Optical Network Control and Management Technology Using OpenFlow

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Abstract

In this paper, we review OpenFlow-based control and management technology for optical networks including multi-layer optical networks, multi-domain optical networks and elastic optical networks. We also present the interworking between OpenFlow and PCE/GMPLS control planes.

I. INTRODUCTION

OpenFlow [1], which allows operators to control the network using software running on a network operating system (e.g. NOX [2]) within an external controller, has recently been proposed and experimentally validated as a promising unified control plane (UCP) technique [3], since it provides satisfactory flexibility for the operator to control a network and is aligned with carrier’s preferences given its simplicity and manageability [4].

In this paper, we review our recent studies regarding OpenFlow-based control and management approaches for optical networks, presenting the key enabling techniques and highlighting their benefits.

II. OPENFLOW-BASED OPTICAL NETWORK CONTROL AND MANAGEMENT TECHNOLOGY

A. For Multi-layer Optical Networks

Fig.1 shows the OpenFlow-based UCP for IP and optical multi-layer networks. Once a new flow arrives at the ingress OpenFlow-enabled IP router (OF-R1), and if this flow doesn’t match any existing flow entry, the OF-R1 forwards the first packet of this flow to the NOX for path computation. After that, the NOX computes the path in the optical layer by using an impairment-aware routing and wavelength assignment (IA-RWA) algorithm, and then controls the OF-Rs and OpenFlow-enabled optical switching nodes (e.g. OF-PXCs in Fig.1) along the computed path for dynamic path provisioning. As Fig.1 indicates, note that implementation of an extended OpenFlow protocol with wavelength switching capability is necessary in the OpenFlow agent. The optical cross-connection information (input and output ports, wavelength, etc) is encapsulated in the extended OpenFlow protocol, so that the OpenFlow agent can correctly cross-connect the underlying optical switching nodes. The previous studies in [5-7] experimentally validated the feasibility and efficiency of OpenFlow-based UCP for IP and wavelength switched optical networks (WSON) multi-layer networks, and Refs. [8,9] experimentally presented other multi-layer optical network paradigms such as optical burst switching (OBS) over WSON and multi-protocol label switching transport profile (MPLS-TP) over WSON.

B. For Multi-domain Optical Networks

Fig.2 shows the OpenFlow-based control plane for multi-domain WSON, as firstly proposed in [10]. Although this architecture can adopt a centralized NOX to compute an end-to-end path by using an IA-RWA algorithm, provided that the complete network information is available at the NOX, such an approach becomes infeasible in an actual operational scenario due to the scalability and confidentiality limitations. On the other hand, the path computation element (PCE) [11] and the PCE communication protocol (PCEP) [12] have been recently proposed and standardized by IETF, targeting, in particular, inter-domain path computations. Therefore, a promising solution involves the deployment of collaborating PCEs in the OpenFlow-based control plane for intelligent path computation in multi-domain optical networks, as shown in the architecture in Fig.2. This solution achieves the inter-domain path computation at collaborating PCEs via the backwards-recursive-path-computation (BRPC), or involves the NOX to decompose an inter-domain path request into multiple intra-domain requests and to send these requests to different PCEs simultaneously (parallelization).

C. For Elastic Optical Networks (EON)

The OpenFlow-based control plane for EON, referred to as OpenSlice, has been firstly proposed in [13]. As Fig.3 indicates, OpenSlice introduces a cross-connection table similar to the flow table in standard OpenFlow, which maintains all the cross-connection information within a bandwidth variable wavelength cross-connect (BV-WXC), including input/output ports, central frequency, slot width, and modulation format. The Slice...
Mod message, which is extended from the standard Flow Mod message, can add/delete a cross-connection entry into the cross-connection table, and thus control the BV-WXC, allocating a cross-connection with the spectrum bandwidth to create an appropriately-sized optical path [14]. In [15], a first field trial of OpenSlice has been successfully carried out, which further validated the efficiency of the OpenSlice for EON control.

The authors would like to thank Dr. R. Casellas, Dr. R. Martínez, and Dr. R. Muñoz for their strong support.

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