Interworking of GMPLS and OpenFlow Domains: Overarching Control of Flexi Grid Optical Networks

R. Casellas [(1)], R. Muñoz [(1)], R. Martínez [(1)], R. Vilalta [(1)], L. Liu [(2)], T. Tsuritani [(3)], I. Morita [(3)]

[(1)] CTTC, Spain ramon,casellas@cttc.es [(2)] Univ. of California, Davis, USA. [(3)] KDDI R&D Labs, Japan

Abstract *Both GMPLS and OpenFlow are positioned to become the pillars of a dynamic control plane for optical transport networks, each with its own strengths and weaknesses. This paper summarizes both approaches and discusses potential SDN interworking architectures.*

Introduction

Optical Transport Networks provide transport, multiplexing, routing, management, supervision and survivability of optical channels. In a flexible DWDM grid with a low channel spacing (6.25 GHz), the required optical spectrum can be dynamically and adaptively allocated in multiples of a width granularity (12.5 GHz), determined by the signal data rate and modulation format.

For such *flexi-grid networks*, a control plane (CP) is used for dynamic provisioning and recovery. Emerging optical technologies bring new requirements such as flexible spectrum allocation, efficient co-routed connection setup and configuration of related optical parameters. Two main CP architectures coexist, enabling common functions like addressing, automatic topology discovery, network abstraction and connection provisioning. One is based on the distributed GMPLS control plane (with optional PCE path computation), the other relies on Software Defined Networking (SDN) principles, with a logically centralized controller and an open protocol, such as OpenFlow[1] (OF). New use cases such as data center interconnection highlight the need for multi-domain (defined e.g., administratively, by topology visibility constraints or by vendor boundaries) service provisioning, and heterogeneous CP interworking, requiring an *overarching control*.

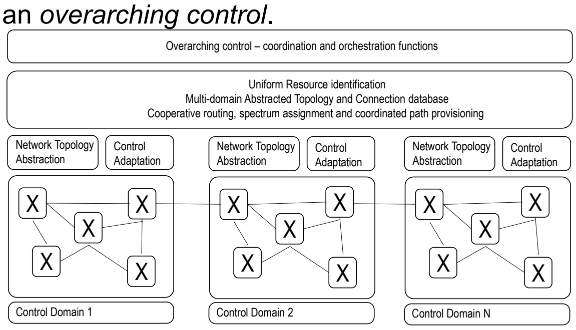

Fig. 1: Overarching control of heterogeneous multi-domain networks

Scalable solutions are expected to rely on distributed architectures with synchronization mechanisms enabling cooperative routing and path provisioning and on the concept of network *abstraction,* which refers to the selection of an entity relevant characteristics, based on targeted functionality and scalability, such as selected network topological information (Fig.1).

GMPLS support for Flexi-grid networks

GMPLS uses established procedures and protocols for topology dissemination and distributed signalling to set up and release optical connections, *Label Switched Paths (LSPs)*, with labels locally representing the media channel and its associated switched frequency slot. From a standardization perspective, support for flexi-grid networks is still in early stages in the Internet Engineering Task Force (IETF) [2], scoped to the control of network media channels transports a single Optical Tributary Signal. The OSPF-TE routing protocol is extended to disseminate, via Link State Advertisements (LSAs), node and link attributes such as the optical spectrum availability, collected in the Traffic Engineering Database (TED). The resource reservation protocol (RSVP-TE) is extended with a new switching type and new types for both the sender descriptor traffic specification and for the flow descriptor objects, conveying the requested and allocated slot widths. A GMPLS control plane can be augmented with an active stateful PCE (AS-PCE), in which the PCE manages the database of active connections and may, autonomously, suggest their re-routing and eventually instantiate connections.

OpenFlow support for flexi-grid networks

A logically centralized CP is attracting attention, given its potential integration with operators' OSS/BSS and software customization. The (now historical) OpenFlow protocol (OFP) v1.0 circuit switching addendum had basic support for fixed-grid optical networks, and OFP 1.4 has improved it. Recently, a significant number of extensions are addressing flexi-grid networks to dynamically create connections along with the direct control of bandwidth variable transceivers. The first extended OpenFlow-based control plane[3] focused on feasibility. Further studies have investigated the control of flexible transmitters[4] or integration with optical performance monitors[5]. From a standardization point of view, the optical transport WG of the Open Networking Foundation is working on the definition of the architecture and requirements, protocol extensions are in progress. Arguably, one of the reasons behind the success of OpenFlow is the logical switch abstraction, hiding vendor-specific hardware details, and mapping high level instructions of the protocol, which mitigates inter-operability issues commonly found in multi-vendor deployments.

Interworking of GMPLS and OpenFlow

The GMPLS/OF interworking alternatives show varying degrees of integration and flexibility. Straightforward approaches are characterized by the *adaptation* of one control model into the other, whereas more advanced interworking requires the definition of common models (e.g. a subset of attributes for network elements) and of *coordination and orchestration* functions.

GMPLS CP with OF as CCI: consists in using OFP as the Connection Controller Interface (CCI), which enables a control plane entity to program the forwarding of a network element. By extension, the applicability of GMPLS for ASON[6] covers multiple transport nodes (a logical network device capable of originating and/or terminating of a data flow and/or switching) controlled by a single GMPLS controller: a GMPLS controller is a basic SDN controller with limited application layer and programming interfaces, driven by signalling.

GMPLS CP with OF Island: likewise, an OF island may be part of a GMPLS network provided that the OF controller implements the GMPLS protocols bound to the abstract node that represents its domain connectivity. The OF controller needs to create control plane adjacencies with its neighbouring GMPLS controllers, disseminate LSAs for its edge links and map RSVP-TE Path/Resv states to supporting connections (both shown in Fig. 2).

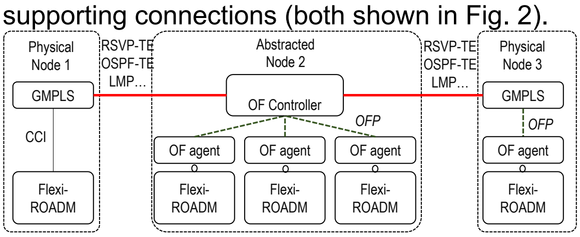

Fig. 2: GMPLS CP with an OF island (node 2). Note the use of OFP as CCI Protocol (node 3)

OpenFlow with virtual node abstraction[7]: by introducing an extra layer of indirection, a GMPLS domain can be represented as a logical OF node, mapping and exporting the domain internal connectivity under policy control, and the GMPLS client interfaces correspond to the OF ports (Fig.3). A virtual cross-connect induces an LSP establishment using the GMPLS provisioning interface or through an AS-PCE. The OF agent of the virtual node acts as a proxy to the GMPLS domain. This notion can be generalized: a GMPLS domain can be abstracted and augmented with an adaptation layer becoming a single interfacing point.

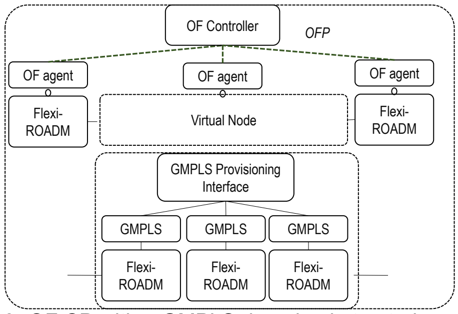

Fig. 3: OF CP with a GMPLS domain abstracted as node

These models are limited by definition; we are generically concerned with the *orchestration* of multiple technology domains or islands, enabling a flexible degree of abstraction and requiring uniform resource addressing to unambiguously identify nodes, links and ports.

Single SDN controller model: a controller with full visibility of the OF/GMPLS regions operates as a single control domain (Fig.4). It uses dedicated provisioning interfaces at defined demarcation points, either directly programming cross-connects or requesting the establishment of *segments* to GMPLS boundary nodes using a provisioning interface, or delegating the task to an AS-PCE. It is a straightforward deployment with e.g. an OpenDaylight controller with OF and PCEP plugins, and is suitable for small domains.

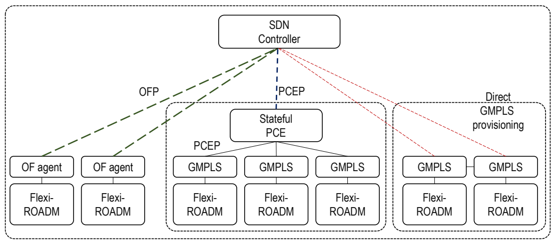

Fig. 4: Single controller approach with dedicated provisioning interfaces

A single controller may not scale or present confidentiality issues, requiring multiple-controllers and inter-controller protocols. Such architectures apply both to GMPLS/OF interworking and to homogeneous multi-domain networks with multiple GMPLS or OF domains. We assume that for each domain, a controller acts as a "proxy" interacting with the rest.

Multiple controller approach [Mesh]: a mesh of controllers is implicit by the domains connectivity, and the controllers hide the internal control technology and synchronize state using East/West interfaces (Fig. 5), managing abstract views of the external domains. The exact definition of the East/West interfaces requires and in-depth analysis of requirements and use cases, and could be based on separate instances of existing protocols (e.g. OSPF-TE, RSVP-TE, PCEP) or new ones. Conceptually, this induces a hierarchical routing similar to the ASON routing or ATM PNNI.

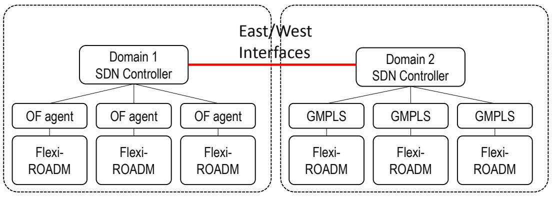

Fig. 5: Multiple controller approach [Mesh] relying on the definition of E/W interfaces and distributed protocols

Multiple controller approach [Hierarchical]: a logically centralized *controller of controllers* or orchestrator handles the automation of connectivity provisioning at a higher, abstracted level, covering inter-domain aspects (Fig.6). Specific per-domain controllers map the abstracted control plane functions into the underlying control plane technology by means of a Multi Domain Northbound interface (MD-NBI).

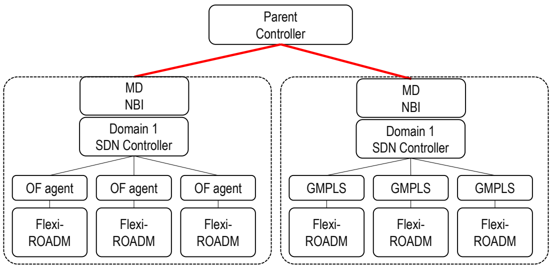

Fig. 6: Multiple controller approach [Hierarchical]

For example, the Hierarchical-PCE has been extended with stateful and OF capabilities[8]; the parent PCE orchestrates the provisioning of services with generalized identifiers and each child PCE acts as a proxy for each domain, either integrated with an OpenFlow controller[9], or delegating to an underlying GMPLS/PCE control plane. PCEP is used for provisioning, rerouting and reporting. Fig. 7 shows the block diagram and message sequence.

Current trends and conclusions

GMPLS deployments are integrated within centralized management systems (NMS), which can benefit from customizing the network behaviour in software, becoming part of a broader SDN architecture. SDN is highlighting the need for interoperable components, open and standard interfaces and common models with the right abstractions, avoiding vendor lock-in. Emerging use cases involve heterogeneous multi-domain scenarios, requiring interworking and orchestration, abstracting and scoping such domains, e.g. behind a single entry point such an AS-PCE. Mesh, hierarchical or hybrid solutions, combining distributed and centralized elements, need to address scalability (CP dimensioning), security and efficiency. For this, the maturity, robustness and proven status of the protocols of the GMPLS/ASON architecture should not be ignored.

Acknowledgements

Work funded by Spanish MINECO project FARO (TEC2012-38119), and FP7 projects STRAUSS (608528), IDEALIST (317999) and PACE (619712).

References

[1] OpenFlow, http://www.openflow.org.

[2] O. González, et al., IETF “Framework and Requirements for GMPLS based control of Flexi-grid DWDM networks”.

[3] L. Liu, et al, “OpenSlice: an OpenFlow based control plane for spectrum sliced elastic optical path networks,” ECOC 2012.

[4] L. Liu, et al., “Demonstration of a dynamic transparent WSON employing flexible transmitter/receiver controlled by an OpenFlow/stateless PCE integrated control plane,” OFC2013.

[5] F. Paolucci, et al, “OpenFlow-based flexible optical networks with enhanced monitoring functionalities,” ECOC2012.

[6] I. Bryskin et al.,IETF RFC 4397, February 2006.

[7] S. Azodolmolky, et al., “Integrated OpenFlow– GMPLS control plane: ...,” Opt. Express, vol. 19, pp. B421–B428, 2011.

[8] R. Casellas, et al. “SDN based Provisioning Orchestration of OpenFlow/GMPLS Flexi-grid Networks with a Stateful Hierarchical PCE”, OFC2014

[9] R. Casellas, et al. “Control and management of flexi-grid optical networks with an integrated stateful PCE and OpenFlow Controller”, JOCN, Vol 5 p A57(2013).

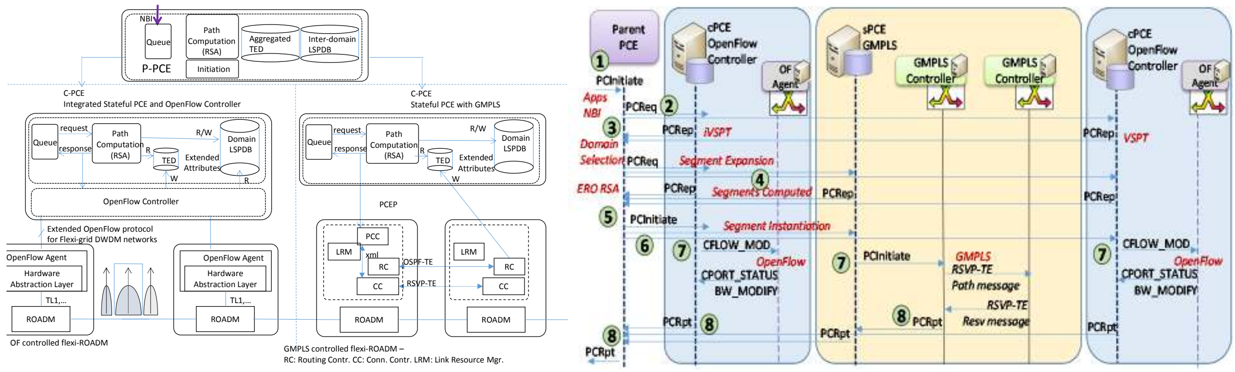

Fig. 7: SDN based Provisioning Orchestration of OpenFlow/GMPLS Flexi-grid Networks with a Stateful Hierarchical PCE