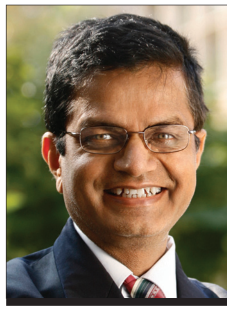
FUTURE INTERNET ARCHITECTURES: DESIGN AND DEPLOYMENT PERSPECTIVES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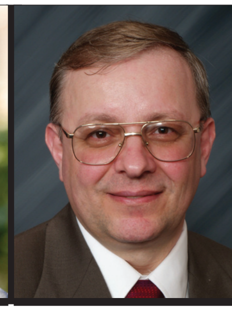
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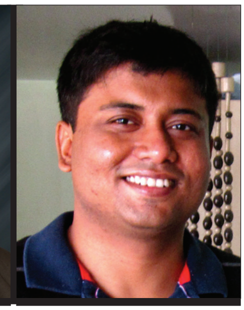
Subharthi Paul

The last 40 years of research has matured packet switching technology as a key communication primitive. Its key use context, the Internet, has been phenomenally successful. From its humble beginning as a research network, it has evolved into a critical infrastructure for the development of businesses, societies, and nations. The Internet's most popular application, the World Wide Web, has powered the present information age that has accelerated progress in all areas. There is no doubt that a lot has been achieved. Yet as we look toward the future, a very different set of research challenges present themselves. These challenges originate primarily from the "responsibilities" of handling an elite infrastructure, the "burden" of satisfying popular expectations, and catering to the "change" in its use context.

The future Internet needs to cater to the responsibilities of a critical infrastructure. Security, energy efficiency, and performance guarantee are the primary issues. Also, the future Internet needs to live up to its "near-magical" perception of communication capabilities. It needs to be able to scale to billions of nodes and also provide support for the diversified requirements of next-generation applications. The original architecture of the Internet and its communication protocols were not designed for such requirements. Moreover, the use context for which the original Internet was designed has changed considerably. We have adapted to these changes through incremental modifications to the original architecture. On the one hand these changes have helped sustain the growth of the Internet while on the other it has increasingly made the Internet architecture brittle and non-deterministic. Thus, the basic underlying principles that have been instrumental in the Internet's success need to be revisited and possibly redefined in light of future requirements.

The networking research community has taken up the task for designing the architecture for the future Internet. Initially started as part of the FIND and GENI programs by the National Science Foundation (NSF) in the United States, future Internet research is now a key agenda for all leading research agencies around the world including the European Union, Japan, and China.

The goal of this feature topic is to present some interesting design and deployment perspectives on the future Internet research. We received 48 papers. Six of these have been selected for publication in this issue. True to the spirit of diversified future Internet design, all six articles address different design and research areas. The topic should be interesting reading, with each article providing a new and fresh perspective on the design space.

"A Survey of the Research on Future Internet Architectures" provides a concise and informative survey of the various next-generation Internet design initiatives around the world. The article is background reading for those who want a high-level look into the research landscape of diversified projects with very different objectives and design approaches. This article provides pointers for further research into specific projects and ideas to an interested reader. While we did not receive any papers from the four winners of the NSF Future Internet Architecture (FIA) competition, or any of the NSF GENI participants, this article provides brief insights into those projects. The reviews of this article were handled directly by Dr. Steve Gorshe, Editor-in-Chief of *IEEE Communications Magazine*.

The article "Loci of Competition for Future Internet Architectures" proposes a new design principle for the future Internet that advocates "designing for competition." This design principle is rooted in economics and represents a relevant interdisciplinary research area for future Internet design. The article identifies various "loci" in the design space that should allow for multiple competitive providers to coexist. This will prevent monopolies. Future design choices and innovations shall evolve more naturally based on market forces. The key challenges are to locate the proper loci across the horizontal and vertical design space that do not unnecessarily make the architecture too complex, and manage the interaction between the different loci to provide a seamless communication infrastructure. Clearly, the current Internet was not designed from the perspective of future commercial use. As a result, policy enforcements, security, and accountability across interorganizational boundaries have perennially been the problem areas for the current design. The "design for competition" principle will hopefully set the right economic circumstances for the design of the future Internet.

Another interesting interdisciplinary research area that might potentially contribute new ideas to the design of a robust, self-managed, and naturally evolving future Internet design is biology. "Biological Principles for Future Internet Architecture Design" maps biological principles to network architectures. Biological systems present different models for intercommunications among elements to implement a self-sustaining system. These mechanisms may be modeled to design a robust and self-managed control plane for the future Internet. The article also provides a possible way to implement these abstract principles on actual networks. The key insight presented is that to correctly map a biological intercommunication mechanism to an equivalent networking mechanism, it is necessary to consider the scale and administrative control boundaries of the intercommunication scenario.

One of the primary components of next-generation Internet research is a testbed platform. Designing testbeds for at-scale experimentation is itself an independent area of research. The article "Enabling Future Internet Research: The FEDERICA Case" presents a discussion on the experiences with building and managing the FEDERICA testbed. Apart from a discussion on the testbed itself, its features, and the different technologies it uses, the article presents a list of projects that run on the testbed and how FEDERICA supports their diversified experimental contexts. While there is a lot of literature on testbed technologies, their properties, and their unique features, this article is differently organized such that the end user may be able to appreciate the different features of the testbed better through real use case examples.

The next-generation Internet design space is highly diversified across different design philosophies, principles, and technologies. "Content, Connectivity, and Cloud: Ingredients for the Network of the Future" provides an integrated design framework from three of the most promising components of the next-generation Internet design space: information-centric network design, cloud computing, and open connectivity. The high point of this article is that it provides a lot of insight into each of these design space components and also integrates them into a coherent framework.

A key area of research for next-generation network technologies is the programmable data plane. There are two aspects to this research. The first aspect is the set of control and management protocols that support the programmability of the underlying data plane. The second aspect is the system-level design of the high-performance programmable data plane itself. "PEARL: A Programmable Virtual Router Platform" presents a system-level design of a programmable data plane with discussion of both the hardware and software platforms.

We would like to thank Editor-in-Chief Dr. Steve Gorshe and the IEEE publication staff for their assistance with this feature topic. Special thanks to 253 reviewers who took time to provide detailed comments. We are also thankful to the authors who submitted their articles for this special issue.

BIOGRAPHIES

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SUBHARTHI PAUL received his B.S. degree from the University of Delhi, India, and his Master's degree in software engineering from Jadavpur University, Kolkata, India. He is presently a doctoral student in computer science and engineering at Washington University, St. Louis, Missouri. His primary research interests are in the area of future Internet architectures.