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Recent advances and future challenges for mobile network virtualization

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Abstract Recently, network function virtualization (NFV) was proposed as a paradigm shift in the telecommunication industry. Both industry and academia have drawn significant attention in mobile network virtualization. NFV decouples the software implementation of network functions from the underlying hardware, leading to considerable reductions in operating expenses (OPEX) and capital expenses (CAPEX), and facilitating the network deployment. However, as an emerging technology, NFV brings both challenges and opportunities in developing new architectures, applying and deployment. In this paper, we first survey the related work of NFV, and then propose promising research directions in this area.

Keywords network function virtualization, mobile networks, software defined networking, network functions, 5G, network slicing

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1 Introduction

To accommodate the considerable growth in wireless traffic and services over the fifth-generation (5G) mobile wireless networks, it is necessary to extend virtualization to mobile networks. The aim to virtualize mobile cellular networks is to realize the process of abstracting, slicing, isolating, and sharing mobile cellular networks. It is well known that mobile networks consist of multiple proprietary hardware appliances. When popularizing a new network service, there is need for another variety of hardware devices. However, it is more and more difficult to offer the space and energy to contain these devices. What is more, with the customers' demands higher, the capital and operational costs increase with the deficiency of skills necessary to integrate and maintain these services, which will be a great challenge for operators in view of their long-term development. On the other hand, as the lifetime of the hardware appliances is always limited, much of the procure-design-integrate-deploy cycle will be repeated resulting in less revenue benefit. Even worse, with the rapid innovating of technologies and services, hardware

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reaches its end of life more quickly, which inhibits the development and promotion of network services seriously [1, 2]. Network function virtualization (NFV) aims to address these challenges by leveraging standard IT virtualization technology and changing the architecture of mobile networks. The main idea of NFV is decoupling the software implementation of network functions (NFs) from the physical equipment. This means consolidating the network equipment types, which are located in data center, distributed network nodes and user premises, onto industry standard high volume servers, switches and storages. By this way, one network service can be decomposed into a set of virtual network functions (VNFs), which can be relocated and instantiated at different network locations without purchasing or installing new hardware. The VNFs can be then implemented in software running on a series of industry standard physical servers. Therefore, NFV could make network services more agile and efficient [3, 4]. For example, network operators may run an open source software-based firewall in a virtual machine on an x86 platform. Recent trials have demonstrated that it is feasible to implement NFs on general-purpose processor-based platforms, for example, for physical layer signal processing and components in cellular core networks [5, 6].

As a breakthrough in the telecommunication industry, NFV makes significant benefits for both network operators and customers, including but not limited to:

(1) Reducing operating expenses (OPEX) and capital expenses (CAPEX). By consolidating equipment and using software instead of hardware equipment, the equipment costs and power consumption will be reduced. The saving in CAPEX and OPEX is clear from the study on a small-sized network: around 30% savings comparing current non-virtualized architecture and VNF [5]. The saving reaches up to 55% with increasing the maximum Building Base band Unit capacity to 256. We can anticipate more significant impact on networks with thousands of cells and heavier traffic.

(2) Shortening time for deploying a new network service into the market by minimising the typical network operator cycle of innovation.

(3) Admitting varieties of customers and applications to work on a uniform platform when logging in different versions of network equipments. This allows network operators to share resources among different services and different customers.

(4) Providing targeted services for the customers in the same region or in the same group. Services can be rapidly scaled up/down as required.

(5) Developing an open and efficient industry chain. Software venders will be encouraged to develop new network services through the accomplished integrative virtual platform.

The concept of NFV was first put forward in October 2012 at a conference in Darmstadt, Germany on software-defined networking (SDN) and OpenFlow [4]. There were seven of the world's leading telecom network operators (AT&T, BT, Deutsche Telekom, Orange, Telecom Italia, Telefonica and Verizon), together with part members of the European Telecommunications Standards Institute (ETSI), jointly authoring a white paper calling for industrial and research action, and declaring ETSI to be the home of the Industry Specification Group for NFV (ETSI ISG NFV) [7]. In November 2012, NFV ISG was officially established. Till now, the membership of ETSI has grown to over 240 individual companies including world's major operators, communication equipment manufacturers and communication equipment manufacturers. Later, this group authored white paper #2 and #3 respectively in 2013 and 2014, on the SDN and OpenFlow World Congress.

The ETSI NFV ISG currently has four working groups: infrastructure architecture, management and orchestration, software architecture, and reliability & availability; and two expert groups: security and performance & portability. The related work of NFV ISG and other groups is summarized in Table 1.

In order to verify the feasibility of NFV applications and estimate their performance, a number of vendors have accomplished their NFV implementations based on the specification of ETSI, which is summarized in Table 2. From these NFV implementations, it is obvious to find that the implementation of NFV needs be supported by SDN and cloud computing technology.

What is more, domestic academia has also participated in the research of NFV. Yang et al. from Wireless Communication Research Center in Shanghai proposed the idea that using the live migration technology of virtual machine to have implemented the all-weather working of cloud computing network

Table 1 Summary of NFV efforts

Organization	Description of NFV-related work
NFV ISG[1)]	Completed Phase 1 with the publication of 11 ETSI Group Specifications including an infrastructure overview, updated architectural framework, and descriptions of the compute, hypervisor and network domains of the infrastructure, and proposed several use cases
3GPP SA5[2)]	Set up a study of the management of virtualized 3GPP network functions, to analyze whether the NFV architecture will have an impact on the existing management reference model of 3GPP
IEFT SFC WG[3)]	Studied how to dynamically steer data traffic through a series of network functions, either physical or virtualized
IRTF NFVRG[4)]	Organized meetings and workshops at premier conferences and invited special issues in well-known publications
ATIS NFV Forum[5)]	Developed specifications for NFV, focusing on aspects of NFV which include inter-carrier inter-operability and new service descriptions and automated processes
Broadband Forum[6),7)]	Worked on how NFV can be used in the implementation of the multi-service broadband network

1) ETSI group specifications on network function virtualization. 1st phase documents. ETSI Ind. Spec. Group (ISG) Netw. Functions Virtualisation (NFV), Sophia-Antipolis Cedex, France, Jan. 2015. http://docbox.etsi.org/ISG/NFV/Open/Published/.

2) The 3rd Generation Partnership Project (3GPP). 2015. http://www.3gpp.org/about-3gpp/about-3gpp.

3) The Internet Engineering Task Force (IETF). Service Function Chaining (SFC) Working Group (WG). Documents. 2015. https://datatracker.ietf.org/wg/sfc/documents/.

4) Network Function Virtualization Research Group (NFVRG). Internet research task force. 2015. https://irtf.org/nfvrg.

5) ATIS Netw. Functions Virtualization (NFV). Alliance for telecommunications industry solutions, network functions virtualization forum. 2015. http://www.atis.org/NFV/index.asp.

6) The Broadband Forum. 2015. https://www.broadband-forum.org/.

7) The Broadband Forum. Technical Work in Progress. 2015. https://www.broadband-forum.org/technical/technical-wip.php.

Table 2 List of proposed NFV implementation

NFV implementation	Functionality
HP OpenNFV[8)]	Services and networks are built dynamically
Huawei NFV Open Lab[9)]	Environment for NFV development is provided
Intel ONP[10)]	Several initiatives are proposed to advance open solutions for NFV and SDN
CloudNFV[11)]	Propose their own NFV architecture
Alcatel-Lucent CloudBand	An agile connection framework is proposed in [8] for the collection of nodes and functions, and to facilitate traffic management
Broadcom Open NFV[12)]	Accelerate creation of NFV applications and allow system vendors to be able to migrate virtual functions between platforms based on various vendor solutions
Cisco ONS	Implementations for some of the functional blocks of ETSI's MANO framework are proposed in [9]
F5 SDAS	F5 Software Defined Application Services proposed in [10] enable service injection, consumption, automation, and orchestration across a unified operating framework of pooled resources
ClearWater[13)]	Voice, video and messaging services are proposed to users in ClearWater
Overture vSE	VNFs are hosted at the service edge in [11]

8) HP OpenNFV Reference Architecture. 2015. http://www8.hp.com/us/en/cloud/nfv-overview.html?

9) Huawei NFV Open Lab. Jan. 2015. http://pr.huawei.com/en/news/.

10) Intel Open Network Platform. 2015. http://www.intel.com/ONP/.

11) CloudNFV. 2015. http://www.cloudnfv.com/.

12) Broadcom Open NFV. 2015. http://www.broadcom.com/press/release.php?id=s827048.

13) Clearwater. 2015. http://www.metaswitch.com/clearwater.

powered by green energy. The technical implementation illustration of the "Greenstar Network" cloud computing node built with this scheme is also introduced [12]. Chai et al. [13] summarized the proposed

SDN-based 5G architectures in detail, followed by a discussion on future research directions. Wang et al. [14] proposed a novel algorithm called Green Load Balancing and proposed an adaptive energy-saving strategy based on network traffic prediction of Data Center.

There has been significant progress on NFV recently. The main objective of this article is to give an overview of these recent advances as well as identifying future challenges and research directions. To sum up, the contributions of this paper can be listed as follows: (1) recent advances in NFV are summarized; (2) challenges and future research directions for NFV are identified.

The remainder of this article is organized as follows. Recent advances, potential challenges, and future directions of NFV are discussed in Section 2. Section 3 investigates the application of NFV and SDN in 5G network architecture. Finally, conclusion is drawn in Section 4.

2 Advantages and challenges

In order to leverage the benefits of NFV, there are a number of technical challenges which need to be resolved:

(1) Making the virtual network appliances achieve high performance and portability among different hardware vendors and different hypervisors.

(2) Achieving co-existence and compatibility with the special equipments in original network platform. That is, achieving the update from original platform to new platform based on remaining of the original network services.

(3) Guaranteeing the security and reliability of the whole network system when managing and orchestrating multiple of virtualized network equipments.

(4) Achieving all the NFs automated in order to guarantee the scalability of NFV.

(5) Ensuring the appropriate level of resilience to hardware and software failures.

(6) Enabling to choose network servers, hypervisors and virtual appliances from different vendors and to integrate them without excessive integration costs.

This section discusses recent crucial advances as well as identifying future challenges and research directions.

2.1 Management and orchestration

The traditional deployment of network services needs to be processing a long procedure including network traffic measurement, hardware equipment purchasing, production debugging and launching. NFV breaks the original procedure of equipment purchasing, operation and maintenance, which will bring significant challenges for the core network in integration modes as well as operation and maintenance.

Management & orchestration (MANO) is the core of network service deployment, which can achieve resource fully shared and NFs Orchestrated on demand, making the whole network programmable, flexible and scalable. It is convenient to orchestrate network services, calculate and apply virtual resource requirements, deploy network by MANO, while speeding up the services to market.

There have been several related work about MANO. In a related effort, Cloud4NFV proposed an end-to-end management platform for VNFs based on the ETSI architectural specification [15,16]. Clayman et al. [17] described an architecture based on an orchestrator, which can collect and report on the behaviour of the resources by a monitoring system, ensuring the automatic deployment of the virtual nodes and the allocation of the network services on them. NetFATE proposed an orchestration approach in consideration of the service chains satisfying traffic flows and the desired quality of experience [18]. In addition, other MANO frameworks and architectures were proposed in [19–24].

However, there are still some open issues. Existing approaches are focusing on NFV management, without considering the management challenges in SDN [25]. However, NFV and SDN always coexist in the real environment. Therefore, a complete management solution should combine requirements from both SDN and NFV. In such cases, we should not only consider the dynamic traffic flows, but also consider that the locations of the VNFs are also switching dynamically.

Moreover, current architecture only defines the inner operation interfaces for NFV, without giving a clear definition for the inter-operable interfaces. Therefore, the network operators can only use traditional models, which cannot achieve the inter-operability of NFV. In addition, due to the portability of NFV, the importance of the monitoring system should be paid more attention to.

Finally, different from the current business mode, MANO orchestrates services through service template and process standardization. Together with OpenStack, Openflow and other open source technologies, MANO has a huge impact on the existing work of telecommunication standardization. In order to satisfy the coexistence and compatibility between the new network architecture and the original one, there is a need to define the relationship between the operational support system and the business support system [26].

2.2 Energy efficiency

According to the survey, since energy expense represent more than 10% of OPEX, reducing energy consumption has been one of the highlights of NFV [27]. However, although decreasing the number of physical equipment leads to reduction of energy consumption, NFV may make the data center become an integral part with high integration level. According to the analysis in the SMARTer 2020 report by GESI [28], if the cloud were seen as a country, its energy requirement would rank the 6th all over the world and may increase by 63% by 2020 [29]. In spite of the progress of energy reduction research for cloud computing, the rapid increasing energy consumption demand is still an urgent unsolved problem [30, 31]. Thus there is a need to study whether NFV will meet its energy saving expectations, or just transfer the energy consumption to the cloud like the NFs dose.

China Mobile recently published their progress in deploying a cloud radio access network (C-RAN) [32]. One of the tests, performed on their 2G and 3G networks, showed that the power consumption could be reduced by 41% once centralizing the RAN, due to shared air-conditioning. In addition, Shehabi et al. analyzed the technical potential for energy savings by shifting U.S. business software to the cloud. The results suggested a significant potential for energy savings [33]. In fact, the authors noted that if all U.S. business users shifted their email, productivity software, and CRM software to the cloud, the primary energy footprint of these software applications could be reduced by as much as 87%.

In order to verify the effectiveness of energy consumption on NFV, Bell Labs has recently extended its G.W.A.T.T. tool [27]. Based on the forecast of traffic increasing, this tool can show the influence of energy consumption after virtualizing different NFs. Using this tool for the evolved packet core (EPC) network models in 2015, the result has shown that total network energy efficiency is 0.0422222 Mb/J, total energy consumption is 92159.8 MW, and that the energy savings resulting from virtualizing the EPC would be 24044.1 MW. However, there is no specific technical documents for this tool to support the validity of these numbers.

Therefore, the energy efficiency problem of cloud based on NFs will be emphasized in the future research. NFV should not only reduce energy efficiency, but also meet regulatory and environmental standards. The ways to improving energy efficiency include employing energy-efficient hardware equipment, deploying more energy-aware NFs, developing more efficient scheduling and chaining algorithms. All these ways should ensure that there is a balance in the trade-off between energy efficiency and function performance or service level agreements.

2.3 Resource allocation

The deployment of the NFV-based network architecture largely depends on resource allocation, which is called NFV-RA (NFV-resource allocation). There are three stages that conform the resource allocation problem in NFV-based network's architectures, which are VNFs-Chain Composition (VNFs-CC), VNF-Forwarding Graph Embedding (VNF-FGE) and NFV-Scheduling (VNFs-SCH). At the first stage VNFs-CC, NFV exploits the flexibility introduced by virtualization to dynamically compose chains of VNFs so as to compose the network service (NS) in the most appropriate way while satisfying the demands of service providers. At the second stage VNFs-FGE, NFV seeks to find where to allocate the VNFs in

Table 3 Related work of NFV-RA

Stage	Contribution
VNF-CC (uncoordinated)	The authors of [35] specify an architecture based on an orchestrator that ensures the automatic placement of the virtual nodes and the allocation of NSs on them
VNF-FGE (uncoordinated)	The authors of [36] introduce a mixed integer programming problem trying to minimize the host and bandwidth deployment costs, and propose a scalable heuristic to solve large instances of the problem. A Linear Programming-based solution to solve the VNF-FGE problem is proposed in [37], trying to minimize the network resource usage. A chain deployment algorithm to find a solution considering the tradeoff between path length and virtual machine reuse factor is proposed in [38]
VNF-SCH (uncoordinated)	The authors of [39] provide a formalization model of the VNFs-SCH, i.e. finding the corresponding time slots for functions to be executed over a given set of machines. The authors of [40] provide the first formalization model for the VNF complex scheduling problem, using the complex job formalization
VNF-SCH, VFN-FGE (coordinated)	The authors of [41] formulate the online virtual function mapping and scheduling problem and propose a set of heuristic and metaheuristic algorithms to solve the VNF-FGR and VNFs-SCH in a coordinated way
VNF-CC, VFN-FGE (coordinated)	The authors of [42] propose a heuristic method to coordinate the composition of VNF chains and their embedding into the substrate network

the network infrastructure in a suitable way. Considering the demands of individual requests and all of the NS, VNFs will be allocated in an appropriate way. At the third stage VNFs-SCH, NFV attempts to decide when to execute each function in order to minimize the total execution time without degrading the service performance and respecting all the precedences and dependencies between the VNFs composing the NS [34].

The NFV-RA problem is completely solved when its three stages are solved. The related work in each stage is summarized in Table 3 [35–42]. However, NFV is still in the early stages. There are still important aspects that should be investigated to efficiently manage and allocate the use of the resources in NFV-based network architectures.

(1) One of the main challenge is to solve the NFV-RA problem in a coordinated way. NFV-RA includes there stages related to each other, where the execution of each stage is intended to carry out in a coordinated way. The aim is to optimize the resource utility and improve the network performance. Moreover, it will also facilitate the flexibility of VNFs of a high volume service. However, to the best of our knowledge, there are no proposals trying to solve the problem in a coordinated way.

(2) In reality, NFV-RA has to be solved as an online problem. That is to say, the service requests (VNFRs) are not known in advance. On the contrary, they arrive at the system dynamically and stay in the network at an arbitrary time. Therefore, NFV-RA algorithms must handle the VNFRs once they arrive, instead of handling a set of VNFRs after they all arrive. In principle, all approaches can be operated in an online mode. To our knowledge, static NFV-RA approaches do not take the possibility of remapping or even recomposing in consideration. However, VNFRs may change over time, that is to say, new VNFs may be added or deleted from a VNFR, which means recomposition. Therefore, remapping and rescheduling may be necessary.

(3) As VNFs execute in a shared environment, the qualification of resources available on network functions virtualization infrastructure (NFVI) should be measurable. For example, scheduling of VNFs requires measurement of bandwidth and latency through distributed measurement mechanisms.

(4) Network services must be deployed in NFVI, in order to guarantee the negotiation of quality of service (QoS) parameters between the telecom service provider and the end user in the service level agreement. So far, most of the existing NFV-RA approaches guarantee bandwidth between VNFs, computation power and memory in physical nodes and end to end latency. However, QoS parameters such as jitter (for real time services) or loss probability (for availability related services) have not been considered up to now. In addition, the survivability has not been solved in NFV-RA yet.

Table 4 Proposed security products for NFV

Product	Function
SECURED	The model in [55] affords a safe environment for providing secure applications for users
OpenNF	The architecture in [56] provides security and flexibility for VNFs control in NFV with minimum overheads
Cisco Evolved Services Platform	The platform in [57] enables secure and dynamic delivery of personalized services
Alcatel-Lucent CloudBand	The platform in [58] manages and orchestrates resources in the NFVI, and affords processing and analysis for historical and real-time data, such as anomaly detection and event prediction
VMware vCloud NFV	The platform in [59] copes with increased service agility and security such as enabling disaster recovery and business continuity

(5) The success of network services depends on the high level of availability and reliability of both hardware and software. In NFV architecture, network services should be provided with resilience to failure, service continuity, and service assurance. Resilience to failure is provided by implementing an automated on-demand mechanism in the NFV framework to reconstitute the chain of VNFs after a failure. Chain recomposition should not have any impact on the system to ensure stable service. Service assurance is provided by the NFV orchestrator, which has functions of monitoring network-function performance and scaling resources in real time.

2.4 Security

When deploying VNFs, operators need to make sure that the security features of their network will not be affected. NFV may bring new security concerns along with its benefits. The security problems mainly come from four aspects — NFVI, standard interface definition, management and orchestration, and elasticity of NFV. How to overcome the security problems from hypervisor, compute, and network domain remains a challenge for applying NFV into 5G network. Firstly, NFVI includes of compute domain, hypervisor domain, and network domain, and suffers from both internal and external security threats. Internal threats result from inappropriate operations of people and it can be avoided by following strict operational procedures. External threats exist because of design or implementation vulnerabilities. To solve this problem, NFVI should adopt a standard security mechanism for authentication, authorization, encryption and validation [43–45]. The security challenges and corresponding solutions to above three domains are summarized in [46]. Secondly, when developing different security services in a virtualized network, standard interfaces should be defined. For example, user authentication, user privilege control, and network configuration can be predefined before using these security functions [47]. The predefined virtualized network security functions can be used in access networks [48], mobile networks [49], data center [50], SDN [51], and NFV [52]. In addition, Keeney et al. [53] discussed the security challenges in managing and orchestrating VNFs when using NFV for mobile telecommunications networks. Szabo et al. [54] identified the challenges on dynamic service scaling and elasticity of NFV. What is more, many security platforms and architectures have been proposed and implemented to assure security in NFV, as summarized in Table 4 [55–59].

Although many solutions have been proposed to overcome the security challenges in NFV, there are still potential security challenges remain.

(1) Compromised VNF: In a NFV network, in order to avoid massive security failure, hardware and software are likely to be provided by different vendors. However, the likelihood of one or a few compromised service increases. How to detect the compromised components and mitigate their impact is still a challenge.

(2) Distributed denial-of-service attack: distributed denial of service (DDoS) can lead to huge harm to NFV-based network if not handled properly. NFV proposes a new defending strategy for telecommunications service providers to defend against DDoS attacks. How to utilize the flexibility to defend against DDoS attacks is another challenge.

(3) Trust management: The merge of NFV provides multiple opportunities for vendors to enter the network architecture market by providing hardware and software that are compatible with NFV. However, how to manage the trust chain and evaluate the trustworthiness of products is another research challenge. How to adaptively configure VNFs to minimize the security risk of the network by choosing software is another challenge.

2.5 Modeling of resources, functions and services

One of NFV's characteristic is the ability to deliver high levels of automation and flexibility. However, the resources and functions in NFV will be provided by different vendors. Therefore, how to standardize and unify these multi-vendor resources, functions and services will be key to NFV deployment. Models should consider both initial deployment and lifecycle. As a part of MANO specification, ETSI provided all the popular models for NFV, including OVF, TOSCA, YANG and SID [60–63]. However, considering other more specific demands of NFV deployment, these models were not initially proposed with explicit, but were only used as starting points and should continue to evolve.

With the models improving continuously, due to the fact that each model has its inevitable defects, it is important to combine their advantages as well as avoiding their disadvantages. For example, TOSCA can set up a virtual route, but it cannot set up, alter or delete the deployment of this route in the runtime. Similarly, YANG can be used to write machine readable schemes, thus it is hard to be used to design the initial service deployment. In this case, it is possible to combine TOSCA and YANG where the file-based templates in TOSCA may be used for deploying VNFs on cloud infrastructure, while YANG can be used to provide a runtime application programming interface (API) both for configuring VNFs after they have been installed and while they are running in the cloud.

3 Applying NFV and SDN in 5G network architecture

According to NGMN [64], a network slice, namely "5G slice", is a key enabler for network operators to expand existing businesses and creating new ones, which supports the communication service of a particular connection type with a specific way of handling the C- and U-plane for this service. A prerequisite for network slicing is the virtualization of the different network elements of the mobile network. Thus, network slicing with the combination of NFV and SDN gained momentum with the setup of the ETSI NFV group, to instantiate the mobile network on demand.

SDN is a new type of network architecture, whose design concept is to decouple the network control and forwarding functions, that is separating the handling of packets and connections from overall network control, and to achieve programable control. SDN consists of application layer, control layer and infrastructure layer, which has the following characteristics: (1) separating control and forwarding; (2) centralized control; (3) open API from control layer to application layer. The core of SDN is decoupling network control and forwarding functions, enabling network control to become directly programmable and the underlying infrastructure to be abstracted from applications and network services.

NFV and SDN have a lot in common since they both have the concept of separating control and bearing, trying to achieving the basic control function in the form of software definition, and advocating for a passage towards open software and standard network hardware. NFV and SDN come from the same technology base which are based on servers, cloud calculating and virtualization technology. Both of them are located in the network control platform, whose key functions will achieved through orchestrators. In fact, NFV and SDN may be highly complimentary, and combining them in one networking solution may lead to greater value. On one hand, SDN can accelerate NFV deployment by controlling and balancing each virtual machine to make the data center more manageable. On the other hand, the centralized control and management applications used in SDN can be realized as VNFs and hence benefit from NFV's reliability and elasticity features. Hence, applying SDN and mobile network virtualization in the 5G network can solve some problems in the future.

Separating control plane from data plane is an important concept in the 5G network architecture. On one hand, by separating coverage from capacity, 5G network can transmit information through those access points in the dense network, while the system information is provided by coverage. In this way, coverage and capacity can be optimized respectively in the future network to ensure the demands of huge number of links and dense nodes. On the other hand, by dissociating part of the control functions on eNodeB and clustering them for centralized control, the user-centered virtual cell can be set up with intelligent management including interference coordination, resource collaboration, and network cooperation between different systems. The future network will be a huge integration with access networks in different modes, which makes users convenient to access the network whenever and wherever. However, there would be large amount of information to be transmitted in this merged network, which brings forward higher requirements for the processing capacity of communication system. In addition, users' demand for bandwidth is also increasing. Therefore, the traditional single access and transmission mode cannot ensure users' demand. On this background, concurrent multipath transmission (CMT) is becoming a hot issue in current researches. Common CMT technology includes stream control transmission protocol (SCTP) and multipath TCP (MPTCP).

SCTP is a message-oriented protocol like user datagram protocol and ensures reliable and ordered data transmission between two end-hosts. Due to the discrepancy of each path under different transmission conditions, the packet may be out of order at receiving ends resulting in unnecessary retransmission, which degrades the transmission performance and decreases the transmission efficiency of the network. In terms of load balancing, SDN-based CMT scheduling algorithms can resolve this problem fundamentally and thus improve the transmission performance and maximize the resource utilization of the network.

SCTP makes only one path as the main path for data transmission. When the performance of this main path degrades rapidly or even leading to a disconnection, another path will be chosen as an alternative to continue the transmission. Unlike SCTP, MPTCP can support both multi-homed hosts and parallel transmission among information in multiple paths, which alleviates the network congestion, improves the end-to-end throughput and increases the network utilization. By using MPTCP, mobile devices can connect to multiple access points at the same time, making handover as a future research highlight. Applying MPTCP to SDN, by designing appropriate algorithms, the seamless handover will be achieved. In this way, the network throughput will be increasing with a guaranteed service quality for users in handover periods.

In conclusion, the new SDN & NFV-based network architecture can not only overcome the disadvantages of the existing network effectively, but also meet the growing requirements of programmability and quick-response for new network services in the future 5G network. Moreover, Tao et al. [65] have proposed a virtualization based 5G ultra-dense aggregated cooperative heterogeneous network architecture with a trial network platform, which can effectively merge cellular networks and WiFi together to reach the data rate as high as 12.5 Gbps.

4 Conclusion

Based on customers' requirement of network services as just-in-time, on-demand, online and cheap, it is crucial to find a new way to provide network services which are more flexible, high-efficient and less-cost. In the concept of open, integration and virtualization, mobile network virtualization will change the network architecture of original network operators profoundly, which leads to both opportunities and challenges to telecommunication industry. In this article, the concept of NFV as well as its background and advantage has been introduced. Based on summarizing of the related work, recent advances, challenges, and future directions of NFV have been analyzed classified. Measurements have revealed that NFV will become a significant technology in the future network for its obvious benefits as well as corresponding challenges, while more research organizations should join in and make the specific standards and specifications.

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