Multi-domain, multi-layer software-defined infrastructure

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New research challenges in multi-domain SDI relate to (i) control-plane functions such as inter-domain routing, path selection, and authentication, (ii) management-plane functions such as Fault management, Configuration management, Accounting, Performance monitoring, and Security (FCAPS), and (iii) interworking of different data-plane protocols that could potentially arise in multi-domain SDIs. New research testbed infrastructure is needed for optical SDNs. Given the increasing flexibility of the optical layer, there are significant new opportunities for advances in optical networking. My group's research work in this area falls into three categories: (i) multi-domain SDN for dynamic Layer-2 (L2) path service, (ii) multi-domain optical SDN for dynamic flexible Layer-1 circuit service, and (iii) Lagopus based NFV for L2 and L3 functions. The research challenges listed above were identified as part of these activities.

In the recent IEEE/ACM NDM workshop, held in conjunction with SC2015, we presented a paper on a dynamic Layer-2 path service on a multi-domain SDN that we created on the Dynamic Network System (DYNES) networks deployed at 8 campuses. OSCARS and OESS are two SDN controllers that were deployed at each DYNES site. Research challenges identified in this experimental effort, which spanned 8 universities and their regional REN providers, and Internet2, include: (i) configuration overhead of OSCARS/OESS, (ii) lack of scalability and commerical applicability of the open topology-sharing approach used for inter-domain routing and endpoint identification, (iii) lack of flexibility in path selection owing to the daisy-chain model used by OSCARS, (iv) lack of tools for L2 path diagnostics, (v) path-setup delay and insufficient error reporting capabilities of the controllers, and (vi) configuration management issues related to software updates and certificates. Most of these challenges fall in the control-plane and management-plane categories for multi-domain SDI.

On Layer-1 (L1) research, we are collaborating with Ciena and CPqD, Brazil, to identify the technologies needed to create an optical SDN testbed for potential addition to GENI. Optical switching technologies are now highly flexible. Reconfigurable Optical Add/Drop Multiplexers (ROADMs) support colorless, directionless, contentionless (CDC) switching, which means dynamic L1 service is now possible. Further FlexiGrid technologies are rapidly advancing allowing circuits to be created with variable bandwidth (no longer limited to the 50 GHz spacing of the ITU-T Fixed Grid). Making ROADMs, EDFAs, Bandwidth-Variable (BV) transponders programmable would allow L1 researchers to experiment with different modulation techniques, and study the impact of different amplification, equalization and polarization settings. Creating a programmable, virtualizable Optical SDN testbed is a critical first step to developing inter-domain dynamic L1 services. Programmable optical circuit switches could also be used within an SDX to provide rate-guaranteed peering.

Finally, appreciating the significant opportunity for developing multiple "internets" by allowing service providers to use different protocols on the same network infrastructure, we are working with NTT Labs and Keio University, Japan, to experiment with the Lagopus software. Lagopus is a high-performance software OpenFlow switch developed for wide-area networks. Lagopus has been executed in a Trident II based whitebox. We are running Lagopus on GENI hosts, and currently experimenting with different VNFs, such as QoS mechanisms (queueing, metering), NAT, and Layer-3 packet forwarding. Our ultimate goal is to study the question of interworking of different protocols that could be used by different federations of multi-domain SDIs. While the opportunity for developing multiple new internets is exciting, architectures and protocols are required to meet the interworking research challenge.

In summary, there are a number of research challenges in developing reliable and scalable multi-domain SDIs that support multiple internets. The dimension of multiple layers increases these challenges by a significant factor.