SOFTWARE DEFINED NETWORKS

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The Internet is at a critical juncture. Growth at the infrastructure and application levels are causing profound changes in the IT ecosystems of industries ranging from telecommunications to financial services to retail. Many core components of the Internet are quickly reaching their limit, threatening the future progress of the digital community and impeding global innovation. Significant infrastructure changes to the Internet are needed if we expect it to support the rise of cloud computing, mobile communications, burgeoning multimedia and streaming media, and high-speed high-throughput low-latency Internet of Things (IoT) driven applications.

David Clark, as one of the founders of the original Internet protocol suite, has argued since early 2000 that the Internet has serious shortcomings. He called out basic flaws that cost firms billions, impede innovation, and threaten national security. It s time for a clean-slate approach as the Internet security industry has become a vast patchwork of firewalls, anti-spam programs, and software add-ons, with no overall security plan. Starting around mid-2000, Stanford University, the University of California at Berkeley, and a number of other universities, funded in part by the National Science Foundation Global Environment for Network Innovation (GENI) program, started on the journey of a clean-slate Internet.

A key outcome from this clean-slate initiative is the new research initiative on software defined networking, which focuses on evolving vertically integrated network models to a more horizontal and open model. A traditional switch or router consists of a high-speed data plane where the packets are routed, and a control plane that includes functions for setting up routing and forwarding, access control, quality of service, and so on. Separating the control plane from the data plane made it feasible to run the control plane in software on standard servers, and thus enable the creation of new virtualized controllers and custom-made services easily. Through well defined APIs, systems and applications can now program the underlying network to control the underlying data plane, and precisely define fine-grained actions and treatment for packets down to the flow level. This enables agile and optimized operation via programming the network, rather than having to resort to manual configuration through low-level interfaces. Using this approach to provide isolation, elasticity, and resiliency in cloud environments enable more agile and flexible deployment of new workloads.

The value proposition of software defined networking (SDN) includes a number of new capabilities, such as rapid introduction of new network functions at software speed rather than hardware or firmware product cycles, and more seamless integration of the network with IT processes in the enterprise through programmable service-oriented APIs. SDN provides a new paradigm for applications to interact with the network, with declarative abstract APIs to direct configuration and operation of the network, and a query API to ask the network for information in order to plan and optimize operations. SDN can also cleanly decouple the network service API from the underlying implementation, allowing the infrastructure to evolve with reduced impact to applications.

The logical next step after software defined networking is the evolution toward software defined environments where resources such as compute, storage, and network are entirely software defined. Software defined storage, similar to software defined networking, separates the control plane from the data plane of a storage system and dynamically leverages heterogeneous storage resources to respond to changing workload demands. Software defined compute establishes abstraction of heterogeneous computing resources in terms of both capacity and capability. The software defined environment brings together software defined compute, networking, and storage, and unifies the control planes from individual software defined components. Unified control planes provide rich resource abstractions to enable assembling purpose fit systems, and provide programmable infrastructures to enable dynamic optimization in response to changing business requirements.

This feature topic includes four closely related articles exploring current and future directions in software defined networks in terms of scalability, improved manageability, and high-level abstractions for creating SDN based applications:

- "On Scalability of Software Defined Networks" explores how to estaablish a distributed control plane for scaling a software defined network.
- "Improving Network Management with Software Defined Networks" explores leveraging software defined networking to simplify network policy management, with a high-level language that enables expressability and flexibility.
- "Languages for Software Defined Network" explores high-level programming abstractions to simplify creation of SDN applications.
- "Meridian: An SDN Platform for Cloud Network Services" explores application of SDN to enable application-level abstractions for networking in cloud environments.

In spite of still being in its embryonic stage, software defined networking (as part of the software defined environment) has the potential to create an entirely new substrate for building the future computing and data center infrastructure. We hope this feature topic will provide an introduction and insight to the readers of *IEEE Communications Magazine* to this exciting new area.

BIOGRAPHIES

CHUNG-SHENG LI [F] (csli@us.ibm.com) is currently the director of the Commercial Systems Department and PI for the IBM Research Cloud Initiatives. He has been with IBM T. J. Watson Research Center since May 1990. His research interests include cloud computing, security and compliance, digital library and multimedia databases, and networking. He has authored or coauthored more than 140 journal and conference papers, and received the best paper award from *IEEE Transactions on Multimedia* in 2003. He is a member of the IBM Academy of Technology Leadership Team. He has initiated and co-initiated several research programs in IBM on fast tunable receivers for all-optical networks, content-based retrieval in the compressed domain for large image/video databases, federated digital libraries, biosurveillance, cybersecurity, and software defined environment. Within the IEEE Communications Society, he served on the Board of Governors (member at large) during 2004–2005, technical editor for *IEEE Communications Magazine Interactive* during 1996–1998, and feature editor for the Book Review column from 1994 to 1996. He also served as a guest editor for two feature topics in the September 1996 and January 1999 issues of *IEEE Communications Magazine* on Digital Library for Next Generation Internet and Emerging Data Communication Standards,, respectively. He received his B.S.E.E. from National Taiwan University, R.O.C., in 1984, and his M.S. and Ph.D. degrees in electrical engineering and computer science from the University of California, Berkeley, in 1989 and 1991, respectively.

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