Multidomain Optical Networks: Issues and Challenges

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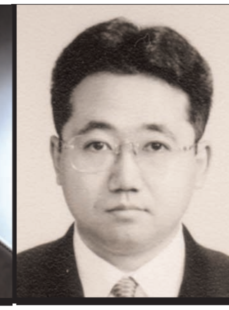

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Today, many leading organizations are undertaking extensive research on a very broad range of new and evolving optical networking technologies. These efforts carry particular significance, especially in light of the "post-bubble" dynamics of the optical networking market and have led to the investigation of various cost-efficient optical technologies. Today's telecom carriers operate several independent optical domains based on diverse technologies, control solutions, standards, and protocols, making interdomain and intercarrier interworking extremely difficult. Standardized interworking across diverse multigranularity network interfaces, and interoperability across disparate vendor equipments and carrier domains are crucial to provisioning end-to-end services and achieving cost-efficient network operation. Needless to say, having an interoperable and standard control plane across multidomain optical networks can benefit carriers through the availability of a wide selection of network elements, platforms, and multiple vendor solutions resulting in faster deployment and reduced CAPEX and OPEX charges.

The focus of this Feature Topic is to share the many experiences and lessons learned in multidomain control plane deployments and, more important, to highlight current work on interconnecting multiple optical domains and identify open challenges in deploying applications across multiple carriers' domains. This Feature Topic presents the collective experiences and insights of leading researchers, network operators, and equipment vendors across many emergent areas in the multidomain optical networking space. The response to our Call for Papers was overwhelming; we received a very large number of articles (around 30). All papers were reviewed by well-qualified independent reviewers, and the selected articles were carefully revised according to reviewer feedback.

As the scale and reach of high-bandwidth applications continue to grow, efficient service delivery across heterogeneous optical domains becomes necessary. Provisioning services across these domains requires a unified control plane, a topic being investigated by several research and standards groups. Along these lines, the first article, "Control Plane Design in Multidomain/Multilayer Optical Networks" by N. Ghani *et al.*, presents a survey of control plane designs for multidomain/multilayer networks and the status of standardization with an emphasis on a series of challenges, such as state dissemination, path computation, and survivability. It also presents a sample study to evaluate the scalability of routing protocols in state dissemination.

Different standards bodies have started addressing the issue of defining a unified control plane to provision services across multidomain networks. The international Telecommunication Union — Telecommunication Standardization Sector (ITU-T) has developed automatic switched optical network (ASON)-based transport networks, and the Internet Engineering Task Force (IETF) has developed the generalized multiprotocol label switching (GMPLS)-based transport network architecture. The interworking among ASON and GMPLS technologies is an important topic to address. Along these lines, the second article, "Multi-ASON and GMPLS Network Domains Interworking Challenges" by S. Okamoto *et al.*, presents challenges involved in provisioning services across these control plane technologies, their possible solutions, and results from field trials.

Recently, the IETF has started addressing path computation and service provisioning across multiple domains using the path computation element (PCE) architecture. However, the standardization does not address how an autonomous system (AS) chain is calculated and how the setup of inter-AS tunnels is subject to stringent business, security, policy, and confidentiality issues. The third article, "A Service Plane over the PCE architecture for Automatic Multidomain Connection-Oriented Services" by R. Douville *et al.*, defines a business model based on service providers' alliance within the scope of the ACTRICE project. Several service elements are identified and defined through the use of a framework developed by IP Sphere for reliable advertisement of service data via SOAP/XML-based Web-services across multiple domains.

The Optical Border Gateway Protocol (OBGP) was proposed as a solution to disseminate and share the control information across border nodes. However, it inherits several well-known limitations such as the need for sharing and the possibility of exploiting traffic engineering (TE) information, the lack of constraint-based routing and multipath routing features, and the large convergence time. The fourth article, "Toward a New Control Model for Multidomain Optical Networks" by M. Yannuzzi *et al.*, presents an alternative route control architecture to exchange network reachability information (NRI) and path state information (PSI) across domains. The proposed architecture is a blend of interdomain

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routing and TE control, and exploits NRI and PSI to compute interdomain lightpaths in an efficient way.

Widely scattered network users usually care less about the network topology and implementation details. What they care about is something fundamental, such as: Do I get services with guaranteed fault tolerance and reliability/availability with an acceptable recovery time at an acceptable level of overhead? The fifth article, "Recent Progress in Dynamic Routing for Shared Protection in Multidomain Networks" by D. L. Truong *et al.*, presents a review of recent work on shared path protection in multidomain networks. Furthermore, it provides a detailed quantitative comparison of the most efficient approaches.

The types of applications being deployed across the public Internet today are increasingly mission-critical; business success can be jeopardized by poor performance of the network. It does not matter how attractive and potentially lucrative these applications are if the network does not function reliably and consistently. In such scenarios optical networks will not be a viable alternative unless they can guarantee predictable performance parameters (fault tolerance, availability, etc.) to users. Along these lines, the sixth article, "Enabling High Availability over Multiple Optical Networks" by D. Staessens *et al.*, presents a vision of how to enable high-availability services over different carrier networks using failure protection techniques under administrative constraints.

Emerging architectures such as lambda grids span multiple optical domains to support multigigabit connectivity for applications such as weather forecasting, remote sensing, and biotechnology. An example of such a grid network services framework is being developed in the Phosphorus project funded by the European Union (EU). Along these lines, the seventh article, "Phosphorus Grid-Enabled GMPLS Control Plane (G2MPLS): Architectures, Services, and Interfaces" by G. Zervas *et al.*, describes setup and restoration of grid services through integrated services procedures developed during the lifetime of the project. It presents overlay/integrated network architectures and defines grid optical user-network interfaces, grid internal network-network interfaces, and grid external network-network interfaces toward development of G2MPLS control plane implementation.

Finally, the interconnection of multiple domains using emerging optical networking technologies such as optical burst switching and optical packet switching has been known to present several limitations due to the lack of optical buffers and standardized protocols. Toward this end, the eighth article, "Dynamic CANON: A Scalable Multidomain Core Network" by A. Stavdas *et al.*, presents a scalable architecture addressing these issues based on the Clustered Architecture for Nodes in Optical Networks (CANON). The CANON concept, developed in the EU IST NOBEL project, is based on collisionless distributed slot aggregation, which enhances the dynamic switching of slots/frames between domains even under heavy traffic conditions.

We believe that the above articles present a good timely snapshot of ongoing research and developmental activities in the rapidly evolving field of multidomain optical networking. We hope that this Feature Topic provides an important reference for network designers, service providers, practitioners, and researchers alike. It was indeed an honor for us to serve as guest editors for this Feature Topic. We would like to thank all the authors who submitted their articles to our call and the many reviewers who contributed their valuable time despite their busy schedules to provide detailed feedback. The advice and support of Drs. Nim Cheung and Tom Chen (current and past Editors-in-Chief of *IEEE Communications Magazine*, respectively) are sincerely appreciated. We are also very grateful to Joseph Milizzo and Sue Lange (*IEEE Communications Magazine* production staff) for their help with the online ManuscriptCentral system and camera-ready preparations, respectively. Finally, we hope that all of you, the readers, will find this Feature Topic interesting, and we appreciate your feedback.

BIOGRAPHIES

CHAVA VIJAYA SARADHI [M] (saradhi@ieee.org) [M'04] received his B.Tech. degree in electronics and communications from JNTU, Hyderabad, India; his M.S. degree in computer science from the Indian Institute of Technology, Chennai; and his Ph. D. degree in electrical and computer engineering from the National University of Singapore. He was with the Institute for Infocomm Research, Singapore, from September 2002 to December 2006 as a senior research engineer, where he was extensively involved in development of signaling protocols for a GMPLS-based optical network testbed under the Optical Network Focus Interest Group (ONFIG) and field trial activities in Singapore. Currently, he is with Create-Net, Italy, working on several industry and EU funded projects. He has over 40 journal and conference articles to his credit. He served as co-chair for IEEE/Create-Net GOSP 2005 and 2006 workshops and co-Guest Editor of *IEEE Communications Magazine*. His research interests include optical networks, MPLS/GMPLS networks, and real-time systems.

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EIJI OKI (oki.eiji@lab.ntt.co.jp) [M'95-SM'05] received B.E. and M.E. degrees in instrumentation engineering and a Ph.D. degree in electrical engineering from Keio University, Yokohama, Japan, in 1991, 1993, and 1999, respectively. In 1993 he joined Nippon Telegraph and Telephone Corporation's (NTT's) Communication Switching Laboratories, Tokyo Japan. He has been researching multimedia communication network architectures based on ATM techniques, traffic control methods, and high-speed switching systems. From 2000 to 2001 he was a visiting scholar at Polytechnic University, Brooklyn, New York, where he was involved in designing terabit switch/router systems. He is now engaged in researching and developing high-speed optical IP backbone networks as a senior research engineer with NTT Network Service Systems Laboratories. He was the recipient of the 1998 Switching System Research Award and the 1999 Excellent Paper Award presented by IEICE, and the 2001 Asia-Pacific Outstanding Young Researcher Award presented by IEEE Communications Society for his contribution to broadband network, ATM, and optical IP technologies. He co-authored two books, *Broadband Packet Switching Technologies* (Wiley, 2001) and *GMPLS Technologies* (CRC Press, 2005).