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A Survey of Functionalities of Virtual Network

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Abstract: ***Nowadays, network functionalities are provided through dedicated hardware middleboxes. These hardware middleboxes are statically embedded with network topology to provide the network services. The types of middleboxes increase in the network, with an increased number of users and network services. The growth in multiple kinds of middleboxes creates an ossified network that is difficult for network management. Network Function Virtualization (NFV) deals with such problems by eliminating network functions from the piece of hardware and implement it as a software to execute in a commodity server. The network virtualization provides more flexibility and elasticity in the network to automatically manage and control the network functions. NFV internally implements the different algorithms to automate the ondemand service provisioning mechanism. This paper presents a survey on algorithms for VNF placement, service chaining, VNFs scheduling, and VNF migration. Moreover, the challenges related to several VNF strategies are explored.***

Key Words: Network Functions Virtualization, Provisioning Ossification, VNF Placement

The demand for new services is continuously growing with an increase in users of the cloud and Internet of Things (IoT) applications. The report from Visual Networking Index 2017 has predicted that the mobile traffic will surmount at the rate of 46 percent Compound Annual Growth Rate (CAGR) between 2017- 2022, and the traffic growth rate will 77.5 exabytes per month by 2022 [9][23][25] . The increased number of users demand new types of services. These services are deployed using hardware devices called middleboxes. The modern networking system relies on these middleboxes, which cooperate to accomplish a specific task. Some of the middle-boxes are IP Multimedia Subsystem (IMS), Deep Packet Inspection (DPI), Network Address Translator (NAT), Content Delivery Networks (CDNs), Quality of Service (QoS) analyzer, Packet Data Network Gate-ways (PDNGWs), Virtual Private Networks (VPNs), firewall, proxy, router etc [21]. As these middle boxes are manufactured for a specific service, therefore service providers are bound to purchase a piece of hardware for creating every new service, which increases the Capital Expenditure (CAEXP) of the service. Moreover, service providers pay to the vendors for configuring, maintaining, and upgrading the services, which increase the Operational Expenditure (OPEXP) of the services. Middleboxes are hardware devices; therefore, it is impossible to extend its functionality. These hardware-based middleboxes are statically embedded in the network topology, which makes on-demand service provisioning a challenge. Further, it slows down the process of service creation and modification. NFV is a promising technology that addresses the limitations mentioned above. It focuses on generalizing network hardware by transforming the hardware middleboxes into software middleboxes. The software middleboxes are capable of executing on a server or Virtual Machine (VM). A running instance of the software middlebox in a VM is known as Virtual Network Function (VNF). New services can be easily deployed by running service-specific VNF on a machine. Thus, VNF based deployment is cheaper, flexible, and agile than the middleboxes based deployment. The substitution of hardware middleboxes with VNFs brings several issues such as orchestration of VNFs, management of VNF life cycle, policy enforcement, NFV performance, VNF

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placement, service chaining, traffic routing, VNF scheduling, VNF migration, security, privacy, resource and service modelling [24] [27] [18] [21].

Many of the issues have been resolved. This article discusses those issues that do not have a standard solution yet, namely, VNF placement, service chaining traffic routing, VNF scheduling, and VNF migration. The objective of the VNF placement problem is to determine the positions of VNFs and their numbers in the network such that they ensure service quality. Due to the NP-hard characteristic of the VNF placement problem, it is hard to get an optimal solution, specifically for the larger problem size [14]. The solutions for the VNF placement problem are either deterministic or heuristic. The deterministic solutions [27] [13] [15] provide the optimal solution with high execution time, whereas heuristics [19] [7] [12]give a sub-optimal solution within an acceptable time [5] [16] [17]. The problem is NP-hard; therefore, finding an optimal solution is not a good choice as it may delay the placement decision. But heuristics may give a poor solution; therefore, most of the researchers have focused on heuristics (with some redefined criteria), which help to evaluate their solution. Service chaining is a process of creating a virtual path in which VNFs are organized in a specified order to form a service. The network service providers utilize the chaining mechanism to deploy multiple services with different characteristics. The service chaining mechanism allows service providers to automate the provisioning of network services; also, it increases resource utilization. The service chaining problem evolves from the VNF placement. Hence, it is an NP-hard [30][25] [26]. It can be transformed into the bin packing or facility location problem to get the solution. The solutions for the service chaining problem are either a multi-stage or single stage. The multi-stage strategy, first solves the VNF placement problem and then finds the optimal solution for the service chaining problem [5] [30] [20] [28]. In contrast, the single-stage strategies get the joint solution for both VNF placement and chaining problems [11] [29] [3] [6]. The solutions for the service chaining problem either deterministic or heuristic. The deterministic methods find the optimal solution in a significant amount of time, which depends on the problem size. Hence, deterministic approaches are not suitable for a large problem [5] [30]. The problem size depends either on network size or the number ofservices running on it. The heuristic approaches find the suboptimal solution for the service chaining problem in low execution time [22] [8] [1]. Hence, researcher stand to design an algorithm that gives an optimal and scalable solution. The VNF migration scheduling problem can be formulated as an optimization problem to optimize the service downtime and VNF migration time. The service downtime is the time in which VNF stops running during migration. The migration time is the period in which the migration takes place. The VNF migration scheduling solutions can be categorized into deterministic and heuristic.

The deterministic solution gives optimal results in high execution time, whereas n the heuristic method gets the sub-optimal solution in lesser execution time. The focuses of the researchers are to design heuristic methods for the VNF migration schedule, which tends to be more closed to optimal results. This article presents a taxonomy for the VNF migration strategies, which are either non-preemptive or preemptive. The different frameworks [18] [27], which are transferring the VNF state or flow state using the migration strategies, that have been discussed. Theobjective of these frameworks is to minimize the service downtime, state transfer time, packet drop rate, and increase the throughput.

Introduction to NFV- NFV brings new ways to design, deploy, manage, and provision network services by decoupling the network functionality from proprietary hardware. In NFV, the network functionality is implemented as software which runs on a commodity server. The

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software characteristic of the network functionality allows it to execute on VM. Hence, each VM can perform an individual operation such as NAT, IDS,proxy, and firewall. Instead of hardware-based middleboxes, NFV can be used for creating new network services, which reduces the manufacturing time and complexity. NFV-enabled the network to provide several benefits:

- Flexibility in deploying and managing network services;
- Reduce the time to create new network services;
- Support execution of multiple networks functions on a single physical machine;
- Reduces capital expenditure by implementing the software middle boxes rather than hardware middleboxes;
- Decreases the operating spending by automating the orchestration and management of network services.

The NFV framework has three functional components- NFV Infrastructure (NFVI), NFV Management Orchestration (NFV MANO), and Network Management Systems (NMS). Each component has a well-defined responsibility.

NFV Infrastructure: The NFVI comprises both hardware and software, which offers the execution environment for the network functionality. The hardware part of NFVI is responsible for providing computation, storage, and connectivity to VNFs. The layer of software i.e. hypervisor, create duplicates of hardware resources, known as virtual resources. Moreover, hypervisor isolates duplicate resources from each other. The hypervisor represents the compute and memory resources of a physical machine in the form of multiple VMs and use networking resources to interconnect these VMs.

NFV Management and Orchestration: The NFV MANO has three functional units and four data repositories. The functional units are Virtual Infrastructure Manager (VIM), VNF Manager (VNFM), and VNF Orchestrator (VNFO). The data repositories are the VNF catalog, VNF instances, NS catalog, and NFVI resources. VIM is responsible for controlling and managing both physical and virtual resources of the NFVI within a controlling domain. It means more than one VIM can exist to control and manage NFVI resources in an NFV network. VIM is capable of handling both specific and general types of NFVI resources; it also keeps the record of the allocated and free resources. The responsibility of the VIM is to allocate, release, upgrade, reallocate resources to maximize its uses. Moreover, it creates the VNF forwarding graphs (VNF-FG) for Service Function Chaining with the help of virtual links, networks, subnet, and ports. VIM ensures access control with the help of a security group policy.

NFV Algorithms- Aim of NFV technology is to automate the service provisioning mechanism that reduces the networking operating cost. The NFV orchestrator executes some optimization programs or algorithms to automate the service provisioning process. These four operations VNF placement, service chaining, VNF scheduling, and VNF migration supports the service provisioning mechanism in NFV enabled network. This section comprises the optimization techniques or algorithms for VNF placement, service chaining, VNF scheduling, and VNF migration.

3.1 VNF Placement-The software implementation of VNFs provides the flexibility to service providers in deploying these VNFs over NFV enabled network. Therefore, a critical issue arises, i.e., determining the locations for deploying the VNFs to meet the service requirements. It is called the VNF placement problem. Bari et al. [5] and Luizelli et al. [30] have transformed the VNF placement problem into two NP-hard problems, i.e., Capacitated Plant Location Problem (CPLP) and Bin packing problemrespectively to find the optimal solution. Hence, the VNF placement problem isproved as NP-hard. Clayman et al. [10] have presented an architecture for theautomation of the VNF placement and service allocation process. It consists of amonitoring system that first collects the status characteristics of VNFs and thendisplays

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them. They have given architecture for the VNF placement, but they havenot given any specific approach for the VNF placement.

3.2 Service Chaining- The service chaining is a process for creating the logical chain of VNFs in a specifiedorder. This chain routes the network traffic across VNFs. The chaining mechanismsupports the on-demand service provisioning in the NFV-enabled network. IETFhas established a Working Group (WG) to standardize the service chaining mechanism. The WG publishes several documents for service chaining architecture andusecases [2].

A Survey of Functionalities of Virtual Network 5Some researchers [3] have formulated the service chain using context-free language. Moreover, the authors have presented a service chain placement modelusing Mixed-Integer Quadratic Programming (MIQP). The placement model hasthree conflicting objectives- i) maximize the data rate on the links; ii) minimizethe active nodes in the network; iii) reduce the latency of the data path. ThePareto analysis makes an optimization trade-off among the data rate, the numberof active nodes, and latency. The experimental results show that the fixed numberof active nodes, the solution latency increases to get a higher data rate, whichmeans decreasing the latency gets a low data rate. The Pareto analysis can helpthe service providers to prioritize the optimization objectives and select the appropriate objective functions. Some people [18] have proposed two solutions for theplacement of service chains. Both the solutions decompose the services into smallercomponents at the time of service mapping. The first solution is based on ILP, which maps the service requests on the available network resources to optimize themapping cost. The second solution is two-phased heuristic based on backtrackingknown as Decomposition Selection Backtracking Mapping (DSBM). In the firstphase, the heuristic solution decomposes the services into sets of VNFs such thatdecomposition takes minimum embedding cost. These sets of VNFs work as inputs for the mapping phase. In the second phase, first, create the groups of VNFsbased on types and their interconnections. Then arrange the VNFs in descendingorder of their requirements within corresponding groups. Now, start the groupwise mapping of VNFs based on their needs. Each group of VNFs is mapped onthe physical network, such that minimize the number of hop counts. The resultsshow that the execution time of ILP based solution increases exponentially withincreases number of nodes in the network. The execution time of the ILP basedsolution also depends on the number of VNFs in the service chains. Whereas, theheuristic solution maps network services in a large network within 100 ms. TheIPL based solution gives the more optimal solution in terms of service acceptanceratio and mapping cost than the heuristic.

3.3 Virtual Network Function Scheduling

VNF scheduling follows Brucker's guidelines. According to Brucker, a schedulingproblem identifies the time slots to performs the various activities under givenconstraints [26]. Therefore, the VNF scheduling problem is defined as to find therespective time slots on the set of VNFs for traversing the traffic flows. Riera etal. [15] have given a two-stage solution for the VNF scheduling problem. In thefirst stage, VNFs mapped on the servers and then formulated the VNF schedulingproblem as a Resource-Constrained Scheduling Problem (RCSP). The objective ofthe VNF scheduling problem is to find a schedule to minimize the flow traversaltime. The two-stage method implemented in the SDN paradigm Mijumbi et al.[25] propose three greedy strategies based on heuristics with different criteria anda tabu search based meta-heuristic to solve the VNF placement and schedulingproblem jointly. For the VNFs mapping aspect, the first heuristic bias towardsbest processing capability of servers, the second heuristic bias towards the leastloaded servers, and the third bias towards most availability. After mapping, allgreedy heuristics sequentially schedule the VNFs execution, which is inefficient.Meanwhile, the tabu search based meta-heuristic minimizes the flow schedulingtime. The tabu search based meta-heuristic defined by the five components whichare - initial solution, neighborhood solution similar to the initial solution, setof servers for VNF mapping, criteria to find another solution, and terminationcondition.

3.4 Virtual Network Function Migration- Before the migration, the migration policy set the rules in which circumstancesrequire to migrate a VNF from one machine to another. Moreover, migration policydetermines the best location and path. In the NFV enabled network, multiple VNFmigrations require a migration schedule. The migration schedule determines themigration order of VNFs. Finally, a migration strategy used to migrate the VNFfrom source node to destination.

Conclusion- The network is transforming into a rigid network due to the increasing number ofmiddle-boxes. NFV deals with such a state by eliminating network functionalityfrom proprietary equipment and implemented as software. The elimination of network functionality provides an elastic ecosystem that automates the control andmanagement of network functionality. In NFV, service providers execute networkfunctionality into the general server instead of built-in equipment that reducesthe operational and maintenance cost. SDN and cloud computing jointly lead theNFV-enabled networking trend.This survey consists of four different issues connected with NFV. The firstproblem is a VNF placement that determines the locations and numbers in anetwork. The second problem is service chaining that establishes the virtual links toform a service. It also efficiently rout the traffic to increase bandwidth utilization.The third one is the VNFs scheduling that determines the execution sequence ofVNFs to minimize the service makespan time. The fourth issue is VNF migrationwithin this discuss the VNF migration policy and VNF migration schedule formigrating a large number of VNFs. The existing solutions for the above problemsare either deterministic or heuristic. Moreover, this paper comprises the hierarchyof VNF migration strategies.

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