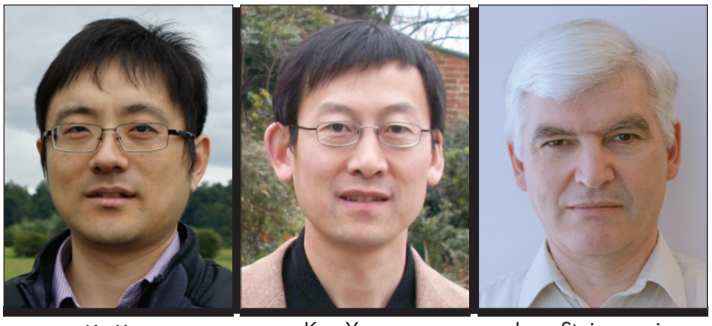
Wired and Wireless Network Virtualization



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The Internet, which is a global heterogeneous network composed of diverse wireless mobile access, home broadband, and core IP/optical networks, is perhaps *the* critical element in future global ICT strategy. However, the way the current Internet is managed and the way it provides services cannot match the fast changing and more demanding requirements imposed by user-end applications. *Network virtualization*, coupled with an effective and efficient approach to managing virtualized resources, is a key solution to the problem.

Network virtualization provides an efficient approach to multiplexing resources for different networks and services. It can easily optimize network resource utilization according to different requirements by user-end applications (e.g., for the purpose of energy savings). In the meanwhile, it effectively reduces the costs of network operations and management. Virtual network providers operate the physical networks for different networks and services. Thus, different network and service operators only need to focus on the management of their own processing logic.

Some work has been published in the literature on network virtualization, and great achievements have been made in several concrete research areas, including business models in virtualized network environments, virtual network embedding algorithms, dynamic resource scheduling mechanisms, substrate network devices supporting virtual networks, and so on. However, there are still many open research challenges calling for more attention. While being widely regarded as a promising emerging research area, the diversity of the network technologies, network structures, protocols, and applications in virtualized networks creates big challenges on network integration and service integration. Although some results have recently been published, there is still a great need for more comprehensive results addressing relevant issues so as to support the emerging content-rich end-user services in a more user-friendly and cost-effective fashion. These issues start from the more fundamental concepts and technologies such as node/link virtualization and their mapping to physical resources, and then the modeling and performance analysis of virtualized networks. Moreover, different virtual networks should meet requirements of different network services ranging from network layer service to application layer service. The virtual networks should provide resource guarantees for different services, and an easy way to operate and manage services.

Research is producing results in the area of systematically addressing the challenges arising from individual virtual networks and their integration and convergence in order to provide end-to-end service guarantees for end users. Now is the appropriate time to show the key results, and disseminate the state-of-the-art concepts and techniques in all aspects of network virtualization.

This Special Issue is dedicated to present the readership of *IEEE Network* with the latest advances in the area of network virtualization, by addressing network virtualization issues related to end-to-end transmission of information. After an impartial and rigorous review, we accepted six articles that cover the area of state-of-the-art work on network interface virtualization, concrete architecture for the integration of virtualized network resources, and algorithms for virtual network embedding.

The article "A Two-Dimensional Architecture for End-to-end Resource Management in Virtual Network Environments" by N. Wang *et al.* proposes a two-dimensional architecture for end-to-end virtual network resource (VNR) management from the distinct viewpoints of service providers (SPs) and network providers (NPs). In the horizontal dimension, SPs could bind VNRs rented from heterogeneous NPs to form unified end-to-end service delivery platforms; in the vertical dimension, NPs perform cost-efficient allocation of VNRs to request SPs without necessarily forcing themselves to collaborate with each other. The proposed VNR management architecture will complement existing network virtualization platforms in practically managing virtual resources for flexibly supporting heterogeneous services.

In the article "VegaNet: A Virtualized Experimentation Architecture for Production Networks with Connectivity Consistency" by M. Xu *et al.*, the authors present VegaNet,

a virtual network architecture that provides an experimental platform atop a physical production network. In order to perform experimentation under realistic network conditions without disrupting the normal operations of existing network devices and protocols, VegaNet uses a lightweight probing mechanism to provide a consistent connectivity view as in the underlying physical production network. It uses virtualization to host multiple experiments on a single physical machine, while reflecting the current connectivity status to each hosted experiment in an accurate and timely manner. The effectiveness of VegaNet has been evaluated atop a real-life production network that is currently deployed in a country.

The next article, "Policy Management: Leveraging Open Virtualization Format with Contract and Solution" by M. Jeyakanthan and A. Nayak, discusses the challenges with respect to policy management. The authors present the fundamentals of machine virtualization and simple network virtualization. Based on a brief overview of network policy management throughout the evolution of virtualization, they segue into current industry trends and some of its novel innovations.

R. Shea and J. Liu, in the article "Network Interface Virtualization: Challenges and Solutions," focus on the virtualization technology of network interfaces, which has become an important technology in nearly every large organization's IT infrastructure. However, the benefit of such technology (e.g., decreased operational costs, improved utilization of computational resource) always comes with overhead (e.g., affecting virtually every subsystem). The authors provide an intuitive understanding of state-of-the-art software-based virtual network interfaces and the causes of virtualization overhead through both system analysis and real experiments. They also further discuss the recent hardware advances in this field as well as the challenges yet to be addressed.

In the article "Socio-Aware Virtual Network Embedding" by A. Leivadeas *et al.*, the authors address a specific aspect of network virtualization, virtual network embedding (VNE), which primarily refers to the efficient mapping of virtual resources onto physical ones. They propose a socio-aware VNE paradigm that extends the conventional objective of minimizing the cost of embedding a request into the substrate by considering an additional objective related to the social features of the physical network. The effectiveness of the proposed socio-aware VNE paradigm has been evaluated by critically comparing with those conventional VNE approaches.

In the last article, "4over6: Network Layer Virtualization for IPv4-IPv6 Coexistence" by Y. Cui *et al.*, the authors develop a 4over6 virtualization architecture that virtualizes IPv4-only networks over IPv6-only networks. Considering that the Internet will consist of IPv4-only, IPv6-only, and dual-stack segments during the coexistence period, this architecture enables two IPv4-only segments to communicate over an IPv6-only network by using an IPv4-in-IPv6 tunnel. The proposed 4over6 virtualization architecture, which is being standardized in the Internet Engineering Task Force (IETF), can be examined in different areas such as addressing schema, layer 3 routing, and packet forwarding.

We would like to thank all the reviewers for their effort and constructive comments. We would in particular like to thank Professor Xuemin (Sherman) Shen, the Editor-in-Chief, for his support and helpful suggestions during the very delicate stages of concluding the Special Issue. Finally, we would like to thank all the authors who submitted their precious research work to this Special Issue.

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