Network slicing is a key to supporting different quality-of-service requirements for users and application in the 5G network. However, allocating network slices efficiently while providing a minimum guaranteed level of service in a mobile core is challenging. To address this question, in our previous work we proposed an optimization model to allocate slices. It provided a static and manual allocation of slices. In this paper, we extend our work to dynamically allocated slices. We propose a dynamic slice allocation framework for the 5G core network. The proposed framework provides user-interaction to request slices and any required services that need to run on a slice(s). It can accept a single or multiple allocation requests, and it dynamically allocates them. Additionally, the framework allocates slices in a balanced fashion across available resources. We compare our framework with the First Come First Serve and First Available allocation scheme.

Index Terms—5G slicing, network slicing, 5G availability, 5G optimization, slice allocation

I. INTRODUCTION

Current mobile networks are static and highly centralized. For instance, 4G core networks are composed of monolithic purpose-built network elements placed in a few data centers [1]. With ever-growing data volume, elastic demand for resources and agile application deployment cycle, it has been challenging to meet these demands in the current mobile network architecture. It is expected that by 2020, there will be a 1000-fold increase in data volume and 100-fold in connected devices [2]. The 5th generation (5G) of the mobile network has been proposed to overcome the shortcomings of the current mobile networks and meet future demands. The 5G network architecture relies on Network Slicing to enable agile and rapid development of applications. Network slicing exploits the concept of Network Function Virtualization (NFV) to split a physical infrastructure into multiple virtual networks [1] and distribute them in an on-demand fashion. In 5G networks, an end-to-end network slice is defined as a complete logical network that includes Radio Access Network (RAN) and Core Network (CN) [3]. However, it is possible to instantiate RAN and CN slices independently. Network slicing in a 5G network presents a unique challenge that is not present in the previous or current mobile networks. The challenge is how to allocate slices optimally and dynamically to efficiently use the mobile network resources as well as guarantee minimum requested resources.

To address these points in this paper, we propose a Dynamic Slice Allocation Framework (DSAF). Our contributions are (1) DSAF can allocate slice dynamically in a real-time (2) it can calculate allocation solution (where feasible) for individual or multiple slice requests and update network topology accordingly, and (3) the proposed framework allocates slices in a balanced fashion (i.e., it spreads them across the available resources). DSAF can perform seamless slice allocation and deallocation as well as provide on-demand intra-slice isolation. Only user interaction required in DSAF is when a user requests a slice allocation; every other procedure is automated. DSAF implements our optimization model that can fulfill several requirements of the 5G mobile core network. We compared our proposed framework with the First Come First Serve and First Available (FCFSFA) allocation scheme. Both are evaluated on a real testbed.

The rest of this paper is organized as follows. In Section II we present the literature review on 5G network slicing and testbeds. Section III provides an overview of the optimization model for 5G network slicing. In section IV we present our Dynamic Slice Allocation Framework. We discuss our experiment setup in section V. In the section VI we discuss our results and lastly, section VII we present our conclusion.
In this section, we discuss existing works on 5G network slice allocation and testbeds.

**Slice Allocation:** M. Jiang et al. [6] proposed a novel heuristic-based admission control mechanism to allocate slices dynamically. In the proposed scheme, two-tier priority levels are used to allocate slices. In order to maximize the quality of experience for the users inside the slices, effective throughput is measured, and service is provided based on the inter-slice priority. The proposed scheme can dynamically change allocated resources to accommodate higher priority slices. X. Zhou et al. [7] discussed providing Network Slice as a Service (NSaaS). It can be categorized into three classes, i.e., business to business, business to consumer and business to business to consumer. NSaaS could also have three scenarios, i.e., industrial slice, monopolized slice, and event slice. Authors discussed the network slice creation and management as well as mapping of functions, service level agreements and different vendors. An auction-based model for network slicing in 5G has been proposed by M. Jiang et al. [8]. The objective of the auction-based model is to allocate slices to maximize network revenue. The model takes into consideration the demand and provisions in the network to decide on the price of the network slice. A digital market place (Network Store) for network applications and network functions has been proposed by N. Nikaein et al. [9]. The proposed Network Store would act similar to a Play store for Android or App store for iOS applications. It will offer hundreds of services that would be available to every slice. Authors demonstrated the proposed Network Store on a real testbed and evaluated the performance.

**5G Testbeds:** A Practical Open Source Solution for End-to-End Network Slicing (POSENS) has been proposed by G. Aviles et al. [11]. POSENS uses open source software and hardware to create end-to-end slices. Authors used srsLTE for radio access network and open-air interface EPC for the core network. The independence of slices and performance throughput is discussed in the paper. It also supports an efficient and flexible deployment of network slices. L. Zanzi et al. [12] demonstrated a real testbed named OVerbooking NEtwork Slices (OVNES). In the testbed, authors considered three different vertical slices, i.e., Public Safety communications, enhanced Mobile BroadBand (eMBB) for voice calls, and eMBB for Internet (best-effort). OpenEPC is used to emulate mobile core and several LTE devices to generate traffic.

### III. Optimization Model

In our previous work [5], we proposed an optimization model to mitigate DDoS attacks. The proposed model mitigated DDoS attacks using intra-slice (between slice components) and inter-slice isolation. In addition to providing defense against DDoS, it can optimally allocate slices. Our model allocated slices to the least utilized servers and finds the minimum delay path. The optimization model also fulfills several requirements of the 5G network. It can guarantee the end-to-end delay and provide different levels of slice isolation for reliability and availability as well as it assures that allocation does not exceed the available system resources. In our model, we only considered CPU, bandwidth, VNF processing delay, and link delay. Intra-Slice isolation could increase the availability of a slice. If all components of the slice are hosted on the same hypervisor, any malfunction

1Please note that in this paper we did not consider the inter-slice isolation.
could result in the slice unavailability. However, different levels of intra-slice isolation can ensure that full or partial slice remains available. More details of the optimization model can be found in [5]. We use this model as the optimization model in this paper.

Fig. 2: Dynamic Slice Allocation Optimization Flow Diagram

IV. DSAF: Dynamic Slice Allocation Framework

To automate the process of slice allocation in 5G core network, we propose a framework. In the proposed framework, slices can be allocated and deallocated dynamically. The Dynamic Slice Allocation Framework (DSAF) consists of five components as shown in Fig. 1:

- **The Orchestrator:** The Orchestrator or the slice manager is responsible for managing slices and facilitating on-demand slice allocation, deallocation, and coordinating different components of the framework as well as user interactions.

- **Optimization Module:** The optimization module implements our optimization model [5]. It reads the current state of the system allocation that includes remaining CPU, link bandwidth and delays as well as network topology and processes the incoming request. If a solution is found, the allocation is stored in a database, and the system allocation statistics are updated accordingly.

- **Database (DB):** The database stores requests information, allocation schemes, renaming system resources, and performance statistics.

- **O Agent:** The Optimization agent (O Agent) is responsible for communicating with the orchestrator and the optimization module. It receives the slice allocation from the orchestrator and forwards it to the optimization module and communicate back the results.

- **H Agent:** The Hypervisor Agent (H Agent) is an integral part of the framework (runs on each hypervisor). It is responsible for allocating and deallocating slices in real-time, starting applications for each slice and reporting slice statistics to the orchestrator.

The dynamic slice allocation process is shown in Fig. 1 and it is described in the following steps (each step corresponds to the circled number in Fig. 1):

1) The orchestrator provides user-interaction and waits for a slice request
2) Once a slice request is received, it interacts with the O Agent to find the allocation scheme.
3) The O Agent starts an instance of the optimization model and pass the slice request to the optimization module. The optimization module reads the current network state from the database and finds the best solution to allocate the slice (if feasible). If no solution is found, the request is denied, and the response is sent to the orchestrator.
4) The flow diagram of the optimization process is shown in Fig. 2.
5) If a solution is found in step 3, then the slice allocation will be stored in a database.
6) The orchestrator receives an accepted or denied response from the O Agent.
7) If the response is slice request accepted, the orchestrator retrieves the allocation scheme from the database and sorts the retrieved allocation scheme according to the slice(s) that will be allocated on each hypervisor.
8) The orchestrator sends the information to target H Agent(s). The information includes slice name, IP address, CPU (GHz), HDD, RAM, bandwidth and any application to start after the creation of VNF.

This process is repeated for every request, although DSAF should be able to process multiple requests at the same time.

V. Experimental Setup

| TABLE I: Experiment Topology Hardware Specification |
|---------------------------------------------|
| Server(s)                                      | Hardware Specs |
| Remote Server                                 | CPU: 8 Cores, RAM: 32GB, Bandwidth: 1Gbps |
| P1 to P3, and the orchestrator                | CPU: 4 cores, RAM: 8GB, Bandwidth: 1Gbps |
| P4 and P5                                     | CPU: 8 cores, RAM: 8GB, Bandwidth: 1Gbps |

To evaluate DSAF, we created a testbed using seven servers. We used five servers (P1 to P5) to allocate slices as shown in Fig. 3. The optimization module and the database are hosted on the same server (Remote Server), and the orchestrator is hosted on a separate server. The hardware specification for all
nodes are listed in Table I and the total resources available for the allocation across all servers are listed in Table II. The slice request parameters are listed in Table III. For simplicity, each request arrives every three seconds (random interval can also be used) and they are allocated in the order of arrival. We note that slice requests do not expire.

TABLE III: Slice Request Parameters

| Parameter          | Value          |
|--------------------|----------------|
| Intra-slice isolation | 1, 2, or 3     |
| VNF/Slice          | 3              |
| Bandwidth          | 40-60 Mbps     |
| CPU                | 0.75-2 GHz     |
| Total Slice Requests | 34             |

We implemented the DSAF in Python [13] and MATLAB [14]. The orchestrator, O and H agents are written in Python, and the Optimization module is written MATLAB. AMPL [15] is used to model the optimization algorithm, and CPLEX 12.9.0 is used as MILP solver. OpenVZ [16] is used for virtualization. It is an open source container-based virtualization platform. OpenVZ allows each container to have a specific amount of CPU, RAM, and Hard Drive (HDD). Each container (which hosts one VNF) performs and executes like a stand-alone server. We have installed the CentOS 6 [17] operating system in every container. We used Linux Traffic control (tc) [18] to allocate bandwidth for each container.

VI. RESULTS AND DISCUSSION

TABLE IV: Experiment Scenarios

| Scenario | Description                          |
|----------|--------------------------------------|
| K1       | one VNF/hypervisor/slice              |
| K2       | two or less VNFs/hypervisor/slice     |
| K3       | three or less VNFs/hypervisor/slice   |

We used three scenarios to allocate slices as listed in Table IV. In each scenario, we compare the DSAF with the First Come First Serve First Available (FCFSFA). In all scenarios, we collected statistics in terms of total slice requests allocated, processing time, and average computation time per slice. In the first scenario, we restricted the allocation to one VNF/hypervisor per slice (K1). In the second scenario, only two or fewer VNFs of a slice (K2) can be allocated on a single hypervisor. The third scenario three or less VNFs/slice can be placed on one hypervisor (K3). In FCFSFA, a slice is allocated based on arrival time and first available server. We make sure that allocated resources do not exceed the available physical resources. However, FCFSFA cannot guarantee the end-to-end delay. We wrote a Python script to perform allocation for FCFSFA. The FCFSFA is implemented on the same server as the orchestrator.

Fig 4 shows slice allocation for all scenarios. In scenario K3, all requests are successfully allocated for both allocation schemes as shown in Fig. 4c and 4f. However in scenario K1, DSAF and FCFSFA only allocated 27 and 17 slice requests respectively before P1, P2 and P3 ran out of CPU capacity. For scenario K1, we can only allocate one VNF/hypervisor per slice therefore once these three hypervisors ran out of CPU capacity we cannot allocate any more slices even though P4 and P5 still have significant resources available (because each slice needs three hypervisor for allocation). An interesting observation to note in Fig. 4 is that FCFSFA (all scenarios) allocates slices in an unbalanced manner. This allocation scheme behaves like a greedy approach, where it will allocate slices at the first available hypervisor. It resulted in lower number of requests being allocated in K1 and K2 as shown in Fig. 4d and 4e respectively. It could also result in slices competing for resources on one hypervisor sooner even though the rest of the system is idle as well as a higher chance of slice unavailability if a hypervisor malfunctions. Whereas DSAF optimally allocates slices in all scenarios and spreads them across the entire system leading to less resource contention between slices and in case of a hypervisor malfunction, there is a higher chance that slices could remain partially or fully available.

DSAF can allocate more or equal number of slice requests in all scenarios as shown in Fig. 5.
Fig. 4: Comparison of Allocation Schemes for Different Scenarios

Fig. 5: Total Slice Requests Allocated

Fig. 6: Overhead: Processing Time

Fig. 7 shows the DSAF and FCFSFA processing time overhead. The processing time includes the time required to process the user requests, sending and receiving information from the H and O agents. For FCFSFA, the processing time is the time required to retrieve allocation requests and read system topology. Although DSAF requires slightly more processing time because of the communication required between the components of the framework, it still performs comparably to the FCFSFA in all scenarios.

The average computation time per slice for DSAF is measured in the optimization module. The average computation time per slice for FCFSFA is the time required to calculate the allocation of slices and updating DB records. FCFSFA have lower average computation times per slice because there is no optimization performed as shown in Fig. 7. DSAF's average computation time per slice is the cost of allocating more slices as well as providing flexibility when allocating slices.
VII. Conclusion

In this paper, we presented a dynamic slice allocation framework to allocate slices in a resource efficient manner. The framework provides automation for slice allocation. We compared our framework with the First Come First Serve First Available allocation scheme. The evaluation of both techniques was done on a real testbed. Our results show that the overall proposed framework have comparable overhead to the FCFSFA. The cost of running DSAF is the average computation time that is slightly higher than FCFSFA. However, DSAF can allocate significantly more slices as well as it can fulfill a few requirements of the 5G (e.g., end-to-end delay). DSAF allocate slices in a balanced manner across the network which means less resource contention between slices until the network reaches saturation state. In FCFSFA, the resource contention could happen prematurely because slices are allocated in an unbalanced fashion (i.e., more slices on one hypervisor then the other).

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