A Review of Network Function Virtualization

Current and Future State

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ABSTRACT

Network function virtualization abstracts the software from a black box appliance, such as firewalls and load balancers, replacing it with commodity hardware while chaining together functions to achieve a fully virtualized network path. Through a literature review of the current NFV research, an overview of the state of NFV is explored. NFV development faces research problems such as identifying optimal placement of commodity hardware within the network. As well, ensuring the virtual network function does not suffer performance issues within the virtual environment. Dynamically scaling service function chains is required and is being orchestrated with SDN. Obvious use cases for NFV have been identified such as NFVaaS while other ideas such as DDoS mitigation are being explored. Presented in this paper is a less explored use case for NFV, inter-organizational service function chaining. NFV is a new networking technology that promises to change the way networks are designed.

Keywords

Network Function Virtualization, NFV, SFC, SDN, Cloud Computing

1. INTRODUCTION

Virtualized compute environments have been prominent in the industry over the last two decades. The abstraction of software and hardware revolutionized the way technology was deployed achieving scalability and cost efficiency. With computer networking however, the hardware and software have remained tightly coupled. Abstracting network hardware started to take hold with the advent of software defined networking (SDN). SDN is the idea of separating the data forwarding plane from the control plane on switches and routers. This enabled the control software (e.g. routing protocols) to exist in a centralized controller enabling greater automation and flexibility while leveraging white box switches to perform one job, forward traffic. This abstraction of switches and routers at the second and third layer of the OSI model was the start of a trend to virtualize more aspects of networking.

Once SDN was more widely understood, people sought out other areas that could be virtualized. Network function virtualization (NFV) is the concept of abstracting the functions of a networking appliance or middlebox away from the physical hardware. Virtualization of network functions at the seventh layer of the OSI model. These appliances provide typical network functions such as firewalling and load balancing, are vendor-specific which require manual configuration and rely on being physically placed in-line of the network path. Historically, it has been very expensive in capital expenditure (CapEx) and operational expenditure (OpEx) to deploy and maintain services when relying on middleboxes [10]. The potential for cost savings, scalability, and speed of service are some of the key drivers for the development of NFV. In 2012, A consortium of telecommunications companies self-organized to pursue the development of NFV. A white paper [5] was released under the auspices of the European Telecommunications Standards Institute (ETSI) encouraging the research and development of NFV. Since then, the effort to develop NFV has expanded to involve over 300 companies, various standardization bodies, and an engaged research community.

The objective of this paper is two-fold. First and foremost, the goal is to provide an overview of the current state of network function virtualization research and development. The survey will cover various aspects of NFV such as: defining what NFV is and is not, current research problems, and identified use-cases. Secondly, a less researched use-case for NFV is briefly explored.

2. WHAT IS NFV

When the concept of virtualized network functions is discussed, it is possible to conclude that NFV has existed in production environments for a while now. Cloud computing provides network functions such as firewalling and load-balancing on-demand to customers. Early research has even explored the idea of outsourcing middleboxes to a cloud environment [17]. These functions are most certainly virtualized in the cloud, however, there are some key aspects of NFV that differentiate it from other infrastructure as a service offerings. Most importantly, NFV is not simply the abstraction of hardware and software, it also involves chaining functions together to create a service function chain (SFC). This is the concept of dynamically linking virtual network functions (VNF) in a certain order, defined by a VNF forwarding graph, to virtualize an entire path. SFCs address many issues identified with service chaining, chief among them being complexity at scale [15]. An SFC could involve traffic being routed first through a firewall VNF, then through an intrusion prevention system (IPS) VNF, and finally a load balancer VNF before being routed to its destination. All of this happens within a virtual environment eliminating the need for physical appliances for each function. Beyond service chaining, NFV's original mandate was to create an open architecture which avoids vendor lock-in and embraces commodity hardware [3], [5]. This is important to telecommunications companies and large-scale web organizations for ensuring NFV is cost effective and rapidly scalable. Finally, to differentiate NFV from a generic virtualized network function that may exist in cloud environments, NFV requires performance to be on-par with their appliance counterparts [13]. Appliances naturally aggregate traffic which have traditionally required application specific integrated circuits (ASICs) designed to pass traffic at line-rate. For large telecommunications companies looking to adopt NFV, performance is a key requirement.

3. RESEARCH PROBLEMS

Current research is tackling various problems present in NFV development. There are many problems that require solving that have been outlined in an IETF Internet-Draft [4]. Due to the scope of this paper, only the issues that are considered to be the core problems for achieving an optimal NFV infrastructure will be covered.

3.1 Placement

As with traditional network appliances, there are challenges with the correct placement of VNFs in a network. The problem is comprised of two placement issues. First, since the hardware is being moved out-of-line of a network path, the challenge is optimally placing the physical hardware [7]. Minimal latency must be guaranteed while consolidating hardware in a central location for scalability. For telecommunications companies, this may entail locating the virtualized compute environment at the edge of the network which is closest to it's customers. However, with large enterprises that may tunnel all traffic back to central data centres, locating the virtualized environment in the same data centre seems appropriate. The second issue with placement has to do with where the VNFs, that are part of a SFC, get placed within the virtual environment. NFV OpenStack deployments use GRE tunnels or VXLAN to route traffic between compute resources. It has been observed that inter-virtual machine (VM) traffic based on GRE tunneling is expensive computationally and can hinder performance [8]. Ideally, the VNFs should reside on the same compute node to reduce latency. Researchers have explored novel algorithms [8] and mixed integer linear programming [1] to efficiently manage the placement of VNFs. The placement issue however, is still an open research area focused on achieving optimal placement.

3.2 Chaining

Tied closely to the placement problem is the issue of scaling SFCs dynamically and efficiently based on demand. To simply chain multiple VNFs together is only achieving part of the overall goal. To truly achieve scalability and cost efficiency, SFCs need to be scaled in and out dynamically based on resource demand. This will ensure that when a spike in traffic occurs, the SFC will have the compute resources required to process all the traffic for each network function without dropping traffic due to oversubscription. However, to achieve this, researchers have required to integrate an ancillary technology, SDN, to perform the orchestration of the underlying infrastructure. The idea is that once additional compute resources are provisioned for VNFs, the SDN controller programs the underlying switching and routing to forward traffic through the newly provisioned VNFs while maintaining the SFC order. There has been great interest in solving this chaining problem as SFC is a core mechanic of NFV. C. Jinlin et al. have implemented scaling algorithms [8] in OpenStack which leverage an OpenDaylight SDN controller for dynamic resource allocation based on demand. F. Bari et al. have explored implementing a heuristic algorithm [3] for optimal provisioning while B. Martini et al. have focused on SFC orchestration within a 5G infrastructure [11]. There are many approaches to solving the SFC problem, however, the constraints of performance, reliability, scale, and efficiency still pose challenges.

3.3 Reliability

Networks are the fundamental underlay which most information and communication technology (ICT) services are transported over, therefore, the reliability of NFV is critical. Traditional networks implement quality of service (QoS) to ensure the timely delivery of important voice and video traffic, ensuring the traffic is not discarded when congestion occurs. NFV demands similar guarantees of traffic delivery. QoS has been explored in 5G NFV networks [11], while other research has focused the QoS problem on ensuring correct VNF placement through integer linear programming [18]. However, without the problems of chaining and placement being solved first, it is difficult to achieve a guaranteed level of service. Due to this tight coupling, as the placement and chaining problems are solved, ensuring traffic delivery, latency, and other quality of service can be more easily achieved.

4. USE CASES

The use cases for virtualized network functions can range greatly, however, the functions that are virtualized should be aligned with the overall goals of NFV; the virtualized function should enable scalability, cost efficiency, while maintaining performance. Shortly after the ETSI released their seminal white paper on NFV, they released a use case paper detailing prime applications of NFV. These use cases were mainly from a telecommunications perspective, however, they can apply to many organizations that operate at scale. Some of core use cases identified were NFVaaS, VNFaaS, mobile core network virtualization, virtualized home network, content delivery network (CDN) virtualization, and access network virtualization [6]. While the paper outlined VNF forwarding graphs as a NFV use case, this paper considers forwarding graphs to be an integral part of SFCs which define NFV.

There has been various research since then exploring the virtualization of different network functions. J. Matias et al. implemented an 802.1x network access control leveraging SDN orchestrated SFCs [12] while T. Alharbi et al. have explored mitigating distributed denial of service (DDoS) attacks using NFV [2]. The concept of mitigating DDoS attacks using NFV is particularly interesting due to the fact that DDoS attacks are meant to overwhelm various functions in the network (e.g. firewalls). With NFV, it is possible to dynamically scale your VNF resources as required while maintaining network performance. Beyond researcher contributions, organizations within the networking industry have also explored the applications of NFV. Data centre

NFV SFCs have been explored by S. Kumar et al. detailed in an IETF Internet-Draft [9]. Further NFV use cases have been collected by Y. Li and M. Chen in their NFV survey paper [10]. Overall, NFV can be applied to a variety of scenarios to achieve scalability and cost-efficiency.

5. GRID NFV

While there are many identified use cases for NFV, there is an area that has seen little research. Minimal discussion has occurred regarding the ability to chain VNFs between different NFV infrastructures, implying that SFCs span organizational boundaries. This can be analogous to grid computing in the computing research domain. Grid computing allows access to distributed computing resources, typically high performance computing (HPC), across different organizations. When searching for research papers on distributed NFV infrastructure, most of the research was contained to a single organization. A single paper was found, written by R.V. Rosa et al. presenting arguments for the development of distributed NFV across organizational boundaries [16]. Beyond this, there appeared to be little research regarding a 'Grid NFV' concept. The ability to distribute the SFC chain between organizations' infrastructures could allow for extreme scalability that would otherwise be unachievable to most organizations. This distributed NFV infrastructure would allow researchers to perform experiments at scale. While cloud computing exists, it may not provide the service function chaining capability or performance characteristics that may be required. As NFV development continues, it will remain to be seen if further research will explore inter-organizational service function chaining as a viable use case.

6. CONCLUSION

Just as SDN is changing the way traditional networks are being designed, built, and operated, so is NFV challenging the current concepts of deploying network function services. NFV requires further development to address current issues of placement, chaining, and reliability. Even so, it has not prevented large telecommunication organizations from being early adopters in deploying NFV [14] going beyond proof of concepts. While many use cases for NFV exist, it is likely that only the most amenable to scale and cost efficiency are adopted first. However, NFV is still a very new technology and areas for further research exist such as inter-organizational service function chaining. Ultimately, networks today will likely be very different in the coming two decades, just as virtualized compute environments have radically changed the way compute resources are deployed.

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