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Technology-aware multi-domain multi-layer routing

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ABSTRACT

Transporting Big Data requires high-speed connections between end-hosts. Research and educational networks typically are state-of-the-art networks that facilitate such high-speed user-created network connections, possibly spanning multiple domains. However, there are many different high-speed optical data plane standards and implementations, and vendors do not always create compatible data plane implementations. These technology incompatibilities may prevent direct communication between domains and therefore complicate the configuration of connections. However, some domains may have adaptation capabilities that can lift the technology incompatibility constraint in establishing paths between incompatible domains. Within this context, we address two problems, namely: (1) how to model the technology incompatibilities of multi-domain multi-layer networks, and (2) how to optimally establish paths in such networks. We introduce the inclusion of the information of the supported technologies and adaptation capabilities of each domain and inter-domain link in our model. We subsequently propose technology-aware routing algorithms for finding the shortest feasible path in a multi-domain multi-layer network.

1. Introduction

Many different scientific research projects are now producing Big Data. For example, the fields of physics and astronomy have traditionally been the largest producers of data with projects such as the Large Hadron Collider [1], the Sloan Digital Sky Survey [2] or the planned Square Kilometer Array [3] and the Large Synoptic Survey Telescope [4]. We now see that other fields, such as biology and medical research, are also producing and transporting large data sets. These data sets are often shared between different institutes, within countries, but also across the globe. Most countries have their own National Research and Education Network (NREN) for providing high-speed connections between universities and research institutes within their country. For instance, the Dutch NREN is called SURFnet [5]. NRENs can be considered as a catalyst of collaboration between research partners in their prospective countries. Currently, as became evident in a project with SURFnet, one of the main problems faced by NRENs is how to cooperate and pool their resources for setting up *international* lightpaths to fulfill the ever-increasing worldwide research needs of scientific equipment sharing, data distribution, cloud computing, etc. An example of a worldwide NRENs cooperation is the Global Lambda Integrated Facility (GLIF) [6] initiative.

Traditionally, NRENs are interconnected by inter-domain links between their border nodes. In the recent years, GLIF has taken the initiative to propose the use of optical exchanges as open and neutral interconnection points between NRENs, as illustrated in Fig. 1. Fig. 1 consists of several administrative domains, e.g., NRENs and optical exchanges, where an administrative domain is defined as a network under the control of a single network administrator. Optical exchanges, e.g., the NetherLight [7] are points of presence where all NRENs that are connected to them can communicate with each other. Optical exchanges may also be connected to other optical exchanges. Ideally, the optical exchanges can adapt their client technologies transparently without any restrictions (e.g., client identities, content type or size).

Multi-domain routing is under the jurisdiction of several standardization bodies, such as the ITU Telecommunication Standardization Sector (ITU-T), the Internet Engineering Task Force (IETF), and the Open Grid Forum (OGF). Though their focus varies, all of them have proposed standards related to the multi-domain networking, namely the ITU-T G.8080/Y.1304 as a telecommunication standard, the Path Computation Element (PCE) framework (e.g., IETF RFC4655) as an internet standard, and the Network Service Framework (NSF) (e.g., OGF GFP173) as a grid standard.

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In the ITU-T recommendation G.8080/Y.1304 [8], an architecture framework referred to as the Automatically Switched Optical Network (ASON) was proposed for a more intelligent optical network operation. The framework introduces a logical architecture of three planes, the transport plane (i.e., data plane), the control plane and the management plane. The framework also encompass the notion of domain, inter-domain links, and several routing approaches.

The IETF RFC4655 [9] aims to decouple the routing function from the control plane such that a dedicated routing component referred to as the Path Computation Element (PCE) is used instead to find more advanced paths, e.g., impairment-aware paths, multi-domain-paths, and multi-layer paths. The PCE architecture can be either centralized or distributed. Multiple PCEs work together via the use of the PCE protocol (PCEP). The standard covers inter-domain routing, intra-domain routing, and inter-layer routing. Muñoz et al. [10] provided a good overview of the PCE functionality.

The OGF GFP173 [11] proposes the Network Service Interface (NSI) protocol [12] for domains to cooperate in servicing multi-domain connection requests. NSI has been implemented by various research partners of GLIF, e.g., AutoBAHN by GÉANT, G-Lambda/A by AIST, G-Lambda/K by KDDI R&D Labs, DynamicKL by KISTI, OpenNSA by NORDUnet, OSCARS by ESnet and BoD by SURFnet [13]. Each domain is associated with a software-based management system referred to as the Network Service Agent (NSA). Multiple NSAs work collectively to establish, maintain, and terminate multi-domain connections spanning their domains. Domains are interconnected at their Service Termination Points (STPs), which represent ports on a switch, border nodes, or specific VLANs on a port as illustrated in Fig. 2. A grouping of two STPs is referred to as a Service Demarcation Point (SDP). Unlike the IETF PCE framework, the OGF NSF has not yet define any specific standard for multi-domain routing.

Administrators usually build and upgrade their domain according to their preferences for vendors and technologies. These preferences could be based on capital expenditure, equipment availability, maintenance ease, etc. The wide selection of vendors and technologies leads to no de facto standard in building domains, rendering possible technology incompatibilities between domains. Technology incompatibilities can occur in the data plane, which contains a number of switches interconnected by physical interfaces. A path between two domains is possible only if they support at least a similar technology, can adapt between the technology incompatibilities, or if there is another domain with suitable technology adaptation capability between them. Hence, routing between domains is not a trivial task. Examples of technology incompatibilities are:

Architecture incompatibilities(e.g., IP over WDM [14], SONET/SDH over WDM [15], EoS over WDM [16], or Ethernet over WDM [17]) imply the needs for common lowest-layer technology and adaptation feasibility to upper layers.

Switching type incompatibilities(e.g., wavelength, waveband and fibre channel at layer 1, Ethernet, Fast Distributed Data Interface (FDDI) and cell switching (ATM) at layer 2, (Generalized) Multi-Protocol Label Switching and Internet Protocol (IP) at layer 3) can exist at various layers.

Interface incompatibilities(e.g., 1 GE Ethernet can be encapsulated into VC-3-21v SDH, VC-4-7v SDH, STS-1-24c SONET, or STS-3c-7v SONET) imply possible adaptation and deadaptation problems [18].

Rate incompatibilities(e.g., 1, 10, 40, or 100 Gbps) imply the need for data-rate conversion.

Wavelength incompatibilities(e.g., 850, 1310 or 1550 nm) imply the need for wavelength conversion.

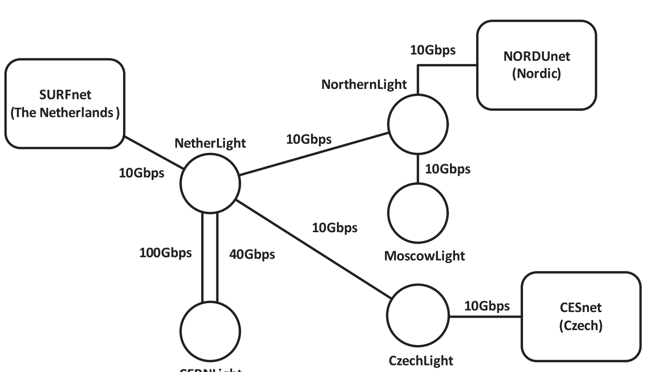

Fig. 1. Example of a multi-domain network.

Since the notion of technology-aware multi-domain multi-layer routing is not yet fully addressed in both IETF PCE framework and OGF NSF, and vendor interoperability issues remain an open research [19], we address this problem in this paper. First, we propose a generic network model that incorporates technology incompatibilities and scales well with the increase of graph size and number of technology incompatibilities. Our network model is applicable for use in modeling variety of technology incompatibilities that can occur in multi-domain multi-layer networks. Our network model would also be a useful addition to existing multi-domain standards, and existing technology representation approaches (e.g. NML [20]). Secondly, we propose exact and heuristic algorithms to find technology-aware loopless path from a source node to a destination node in networks with technology incompatibilities. Although triggered by a realistic problem in the NREN community, our work applies to multi-domain multi-layer networks in general.

The remainder of this paper is organized as follows. Section 2 gives an overview of related work and highlights our contributions. In Section 3, we introduce our network model and give some application examples. In Section 4, we define the problem formally, for which routing algorithms are proposed in Section 5. We present a simulative performance analysis of our algorithms in Section 6, and conclude in Section 7.

2. Related work

In a network with limited wavelength conversion, only a subset of nodes can convert between wavelengths. A path between two distinct nodes is *feasible*[1] if the wavelength of the path is continuous, or if appropriate wavelength conversion is conducted along the path. Chlamtac et al. [21] modeled wavelength incompatibilities by introducing a wavelength graph of NW nodes. The graph contains N columns and W rows, where N is the number of nodes in the original network, and W is the number of wavelengths. Link existence between nodes depends on the wavelength availability (horizontal links), and the wavelength conversion (vertical nodes). Though their work focuses on the intra-domain routing, their model can also be applied to multi-domain networks (see Table 1).

The ITU-T ASON framework does not include any specific control plane protocol, since it was meant to be a generic architectural framework. In the IETF RFC3945 [25], a control plane protocol suite referred to as the Generalized MultiProtocol Label Switching (GMPLS) [26] was proposed to support multi-layer applications that consist of different types of switching technologies. A GMPLS node may support several types of switching technologies, e.g., Packet Switch Capable (PSC), Layer 2 Switch Capable (L2SC), Time

[1] A feasible path faces no technology incompatibility.