dynamic slicing than static slicing. An increased number of connected clients for a particular moment in the dynamic slicing strategy is the cause for this observation. When we compare the average number of blocked clients, dynamic slicing has significantly dominant performance than static slicing. In the dynamic scenario, resources can be shared between the slices based on the current availability. Thus, the possibility of getting a sufficient amount of resources to accomplish the communication requirements of a particular client is higher.

Due to the low mobility patterns in a hospital environment, the movements of clients from one BS to another is low. The clients who are in the overlapping area of BSs have a higher probability of moving from one BS to another. However, in the dynamic strategy, BS tries to provide required resources for clients by sharing resources between slices. Therefore, in the dynamic strategy, the clients may have a lower tendency to move from one base station to another to access the required resources. In static strategy, clients have a lower probability of receiving resources from the same connected BS by causing them to move between BSs. This phenomenon increases the HO count in static strategy.

B. Performance Comparison of MNO vs L5GO slicing

The experiment performed for investigating the behaviour of the slicing strategies based on the ownership is shown in the figure 4.

When considering the average BW utilization, the L5GO scenario and the MNO scenario have nearly equal values throughout the period. However, when considering the consumed BW amount, the L5GO scenario utilized a higher amount of resources than the MNO scenario. Since, in the L5GO strategy, a higher resource amount (BSs) is available in the system, more users can connect and consume. Also, due to the higher slice density in the L5GO scenario, BW allocation is organized to increase the number of connected clients within a particular moment. Thus, the average block count per second shows a very low value in the L5GO strategy than the MNO strategy. The environment is stabilized in the L5GO scenario rapidly than the MNO scenario as users can receive required resources promptly within fewer attempts due to the higher amount of resources in the environment in the L5GO scenario. When considering the average HO count per second, the MNO scenario shows a higher value than the L5GO scenario. Due to the higher number of BSs in the L5GO strategy in the hospital environment, the average number of clients per BS is a lower value in the L5GO scenario. Therefore, clients have more opportunities to receive required resources from the BS in the L5GO strategy. Hence, clients don't need to move from the connected BS to another. Therefore, the average HO count is a lower value in the L5GO scenario than the MNO scenario.

C. Performance Comparison of Horizontal vs Vertical slicing

Figure 5 shows the results of the experiment performed to investigate slicing strategies based on the application. In both strategies, BS distribution and the resource quantity in the system are the same. However, the slice allocation is different.

For assuring the locality property, we assume that a particular client connects to multiple slices in the same BS instead of multiple BSs. Though slice allocations are different in these strategies, the number of slices in the system is the same in both strategies according to the considered applications in the hospital environment. When considering the BW utilization, the horizontal slicing strategy shows a lower value than the vertical slicing. The requirement of connecting to multiple service slices to achieve network requirements is the reason for this observation. The same reason causes for the higher values

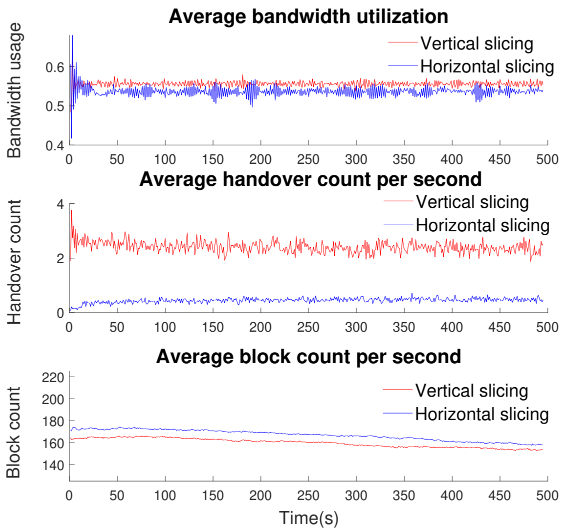


Fig. 5: Bandwidth usage, handover count and block count variation for horizontal and vertical slicing strategies

of block count per second in the horizontal slicing scenario. A Client needs to connect with all the required service slices in the adjacent BS to achieve a successful HO in the horizontal slicing scenario. The probability of being available of all the service slices in a particular BS is a relatively smaller value than being available in a specific slice. A very low value of successful HOs in horizontal slicing than vertical slicing can be caused due to the mentioned reason.

IV. Discussion and Conclusion

Selecting an optimal slicing strategy for smart hospital environments is arduous, considering the advantages as well as disadvantages of different slicing mechanisms. This paper investigates how NS techniques can be efficiently deployed in a smart hospital environment through a simulation study.

Initially, simulations are carried out to compare the performance of dynamic slicing and static slicing mechanisms while maintaining the same total network resources. Throughout the simulations, dynamic slicing exhibits a higher average BW utilization compared to static slicing, proving its capability for better network resource utilization compared to static NS. Furthermore, a lesser number of blocked clients and lesser HO count per second in dynamic slicing over static slicing ensures reliable connectivity to more users. This highlights dynamic slicing as the obvious choice for NS in smart hospital applications. However, it should be noted that dynamic slicing requires network nodes and devices to establish seamless communication to understand and predict the network status and user requirements through advanced learning techniques.

Subsequent simulations are conducted considering the ownership of slices. Simulations are performed at the L5GO and MNO in a smart hospital environment. L5GOs can manage the network resources, slicing configuration and BS distribution within the hospital premises. Therefore, the total available resources are higher with L5GO based slicing compared to MNO based slicing. Hence, L5GO based slicing exhibits a higher average BW utilization compared to MNO based slicing. Furthermore, the blocked count per second and the HO count per second in L5GO based slicing is lower, ensuring successful connectivity attempts and reliable connectivity in a smart hospital environment. Hence, L5GO based slicing qualifies as the better slicing configuration in a smart hospital environment. However, this requires L5GO deployment in hospital premises, which will demand additional deployment, operational and maintenance costs.

Then, simulations are performed considering NS for large scale applications. Vertical network slices are allocated for the industry after generalizing its connectivity requirements. On the other hand, horizontal slicing allows a client to connect to multiple network slices generated for specific applications. Horizontal slicing exhibits better BW utilization and lower block count per second, which are preferable compared to the vertical slicing configuration. However, the number of HOs per second is low with vertical slicing, providing reliable connectivity for the users of smart hospital applications. Thus, careful consideration is required when performing NS based on slicing applications to ensure feasible NS deployment, commercial viability, and the smooth functionality of applications.

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