The Scanning the Literature column provides concise summaries of selected papers that have recently been published in the field of networking. Each summary describes the paper's main idea, methodology, and technical contributions. The purpose of the column is to bring the state of the art of networking research to readers of *IEEE Network*. Authors are also welcome to recommend their recently published work to the column, and papers with novel ideas, solid work, and significant contributions to the field are especially appreciated. Authors wishing to have their papers presented in the column should contact the Editor.

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The cellular network is an important infrastructure providing wireless connectivity to Internet of Things (IoT) devices. However, the explosively increasing IoT applications require not only network access but also application-oriented functionalities such as authentication, firewalls, and proxies. In order to quickly respond to the application demands of the market, operators desire a flexible architecture in the core network, in contrast to the traditional one with a vertically integrated paradigm. To this end, the network functions virtualization (NFV) paradigm is proposed, which realizes different network functions (NFs) over the high performance-price ratio IT hardware by utilizing the standard virtualization technologies. The column in this issue focuses on the research on IoT and NFV, particularly, performance improving methods of NFV, NFV for mobile edge–cloud, and NFV-based frameworks for practical IoT applications.

Currently, many automotive manufacturers including Mercedes Benz and BMW have released new products equipped with intelligent onboard systems (IOSs) that support interconnection between vehicles and the remote service center. However, IOSs adopt a closed architecture and are very difficult to upgrade to support new services. In the following paper, Zhu *et al.* introduce NFV as a new methodology that offers a potential way out of this bottleneck.

Providing Flexible Services for Heterogeneous Vehicles: An NFV-Based Approach

Ming Zhu, Jiannong Cao, Zhiping Cai, Zongjian He, Ming Xu, IEEE Network, Vol. 30, No. 3, pp. 64-71, May-June 2016.

In this article, the authors propose an NFV-based vehicular ad hoc network (VANET) framework to transform IOSs into open ones. Not only can the openness of IOSs reduce the cost of service upgrade, but it can also bring other benefits. Besides the benefits, there are several technical challenges that NFV-based VANETs face. The authors also utilize a use case to show how the proposed framework can reduce service upgrading cost and improve the flexibility of service deployment. Finally, the authors conduct some simulations to evaluate the performance of the proposed framework.

The performance of an NFV framework is important to Internet of Things (IoT) users. Unfortunately, software-based sequential service chains in NFV could introduce significant performance overhead. Current acceleration efforts for NFV mainly target optimizing each component of the sequential service chain. However, based on the statistics from real-world enterprise networks, people observe that many NF pairs could be parallelized without causing extra resource overhead. To fill this gap, Sun *et al.* introduce their parallelism design in the following paper:

NFP: Enabling Network Function Parallelism in NFV

Chen Sun, Jun Bi, Zhilong Zheng, Heng Yu, Hongxin Hu, Proc. SIGCOMM, Los Angeles, CA, USA, Aug. 21–25, 2017.

In this paper, the authors present NFP, a high-performance framework that innovatively enables network function parallelism to improve NFV performance. NFP consists of three logical components. First, NFP provides a policy specification scheme for operators to intuitively describe sequential or parallel NF chaining intents. Second, an NFP orchestrator intelligently identifies NF dependency and automatically compiles the policies into high-performance service graphs. Third, NFP infrastructure performs lightweight packet copying, distributed parallel packet delivery, and load-balanced merging of packet copies to support NF parallelism. The authors implement an NFP prototype based on DPDK in Linux containers. The evaluation results show that NFP achieves significant latency reduction for real world service chains.

E2E packet delay of a delay-sensitive service flow traversing an embedded virtual network function (VNF) chain is a main metric indicating embedding performance. However, how to develop an analytical model to evaluate the delay that each packet of a flow experiences when passing through an embedded VNF chain, including packet queueing delay, packet processing delay on NFV nodes, and packet transmission delay on links, is a challenging research issue. To solve this problem, Ye *et al.* illustrate their solution in the following paper:

End-to-End Delay Modeling for Embedded VNF Chains in 5G Core Networks

Qiang Ye, Weihua Zhuang, Xu Li, Jaya Rao, IEEE Internet of Things Journal, Early Acess, July 9, 2018.

In this paper, an analytical E2E packet delay model is established for multiple traffic flows traversing an embedded VNF chain in 5G communication networks. Dominant-resource generalized processing sharing (DR-GPS) is employed to allocate both computing and transmission resources among flows at each NFV node to achieve dominant-resource fair allocation and high resource utilization. A tandem queueing model is developed to characterize packets of multiple flows passing through an NFV node and its outgoing transmission link. An M/D/1 queueing model is developed to calculate packet delay for each flow at the first NFV node. The queueing model is proved to achieve more accurate delay evaluation than that using a G/D/1 queueing model. Extensive simulation results demonstrate the accuracy of the proposed E2E packet delay modeling, upon which delay-aware VNF chain embedding can be achieved.

As a key enabling technology for 5G network softwarization, NFV provides an efficient paradigm to optimize network resource utility for the benefits of both network providers and users. However, the inherent network dynamics and uncertainties from 5G infrastructure, resources, and applications are slowing down the further adoption of NFV in many emerging networking applications. Motivated by this problem, Cheng *et al.* illustrate their idea in the following paper.

Network Function Virtualization in Dynamic Networks: A Stochastic Perspective

Xiangle Cheng, Yulei Wu, Geyong Min, Albert Y. Zomaya, IEEE Journal on Selected Areas in Communications, Vol. 36, No. 10, pp. 2218–2232, Oct. 2018.

In this paper, the authors investigate the issues of network utility degradation when implementing NFV in dynamic networks, and design a proactive NFV solution from a fully stochastic

perspective. Unlike existing deterministic NFV solutions, which assume given network capacities and/or static service quality demands, this paper explicitly integrates the knowledge of influential network variations into a two-stage stochastic resource utilization model. By exploiting the hierarchical decision structures in this problem, a distributed computing framework with two-level decomposition is designed to facilitate a distributed implementation of the proposed model in large-scale networks. The experimental results demonstrate that the proposed solution not only improves network performance three- to five-fold, but also effectively reduces the risk of service quality violation.

Mobile edge–cloud (MEC) aims to support low-latency mobile and IoT services by bringing remote cloud services nearer to mobile users. However, in order to deal with dynamic workloads, MEC is deployed in a large number of fixed-location micro-clouds, leading to resource waste during stable/low workload periods. In the following paper, Yang *et al.* introduce their NFV-enabled MEC framework, which offers new flexibility in hosting MEC services in any virtualized network node.

Cost-Efficient NFV-Enabled Mobile Edge-Cloud for Low Latency Mobile Applications

Binxu Yang, Wei Koong Chai, Zichuan Xu, Konstantinos V. Katsaros, George Pavlou, IEEE Transactions on Network and Service Management, Vol. 15, No. 1, pp. 475–488, Mar. 2018.

In this paper, the authors propose a dynamic resource allocation framework that consists of a fast heuristic-based incremental allocation mechanism that dynamically performs resource allocation, and a re-optimization algorithm that periodically adjusts allocation to maintain a near-optimal MEC operational cost over time. The authors show through extensive simulations that the flexible framework always manages to allocate sufficient resources in time to guarantee continuous satisfaction of applications' low latency requirements. At the same time, the proposal saves up to 33 percent of cost in comparison to existing fixed-location MEC solutions.

Large-scale disaster management applications are among several realistic applications of IoT. Several heterogeneous IoT devices are used in such applications (e.g., sensors and robots). Moreover, in disaster scenarios, the existing communication infrastructure may become completely or partially destroyed. Utilizing these applications raises challenges such as the need for gateways that can accommodate new applications and new IoT devices. To solve this problem, Mouradian *et al.* show their NFV-based solution in the following paper.

NFV and SDN-Based Distributed IoT Gateway for Large-Scale Disaster Management

Carla Mouradian, Narjes Tahghigh Jahromi, Roch H. Glitho, IEEE Internet of Things Journal, Vol. 5, No. 5, pp. 4119–4131, Oct. 2018.

This paper proposes an architecture for on-the-fly distributed gateway provisioning in disaster management using NFV and software defined networking (SDN) technologies. NFV allows upgrading of the pre-existing gateway and deploying the gateway functions anywhere anytime, and SDN enables reusing the same gateway functions in different flows for different applications. The gateway functionalities are provisioned as virtualized network functions (VNFs) and are chained dynamically using application-level SDN switches. The IoT gateway is built as a peer-to-peer (P2P) overlay taking into consideration the mobile ad hoc network settings of the disaster management scenarios. Finally, a prototype of the proposed architecture is provided and a set of experiments are conducted to evaluate the architecture.

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