SoftChain: Dynamic Resource Management and SFC Provisioning for 5G using Machine Learning

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***Abstract*—Network automation is an area of interest which further incurs in Zero-touch network and Service Management (ZSM). Machine Learning (ML) is acting as a key tool for the realization of such intelligent reformations. Adopting all new technologies inside the network needs enhancement of current orchestration frameworks. Even though existing works are contributing enough to technologically superior countries, this work exclusively aims at developing countries. In this work, a dynamic VNF allocation and embedding problem is addressed on the shared network slices (NSs) using softwarized Service Function Chaining (SFC). The ML techniques are specially designed to make the placement decisions more dynamic and resilient. The proposed VNF-CAR (VNF-Creation, Allocation, and Release) approach is portable among heterogeneous slices and backed by a systematic performance evaluation over a real network topology (INDIA-SDNlib). Accurate VNF selection and embedding are done by supporting OSM MANO decisions (Open Source Management and Orchestration). Through eventful actions, we have shown 20-30% of overall improved VFN selection efficiency against other existing benchmarks.**

***Index Terms*—vSDN, 5G and beyond, VNF, SFC, TSPs, Machine Learning**

I. Introduction

Contemporary communication networks are adopting programmable automation based on two fundamental concepts: (i) Software-Defined Networking (SDN) and (ii) Network Function Virtualization (NFV). Network operation and management are getting facilitated by SDN technology directly via all programmable infrastructure, NFV does the decoupling of NFs (Network Functions) from dedicated hardware of special purpose by virtualizing them all into segmented softwarized building blocks. The forthcoming 5G and the emerging 6G networks along with their subsequent building blocks. The network intelligence augmentation also results in the ZSM concept as defined by the ETSI's next-generation management & operation model [1], [2]. The evolving ML techniques are also putting their effects on network transition concurrently in real-life problems. The adaptation of such techniques is widely used in the case of autonomous intelligent vehicular networks.

As with emerging 6G, the combination of enhanced ML models and programmable communication networks opens a wide spectrum of MLN (ML in Networking). Issues like ZSM and other traditional challenges which include quality-of-service (QoS) and quality-of-experience (QoE) requirements, dynamic traffic steering, dynamic network resource management, etc., are targeted to solve efficiently using the above-mentioned techniques.

The existing MLN applications encounter the following concerns, (i) inefficient model adaptability, and the associated (ii) infeasible mode of applications due to high training and maintenance costs. The above-mentioned issues also do not show similar characteristics while they act upon the various modes of operations e.g., vehicular networks, UAV networks, satellite communication, deep sea communication, inter-planetary communication and also in case of mobile communications as well.

The versatile domains of network applications require different ways to address the problem. Network slicing is one such way where all proprietary networks are not physically separate but all of the slices use the same underlying physical infrastructure for their functioning. However, the specialized network hardware that has been used up to this point, like switches and routers, is too specific to work well with network slices. This is where SDN and NFV come to the rescue. SDN facilitates the separation of the control plane of a network from the forwarding plane. This means increased flexibility and more control over the network by making the control plane more under our control [3], [4]. NFV comes into the picture when the specialized network hardware is replaced with more generalized hardware which can be programmed to our liking and can perform the varied network functions according to the different network slices [5]. It's important to note that this generalized hardware is essentially computers or servers.

Once the virtualization of network functions is done, the next step is to divide the computing power and resources among the various slices and the different users. One obvious way to do it will be to allocate fixed resources, but that will create problems like over-allocation and under-allocation of resources. If too much is allocated, then it is wasteful and some other waiting process might not be able to use the resources which are needlessly being held by the current process. If not enough resources are provided, then the network service quality will worsen. One way would be to increase the fixed

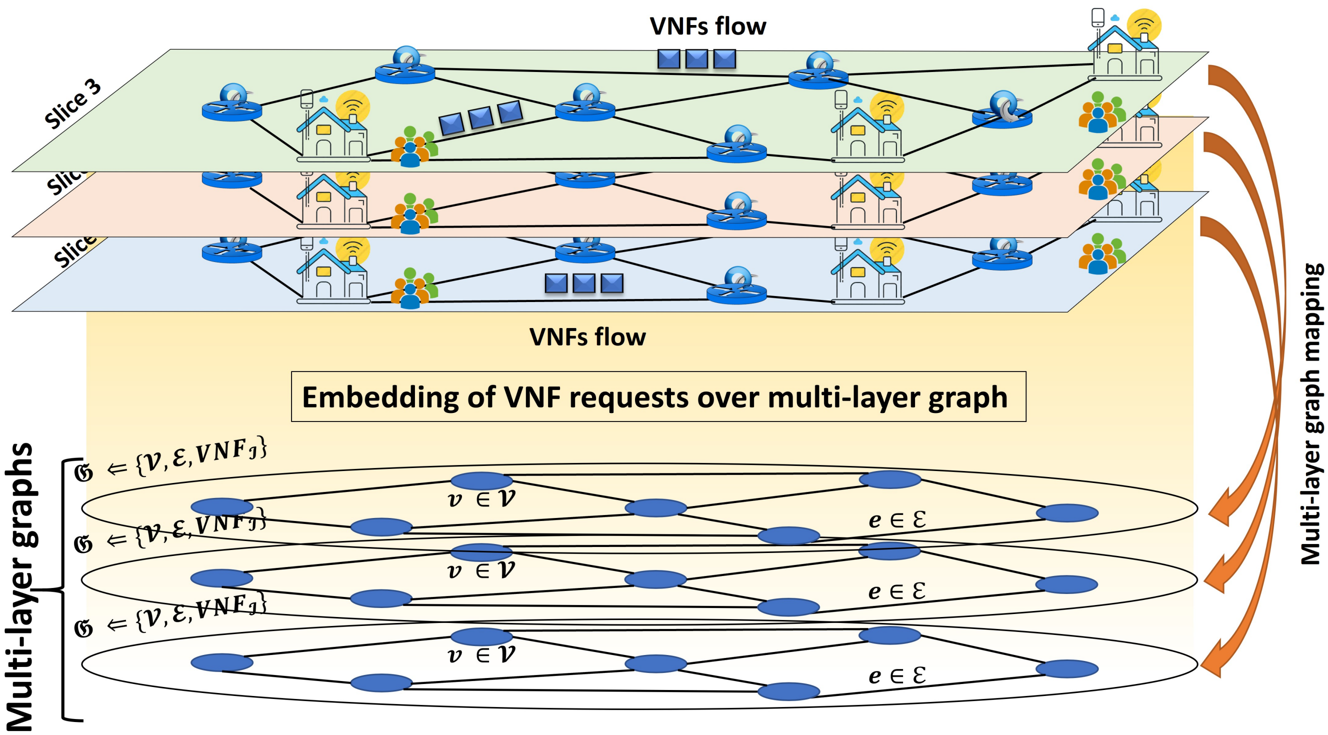


Fig. 1: vSDN-based network slicing architecture for 5G and beyond networks with shared-SFCs

amount of resources but that would drive up the cost too much for the network operators [6], [7].

Main Motivation Behind the Work:

The state-of-the-art analysis of the latest research has shown the importance of SFC provisioning on dynamic network traffic in a shared slicing environment. A detailed case study on the effect of dynamic SFC over network slicing is done in [8], [9]. Due to massive traffic overshoot, local consumers are facing serious connectivity challenges and TSPs are facing difficulties to satisfy the required demands. The distribution of network functions for versatile network applications changes abruptly in developing countries due to the co-existence of urban and rural areas. The traffic categorization of both regions is non-symmetric. Even though SDN, NFV, NS, ML, and AI are trying to bridge the gap of QoS benchmarks in different geographic regions [10], [11], the resource in form of VNF over SFCs allocation, re-allocation, rolling-back, and deletion are still major area for contributions. These factors primarily motivate us to contribute to this field by developing suitable VNF-to-SFC allocation mechanisms with improved accuracy.

VNF is a network function which is placed in form of a sequential chain to produce demand-based applications for end-user. Considering two heterogeneous environments where VNF requirements are growing haphazardly and at variable speeds. Now, multiple VNF instances need to be grouped in such a way that, the resultant SFC must satisfy the flow of action. Figure (1) shows a generalized overview of the multi-slice framework for the 5G network. The two issues mentioned in the previous section have been concatenated as SFC provisioning problems. A vSDN-enabled (virtualized Software-Defined Networking) 5G slicing model on real network topology is taken for our test case analysis. The ML algorithms are used to select the VNF for both uniform and random distributions over SFCs. We have further included VNF-type casting into the frame considering different modes of behavioural demands.

Contributions The SFC provisioning and VNF embedding problems are executed over a real network topology (especially considering the infrastructure of a developing country). The objective is to improve the VNF accuracy values and better the selection mechanism for SFCs. We have proposed a suitable dynamic VNF selection algorithm for both uniform and random resource distribution. The brief contributory summary is explained below.

- Indian geographical model has been considered as the base level topology on which a multi-layered graphical re-modelling is done analytically. The system model parameters and their respective values are considered from standard models and associated matrices.
- The next phase of SFC provisioning is VNF embedding after selecting them with care. We have proposed the VNF-CAR method with each VNF instance embedded for each incoming flow of service request.
- The machine learning algorithm is used to select the VNF instances properly improvising the selective error margins. To avoid sample point discrepancies inside the used dataset, two selective ML approaches are used for better data interpolation.
- Finally, the selection accuracy of multi-point VNFs is

shown through comparative analysis. Our method has shown some significant improvement in VNF selection, allocation, creation, and release.

Paper Organization: The rest of the paper is organized as follows: related state-of-the-art techniques and the existing solutions are shown in section II. Sections III and IV explain the system model over the real network topology and explain the problem mathematically. Section V demonstrates the proposed VNF-CAR algorithm with extensive simulations. Section VI does the result analysis and discussions to show the efficiency of our proposed approach. Finally, section VII concludes the work with some open research directions.

II. Related Works

The concept of NS is still emerging as a promising factor for next-generation wireless communication networks. It encompasses different 5G-oriented network services such as eMBB, mMTC, URLLC, etc., which are different for different sets of end-users [12]. The classifications wisely vary from urban to rural areas. The challenges due to wide discrepancies in traffic characteristics in different geographical regions are critical and researchers are continuously working on developing solutions for the same.

A. Network Virtualization for NS

NFV enabled us to virtualize specialized network hardware in favour of generalized hardware like computers or servers [13]. This meant a reduction of costs of installation and maintenance as well as making the network infrastructure more flexible and scalable. These virtual elements were called VNFs (Virtual Network Functions). VNFs are the key factors of VMs (virtual machines) that work as Network Functions. Designing suitable placement techniques for the VNFs themselves is an extremely complex and challenging issue in modern mobile communication networks. The key factors on which the VNF placement depends are network overall performance, processing power, CPU capacity and memory organization. Most of the existing algorithms for VNF placements do not consider resource availability choosing VNF as a host. These approaches do not assure optimum performance for VNFs due to the dynamic nature of network demands. Even though the automation of the network demands ZSM, which requires no human interaction but the aim is far from over as most of the well-defined orchestrator still needs human interaction [14].

B. SFC Provisioning for Network Slicing

NS is the concept of the co-existence of multiple network slices working together providing services to multiple and distinct applications such as e-healthcare, Industrial IoT, UAV networks, Smart Agriculture, Deep Space Communication, Underwater Communication and many other related fields. Ns includes two basic steps called *slice framing* & *slice rendering* [15], [16]. Framing is done using SDT (Software-Defined Technology) and the rendering is done using both SDN and NFV. Multiple SFCs are concatenated together to structure one slice and multiple VNFs are augmented together for an SFC formation. VNF instances are getting created inside virtual containers using programmable interfaces. Selection of the VNFs for suitable SFCs is done by the MNOs (Mobile Network Operators) satisfying the network demands and considering the traffic characteristics. A detailed survey on VNF embedding is done in [17]. Authors have mentioned that dynamic behaviour creates problems with random VNF allocation. Areas are still open for further contribution in this area.

C. Dynamic Resource Management in Network Slicing

The base level vSDN needs central controller and hypervisor units as its main backbone infrastructure. All the NFs are installed inside the C-plane Controller and H-plane Hypervisor instances. Authors in [18], [19] have widely studied the placement problem related to these devices. Further, the installation of VNFs inside this equipment is needed for the smooth flow of services. This work targets to solve the issues related to the VNF to SFC mapping and optimal placements of VNF with high accuracy. NFVI (Network Function Virtualization Infrastructure), VNF Manager, and Network Slice Orchestrator are the key agents who proctor all the events inside the network [20]. The dynamism and random traffic behaviour in different regions demand different ways of solutions. Most of the existing literature focuses on a single region with uniform demand or high-level demands, which further triggers resource under-utilization problems or utilization problems. In this work, we have put special effort to address this serious networking issue.

D. Intelligent Resource Sharing using ML

The advancements of 5G and emerging 6G networks associated wide range of applications are becoming very popular among end-users. Vehicle-to-vehicle, vehicle-to-everything, machine-to-machine, Aerial communication, Ground-to-Aerial communication, industry 4.0, Deep sea communication, and interplanetary networks, almost in every field the 5G is growing branches. All verticals with various and distinct demands require unique attention. In solving this matter, network slicing plays a crucial role. Slicing allows intelligent resource sharing among multiple layers of applications in a heterogeneous environment. The introduction of technologies like machine learning, deep learning, artificial intelligence, etc. added additional advantages in the domain of network automation.

Thanks to the aforementioned concepts, network scientists now had more control over the network, and to reduce costs further, a need arose to provide dynamic resource allocation to the VNFs, which in contrast to static resource allocation, could mitigate the chance of overallocation (increases cost) and under allocation (degrades service quality) [21]. So we resort to machine learning to predict resource requirements. Along with that, the reduction of latency in resource allocation could provide much better network service to time-critical applications like disaster management, UAV networks, autonomous vehicles, and e-healthcare.

III. SYSTEM MODEL ARCHITECTURE ON INDIAN NETWORK TOPOLOGY

A. SDN and NFV for NS

The introduction of SDN and NFV in networking opened up a lot of avenues for innovation. Before the introduction of such concepts, the data plane and the control plane had no separation between them and as a result, there was not much control over it, but with the introduction of SDN, the data plane and the control plane were separated which meant, we could control the data plane more centrally. This meant that we could determine paths for data packets to take without the data having to go through unnecessary routes. As a result of SDN, network security increased as well as costs were cut down since the control plane was more centralized. SDN paved the way for Network Function Virtualization to appear in the picture.

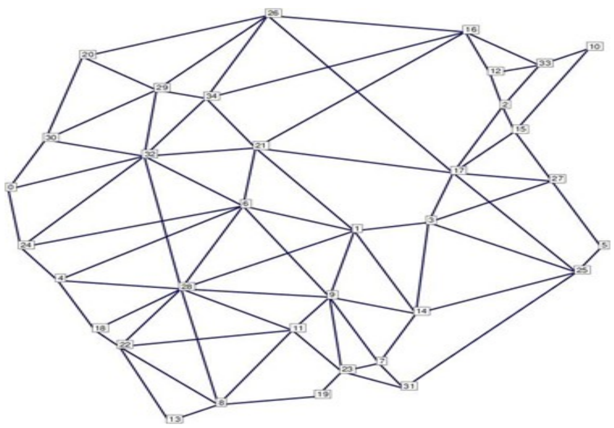


Fig. 2: Indian Graphical Topology [22]

B. VNF and SFC over NS

Figure (2) represents the reference framework for the base-level model. The topology contains $\mathcal{N}$ = 35 nodes, $\mathcal{L}$ = 80 links and $mathcalD$ = 595 SFC requests. The requests are getting generated randomly for the network. The other parametric data are taken from the data set of SDNLib [22]. The nodes in the graph represent the potential C-plane and H-plane entities. TSPs can use vSDN and SND networks by selecting suitable nodes for installation. The network functions are installed inside the entities placed on the nodes. The connection paths are the wired optical fibre connections working as the back-bone network. The objective here is to select suitable VNFs to be installed and later make the connections for optimum SFC provisioning. The values are considered as an average of high and low-level demands. The detailed simulation analysis, associated parameters, and corresponding values are given VNF-CAR on SFC for 5G. The system can be tuned more specifically with real-time data on which we will extend this work in the future.

IV. PROBLEM FORMULATION FOR VNF-CAR

For this part of the work, we have collected network topological parameters from [22] which contain various network topologies from various regions around the world. Each of these topologies contains $\mathcal{N}$ nodes with given 'x' and 'y' coordinates, $\mathcal{L}$ links connecting any two nodes from the $\mathcal{N}$ nodes, and the bandwidth capacity of each link and finally $\mathcal{R}$ number of SFC requests with a source node and destination node. The request generation on each node is done randomly taking the mean average as the reference value. The parameters are customizable, so in the future, the application-based demand-specific modifications can be done as per any requirements. After the modelling of the nodes, links, and SFC requests, a multilayered graph is created using an adjacency matrix representation. The multilayered nature of the graph originates from the fact that there are multiple SFCs SFC_i, at a particular node, which can be used to serve multiple service requests simultaneously. The service requests follow SFC paths for end-to-end connections. The SFC paths are slice specific and also virtual in nature. It is made programmable and flexible to support traffic dynamism. For each SFC request, however, this multilayered graph is converted into a single-layer graph, before further VNF allocation. This step is for simplification of the model.

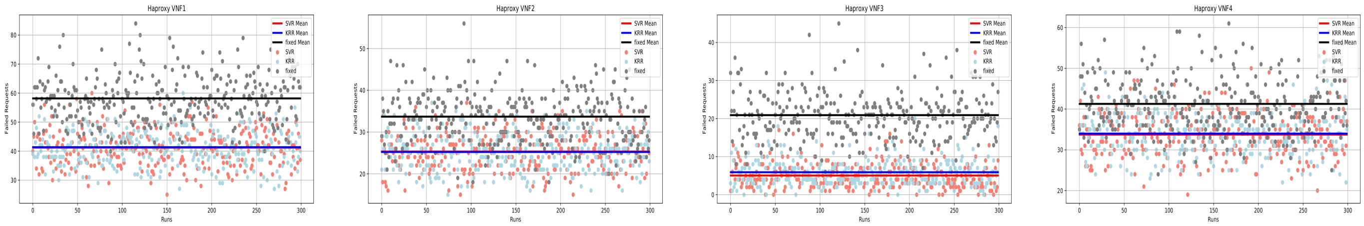
V. PERFORMANCE EVALUATION

The algorithmic solution approach results in suitable VNF embedding on shared SFCs and subsequent slice formation is done by optimizing resource utilization and overall network capacity consumption. As the VNF selection is done with minimal error, the corresponding service quality gets improved automatically. We have assumed that the interfacing network is following standard 5G architecture. The reduction in total physical nodes usage can be explained by the fact that a shared VNF needs to be instantiated on a virtual node only once and hence only a single physical node would be used for its corresponding mapping because otherwise due to multiple embeddings between the same VNF type and virtual nodes a much higher number of physical resources would have been used. Since the number of virtual nodes to be utilized for shared VNF placement reduces, the number of virtual links to be used for linking also decreases which ultimately affects the total physical link utilization. This can be easily verified in figures (3), (4), and (5). The effect of overall capacity consumption is reduced eventually, and the same has been depicted in figure (6).

System Specification and Complexity Analysis: The ML follows sparse SVR and non-sparse KRR methods. The XML parsing is done in linear time for VNF placement. So the time complexity of it is $\mathcal{O}(L)+\mathcal{O}(N)+\mathcal{O}(D)$. The simulation was run on Google Colab with 12.7 GB of RAM.

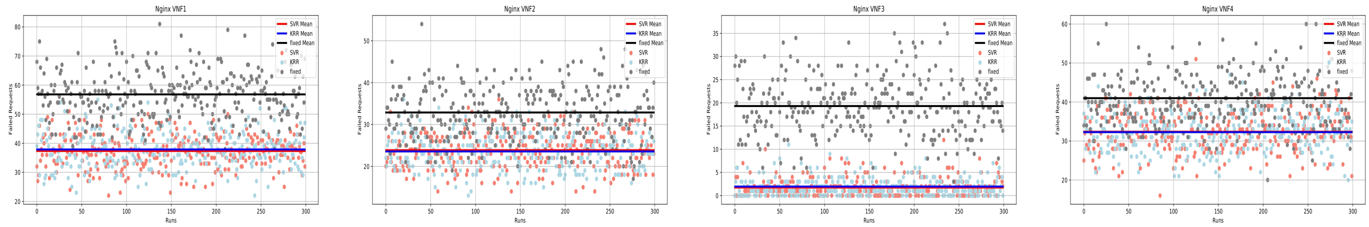
VI. RESULTS AND DISCUSSIONS

From the results we obtained, it is clear that our proposed solution gives better QoS under both ideal uniformly distributed VNF types as well as more realistic random VNF type allocation for different topologies of India and the US. We have taken 300 runs of our VNF placement algorithm each time with randomized SFC requests. From the distribution



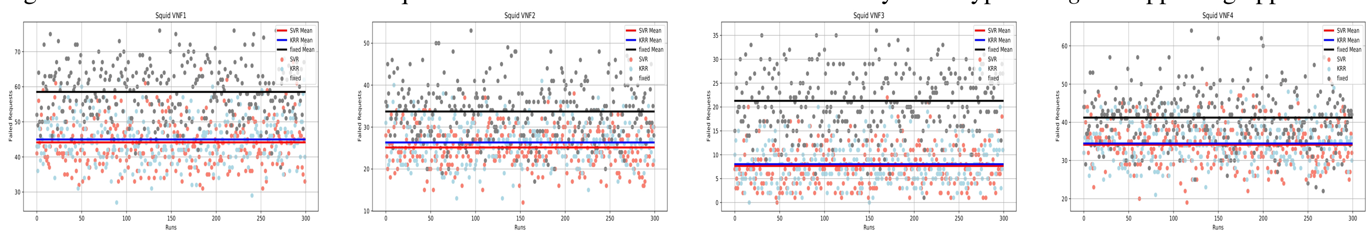
(a) VNF type (1) SFC fail rate (b) VNF type (2) SFC fail rate (c) VNF type (3) SFC fail rate (d) VNF type-(4) SFC fail rate

Fig. 3: Distribution of Failed SFC requests for random VNF distributions for every VNF type on *Haproxy* supporting applications



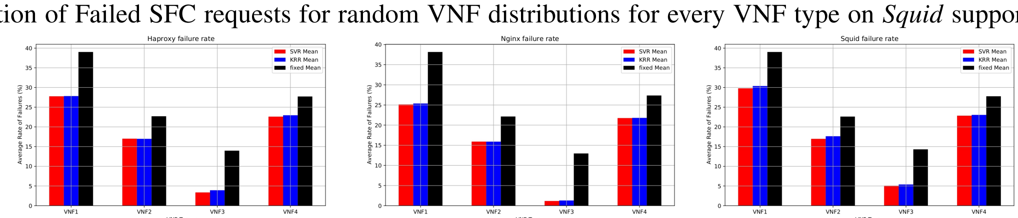
(a) VNF type (1) SFC fail rate (b) VNF type (2) SFC fail rate (c) VNF type 3) SFC fail rate (d) VNF type 42) SFC fail rate

Fig. 4: Distribution of Failed SFC requests for random VNF distributions for every VNF type on *Nginx* supporting applications



(a) VNF type (1) SFC fail rate (b) VNF type (2) SFC fail rate (c) VNF type (3) SFC fail rate (d) VNF type (4) SFC fail rate

Fig. 5: Distribution of Failed SFC requests for random VNF distributions for every VNF type on *Squid* supporting applications



(a) VNF failure rate for Haproxy (b) VNF failure rate for Nginx (c) VNF failure rate for Squid

Fig. 6: Avg. rate of failed requests for different applications running on different geo-locations for random VNF dist.

Table I: Analysis on shared VNF utilization

Uniform VNF type resource distribution		Percentage Improvement for VNF types (Absolute percentages)			
Data Set	**Comparative Analysis**	**VNF Type I**	**VNF Type II**	**VNF Type III**	**VNF Type IV**
Hap-roxy	**Fixed Allocation to SVR**	16.45%	16.60%	16.70%	16.73%
	Fixed Allocation to KRR	17.05%	16.70%	17.17%	17.00%
	KRR to SVR & vice-versa	0.60%	0.11%	0.49%	0.27%
Nginx	**Fixed Allocation to SVR**	19.97%	19.40%	19.56%	19.96%
	Fixed Allocation to KRR	19.68%	19.15%	19.21%	19.60%
	KRR to SVR & vice-versa	0.29%	0.26%	0.34%	0.37%
Squid	**Fixed Allocation to SVR**	16.12%	15.91%	15.40%	16.29%
	Fixed Allocation to KRR	15.01%	14.61%	14.06%	14.87%
	KRR to SVR & vice-versa	1.11%	1.30%	1.35%	1.42%

Table II: Analysis on shared VNF utilization

Random VNF type resource distribution		Percentage Improvement for VNF types (Absolute percentages)			
Data Set	**Comparative Analysis**	**VNF Type I**	**VNF Type II**	**VNF Type III**	**VNF Type IV**
Hap-roxy	**Fixed Allocation to SVR**	11.25%	5.69%	10.60%	5.11%
	Fixed Allocation to KRR	11.20%	5.73%	10.04%	4.77%
	KRR to SVR & vice-versa	0.05%	0.04%	0.55%	0.35%
Nginx	**Fixed Allocation to SVR**	13.02%	6.23%	11.80%	5.60%
	Fixed Allocation to KRR	12.79%	6.24%	11.67%	5.55%
	KRR to SVR & vice-versa	0.23%	0.01%	0.13%	0.05%
Squid	**Fixed Allocation to SVR**	9.22%	5.65%	9.23%	4.92%
	Fixed Allocation to KRR	8.64%	4.99%	8.93%	4.72%
	KRR to SVR & vice-versa	0.58%	0.67%	0.30%	0.19%

diagrams in figures 3 through 6 it is clear that the number of failed SFC requests follows a constant trend throughout the 300 runs of the algorithm for all scenarios that have been considered. Figure 6 shows us the average failure rate for SFC requests over 300 runs for different VNF types and different applications. In every possible scenario, resource allocation done with the help of machine learning over fixed allocation performs better. In ideal conditions where different types of VNFs are distributed uniformly among all available VNFs at a node, intelligent resource allocation can achieve 15%, 17% and 20% fewer failed requests than fixed resource allocation in the Indian topology for Squid, Haproxy and Nginx (dataset library) applications respectively. For the Indian topology and random VNF distribution, our proposed solution achieves 16%, 20% and 25% fewer failed requests than fixed resource allocation for Squid, Haproxy and Nginx applications respectively. Tables I and II show the comparative analysis of SFC failure rates for different networking conditions. We have extended the experiments to rural regions considering uniform VNF distribution. This is done because of the sparse population with less diversity of demands and applications. This method saves resources enormously and the resources can be used for the extension of new services in the network.

VII. Conclusion and Future Work

Through VNF placement along with intelligent resource requirement estimation, we have shown an actual improvement in QoS as there are fewer failed SFC requests as compared to fixed resource allocation. The *VNF-CAR* is used for suitable and dynamic resource management over the real network topology of any developing country. The novelty lies within the concept of geological traffic disintegration. The random differences which increase the wastage of resources can be improved easily using this approach. This improvement is also achieved in various scenarios under different topologies and different distributions of different types of VNFs at the nodes. One potential area of future work would be an intelligent division of VNF types at the nodes instead of uniform or random distribution. This is because different areas or nodes can have different traffic loads for a particular type of VNF. There could also be some nodes which are affected by some natural disaster and are out of service. In such a scenario, the nodes neighbouring those damaged nodes should be able to adapt and share the load of the out-of-service node.

VIII. Acknowledgement

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