Field Trial of Broker-based Multi-domain Software-Defined Heterogeneous Wireline-Wireless-Optical Networks

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Abstract: Driven by a broker-based OpenFlow control plane, we report the first field trial of software-defined heterogeneous wireline-wireless-optical multi-domain networks connecting UC Davis Campus, USTC, California OpenFlow Testbed Network (COTN) and Energy Sciences Network (ESNet).

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1. Introduction

Software-defined Networking (SDN), in particular, the OpenFlow (OF) architecture and its associated protocol has been widely studied in recent years due to its open interface and flexibility for network programming. Most of the works have focused on a single domain scenario, and some recent studies have started to extend SDN/OF to support multi-domain networks [1-4]. However, to the best of our knowledge, there has not been an experimental demonstration for a multi-domain software-defined heterogeneous network where wireline, wireless and optical domains co-exist, especially through a field trial using practical network testbeds including real data plane hardware and in-ground field fibers. In this paper, we report the first field trial of software-defined heterogeneous wireline-wireless-optical (including both fixed-grid and flexi-grid) multi-domain networks, which connect UC Davis Campus Network, USTC, California OpenFlow Testbed Network (COTN) and Energy Sciences Network (ESNet) [5] and Energy Sciences Network (ESNet) [6]. A market-driven broker-based [2] OF control plane is deployed to dynamically program and control the multi-domain heterogeneous network for end-to-end resource management and service provisioning.


Fig. 1(a) illustrates the concept behind the broker-based OF control plane for multi-domain heterogeneous networking. In each domain, an OF Controller (OFC) is deployed, which manages the entire intra-domain information and can control the wireline, wireless and/or optical switches in its domain through the OF (or extended OF) protocol. Due to the security and confidentiality requirements, each OFC has no visibility of other domains. On top of OFCs, at least one broker agent is deployed which has a virtualized global view of domains, including full information of the inter-domain links and virtualized network status in intra-domains. An inter domain broker protocol is proposed, as the southbound interface, for the broker to communicate with OFCs, as the detailed procedure for end-to-end path provisioning is shown in Fig. 1(a). If a flow arrives at a domain ingress node (A1), and if this flow doesn't match any existing flow entry in A1, A1 forwards the first packet of this flow, as the Packet_In message to the controller OFC1 (step 1 in Fig. 1(a)). If the destination of this flow is in another domain, OFC1 sends this request to the broker, by using the Broker_Request message (step 2). Then the broker requests the intra-domain network status from OFC1 and OFC2 using the Status_Request messages (step 3), and in turn, each OFC provides the virtual intra-domain information to the broker with the Status_Reply messages (step 4). Here, OFCs abstract the related intra-domain path segments, including the source node to egress nodes in the source

Fig. 1: (a) Broker-based OF control plane for multi-domain networks; (b) Wireshark capture of Broker 1 for dynamic path provisioning from UC Davis to COTN to ESNet; (c) Wireshark capture of OFC1 for dynamic path provisioning from UC Davis to COTN to ESNet.
domain, ingress nodes to egress nodes in the intermediate domains, and ingress nodes to the destination node in the destination domain, respectively, as virtual links. The virtual links represent the segments’ information, which can include the aggregated information such as resource availability and link distances, or even more, depending on the service agreement between the broker and OFCs. Once the broker receives all the Status Reply messages, a virtual topology with the inter-domain links and virtual intra-domain links can be constructed, as shown in Fig. 1(a), and then the broker can perform path computation and send the results to the corresponding OFCs through the Broker Reply messages (step 5). After that, each OFC parses the Broker Reply message, maps the selected virtual link to the physical path segment in its domain, and then configures the data plane switches accordingly to set up the path by using the Flow Mod messages. Note that the messages in the above steps 2-5 are newly proposed in the inter domain broker protocol, whereas the Packet In and Flow Mod are OF messages, and extensions to them are needed in order to support fixed-grid or flexi-grid optical networks [7, 8].

Macroscopically, from the control plane architecture point of view, the proposed broker-based approach adopts an hierarchical model, which is similar with the Hierarchical Path Computation Element (H-PCE) [9] or SDN orchestration [3, 4]. However, the brokered approach can be naturally applied to the future multi-domain heterogeneous networks, in particular in a multi-carrier scenario, as the relationship between the broker services and domains are through market-driven incentives [2]. Multiple broker agents can be deployed, which compete freely with each other to provide attractive inter-networking services to domains, while the domains choose service plans from one or multiple brokers that are valuable for their inter-networking needs.
1 to domain 4 to domain 5. To facilitate the end-to-end service delivery, a VLAN stitching technique is adopted. When inserting flow entries in the OF switches, in addition to the input and output ports, we also identify the input VLAN ID in the MATCH field and set the output VLAN ID in the ACTION field, as the Wireshark capture shown in Fig. 3(a). By using this approach, a VLAN tag is added to the flows, so that the non-OF switches can route the flow to the correct destination according the VLAN tag. Fig. 3(d) shows the data plane round trip time (RTT) for the traffic during the path provisioning. Due to the configuration delay and packet inspection at some border devices along the path, the RTT at the beginning is very long (around ~3200ms). Once the created path is stable, the RTT is sharply reduced to ~11.5ms and is kept at this value during the flow transmission. Domains 3 and 6 are emulated flexi-grid optical networks with control planes only, which are deployed in UC Davis and USTC respectively. The Broker 2, OFC3 and OFC6, with the capability to support routing and spectrum assignment and related protocol extensions, are deployed to control domains 3 and 6. Fig. 3(b) shows the Wireshark capture of a Broker Reply message for path provisioning from domain 6 to domain 3. This message includes selected virtual link, frequency slots and modulation formats calculated by Broker 2, and is sent to OFC3 to control the flexi-grid optical domain. Fig. 3(c) summarizes the control plane processing latencies for different scenarios reported in this field trial.

Fig. 3: Field trial results: (a) Wireshark capture of the Flow_Mod message; (b) Wireshark capture of the Broker_Reply message; (c) Control plane processing latencies for different scenarios; (d) Data plane RTT during the path provisioning from UC Davis to COTN to ESNet.

4. Conclusions
In this paper, we report the first field trial of software-defined heterogeneous wireline-wireless-optical (including both fixed-grid and flexi-grid) multi-domain networks, which connect the UC Davis campus network, USTC, COTN and ESNet. By using the proposed market-driven brokers with OF protocol extensions, we successfully demonstrate various services such as end-to-end dynamic path provisioning across multiple domains, high-bandwidth and low latency 4K signal switching and seamless wireless handover, validating the overall feasibility and efficiency of the proposed solutions for future multi-domain, multi-carrier, multi-vendor heterogeneous networks.

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