Deployment Options of 5G Network Slicing for Smart Healthcare

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***Abstract*—Network slicing enables the creation of multiple logical independent networks on physical networking infrastructure. Network slice deployment in a Fifth Generation (5G) mobile network can be classified as vertical and horizontal slicing. The paper compares the performance of the two slicing methods through solving two convex optimization problems, considering several smart hospital scenarios that differ from each other based on their medical speciality. The results are used to draw insights on the most appropriate slicing approach for each setup.**

***Index Terms*—5G, Network Slicing, Smart Hospital, Telehealth**

I. Introduction

Network slicing methodologies in a Fifth Generation (5G) Mobile Network Operator (MNO) environment have been discussed and classified considering different contexts [1]. One such classification is vertical and horizontal network slicing, which is the main focus of our paper. *Vertical network slicing* is the most widely discussed slicing approach, where the End-to-End (E2E) traffic flow is usually between the MNO core network and the end user device, through the access network and the backhaul network. *Horizontal network slicing* decomposes the 5G network into matching technical sub-systems. These sub-systems do not empower the end user necessity individually, but when put together, they can satisfy an E2E user requirement [2]. Upon the medical forte and revenue generation opportunities, a given smart hospital can prioritize different telehealth applications, creating unique 5G network service requirements, and a 5G MNO can utilize various network slicing methods to cater these high demanding service requirements. This paper compares two such slicing methods, vertical and horizontal, using two optimization problems which facilitate exclusive telehealth prioritization through a cost based objective function, and the constraints capture the network and hospital resource limitations.

II. System Model

Let us consider a smart hospital with Q applications running simultaneously. The traffic from these applications can be segregated into M services. Thus we consider Q vertical slices and M horizontal slices. The network consists of T types of resources, $R_1, \ldots, R_T$, that need to sliced appropriately into the aforementioned slices. For this purpose, we introduce a cost based objective function that maximizes a weighted sum of the number of end users, given by $\sum_{i=1}^{Q} \beta_i U_i$, where U_i, $i \in \mathcal{A} = \{1, \ldots, Q\}$, is the number of users utilizing the i-th telehealth application, and β_i is a cost associated with the i-th telehealth application, for $i \in \mathcal{A}$. The introduction of β_i in the objective function eliminates trivial solutions in our optimization problems, that we will discuss next.

Let $r_{i,j,k}$ denote the amount of the k-th resource allocated to a user utilizing the j-th service associated with the i-th application, where $i \in \mathcal{A}$, $j \in \mathcal{S} = \{1, \ldots, M\}$, and $k \in \mathcal{E} = \{1, \ldots, T\}$. Then, the optimization problem in concern (P1) for vertical slicing can be written as follows:

$$\text{(P1):} \underset{\alpha_{i,k}}{\text{maximize}} \quad \sum_{i=1}^{Q} \beta_i U_i \tag{1a}$$

subject to

$$\sum_{j=1}^{M} r_{i,j,k} U_i . \mathbb{1}_{\{E_{i,j}\}} \leq \alpha_{i,k} R_k, \quad \begin{matrix} i \in \mathcal{A}, \\ k \in \mathcal{E} \end{matrix}, \tag{1b}$$

$$\sum_{i=1}^{Q} \alpha_{i,k} = 1, \quad k \in \mathcal{E}, \tag{1c}$$

$$U_i^{\min} \leq U_i \leq U_i^{\max}, \quad i \in \mathcal{A}. \tag{1d}$$

A given telehealth application may use only a subset of the services. Therefore, we consider event $E_{i,j}$ is true if the j-th service is associated with the i-th application, and the indicator function to incorporate this in the optimization problem through constraint (1b). $\alpha_{i,k}$ denotes the fraction of the k-th resource allocated to the i-th application for $i \in \mathcal{A}$ and $k \in \mathcal{E}$, as given in (1b), thus summation of the values across all applications is one (1c). We also assume that the number of users for the i-th application can vary between $U_i^{\min}$ and $U_i^{\max}$ (1d). By solving this optimization problem, the MNO can obtain how the resources can be sliced vertically such that each vertical slice is allocated to a telehealth application.

$$\text{(P2):} \underset{\gamma_{j,k}}{\text{maximize}} \quad \sum_{i=1}^{Q} \beta_i U_i \tag{2a}$$

subject to

$$\sum_{i=1}^{Q} r_{i,j,k} U_i . \mathbb{1}_{\{E_{i,j}\}} \leq \gamma_{j,k} R_k, \quad \begin{matrix} j \in \mathcal{S}, \\ k \in \mathcal{E} \end{matrix}, \tag{2b}$$

$$\sum_{j=1}^{M} \gamma_{j,k} = 1, \quad k \in \mathcal{E}, \tag{2c}$$

$$U_i^{\min} \leq U_i \leq U_i^{\max}, \quad i \in \mathcal{A}. \tag{2d}$$

Similarly, let $\gamma_{j,k}$ denote the fraction of the k-th resource allocated to the j-th service for $j \in \mathcal{S}$ and $k \in \mathcal{E}$. Then, the optimization problem in concern (P2) for horizontal slicing can be written as above. Note that the objective functions and constrains in (P1) and (P2) are all linear, thus both problems are convex optimization problems, and optimal solutions can be achieved through linear programming.

III. Results

Telecommunication service providers allocate E2E network resources based on the SLA with the customer. Therefore, resources required to transmit E2E traffic in a 5G network can be primarily categorized as, bandwidth ($k = 1$), processing time ($k = 2$) and storage ($k = 3$). Thus $T = 3$ according to our setup. We consider three potential applications in a future smart hospital environment having 5G connectivity [3]–[5], therefore $Q = 3$. The applications are Augmented Reality Assisted Surgery (ARAS) ($i = 1$), Robotic Aided Surgery (RAS) ($i = 2$) and Internet of Medical Things (IoMT) ($i = 3$).

The applications produce 5G network traffic which can be primarily classified into three services. That is $M = 3$, and the services are audio ($j = 1$), video ($j = 2$) and control ($j = 3$).

The association between applications and services are as follows:

- ARAS $\Rightarrow$ video + control
- RAS $\Rightarrow$ video + audio + control
- IoMT $\Rightarrow$ control

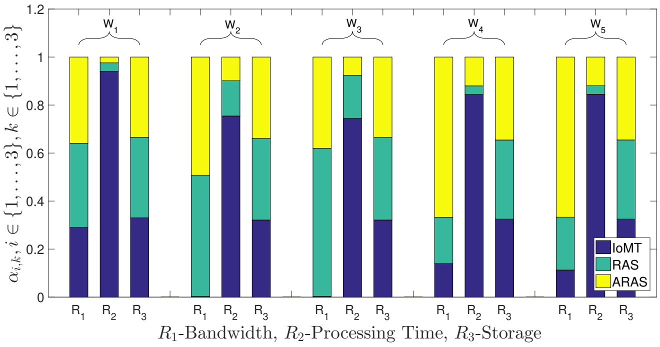
We consider five different smart hospital setups based on their specialization in terms of medical treatment and set the weights β_i, $i \in \{1, 2, 3\}$, to suit the requirements of each type of hospital. They are an elderly care hospital (W_1), an emergency care hospital (W_2), an infectious disease center (W_3), a teaching hospital (W_4) and a pediatric hospital (W_5). It should be noted that hospitals have limited operating theatres, which leads to an upper limit for the number of concurrent surgeries. We set $U_1^{\min} = U_2^{\min} = 2$ and $U_1^{\max} = U_2^{\max} = 10$ in our results, and the rest of the calculation parameters are tabulated in Table I. Figure 1 illustrates 5G network resource allocation percentages for different weight types.

TABLE I: Simulation Parameters.

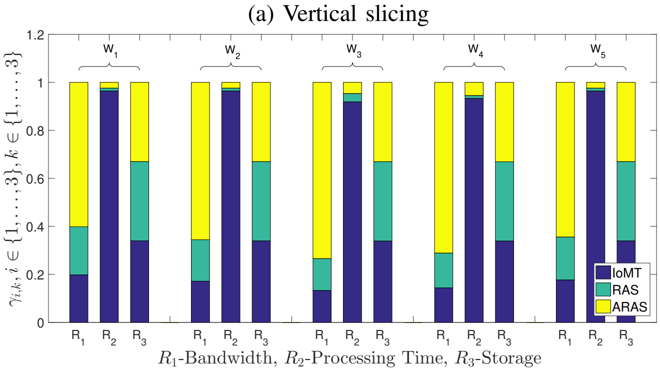
	Bandwidth (Mbps)	Processing time (ms)	Storage (Mb)
Total Available	200000	1000	32000
For a 4K video transmission	12000 [3]	6 [3]	96
For a HD audio transmission	300 [3]	6	2.4
For control data stream transmission	2 [3]	6	0.2

TABLE II: Weight assignments and the respective values of the objective function.

Type	β_1	β_2	β_3	Vertical Slicing			Horizontal Slicing		
				ARAS	RAS	IoMT	ARAS	RAS	IoMT
W_1	1	1	1	2	2	156	2	2	478
W_2	2	3	1	8	8	125	2	2	478
W_3	2	7	1	6	10	124	2	5	451
W_4	4	2	1	10	2	140	7	2	457
W_5	2	2	1	9	2	140	2	2	478



(a) Vertical slicing



(b) Horizontal slicing

Fig. 1: 5G network resource allocation percentages for different weight types.

IV. Conclusions

This paper introduce the formulation of two convex optimization problems for optimal resource allocation, and compares vertical and horizontal slicing methods, in a Fifth Generation (5G) Mobile Network Operator (MNO). Numerical results have shown that horizontal slicing can support more telehealth application users than vertical slicing. However, the total end user count is dominated by IoMT users in both the slicing methods due to its low resource consumption.

Acknowledgement

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