

A Framework for Internetworking Heterogeneous High-Performance Networks via GMPLS and Web Services

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ABSTRACT

In this paper we describe a framework for internetworking heterogeneous high-performance networks. We believe GMPLS and Web services will be the proper technologies in such internetworking while the latter will be more widely accepted. We describe Web services for multi-layer, multi-domain topology description and advertisement, routing, path computation, and signaling functionalities as inspired by GMPLS.

I. INTRODUCTION

High-performance networks have become the vital components for many research and education organizations, enterprises and government agencies to conduct large-scale science projects and programs. These networks have high capacity backbones built over optical fibers and provide dedicated high-capacity circuits (or virtual circuits) to interconnect far-apart facilities such as super computers and data storage servers. Most importantly such end-to-end high-capacity circuits can be provisioned or scheduled on users' demand. The on-demand flexibility best fits the dynamic nature of scientific research activities. Due to the high cost of high-performance network equipment, each network can only have limited resources to cover a relatively small footprint as compared to the Internet. It will be of great interest for these networks to interconnect in a manner that dedicated high-capacity circuits can be dynamically created beyond the domain of a single network. There are many benefits in doing so. Firstly, it extends the reach of any individual network. Secondly, based on lease or exchange agreement, users can obtain extra bandwidth without waiting for network upgrade. Thirdly, internetworking can provide temporary detour for high volumes of traffic in some emergency situations. Finally, the interconnected networks can also provide persistent mutual protection of critical services for each other.

Despite their similarity and common interest, however, most existing high-performance networks use heterogeneous networking technologies. The following are some example networks and their networking technologies in use. The Internet2 Hybrid Optical/Packet Infrastructure (HOPI) [2] is a national Ethernet network built over static DWDM connections and can provision high-capacity VLAN circuits in the Layer-2 Switching Capable (L2SC) layer. The Internet2 Abilene network [3] and the DoE Energy Sciences network (ESNet) [5] are pure IP networks that can provision Multi-Protocol Label Switching (MPLS) virtual circuits in the Packet Switch Capable (PSC) layer. The DoE UltraScience Network (USN) [4] is built over SONET cross-connects overlaid with Ethernet switches and is both TDM and L2SC capable. The NSF Dynamic Resource Allocation via GMPLS Networks (DRAGON) testbed [1] supports three network layers, an optical switching and add-drop layer (Lambda Switching Capable (LSC)), a Gigabit Ethernet switching layer (L2SC), and an IP routing layer (PSC). As the result of technology heterogeneity, these networks may not be able to deliver a service continuously across the network boundary. In addition, there is typically an administrative barrier to exclude direct interoperation at the routing and signaling levels. A bottom-line solution is to create static BGP routes between them via an overlaid IP layer, which however only works for 'internetworking' in the sense of lower performance and less flexibility.

The only true multi-layer networking technology currently available is the Generalized MPLS (GMPLS) [11]. GMPLS provides a suite of standard routing and signaling protocols for arbitrary network layers to participate in a unified control plane and co-allocate resources based on a generalized labeling structure. The NSF DRAGON project has developed an open source GMPLS stack and deployed a genuine multi-layer GMPLS network. The Internet2 HOPI has adopted the same technology and realized seamless internetworking with DRAGON in the Ethernet layer. Some networks such as the DoE USN are also working towards this direction. While GMPLS is quite a promising technology with strong standardization and industry support, it has to enforce a 'tight coupling' control plane. Internetworking via GMPLS requires participating networks interoperate with the same GMPLS routing and signaling protocols. Such interoperation requires the participating networks to share topology information (fully or partially) and allocate low-level resources in a continuous signaling process beyond their own administrative domains. However, many existing high-performance networks do not support GMPLS. Some even do not have a network control plane and rely on management plane functions for service provisioning. The GMPLS approach demands heavy reinvestment for these networks to upgrade their equipment, change security infrastructure and consolidate administrative policies, which are practically impossible for many such networks. As a result, a pragmatic internetworking framework must also include a 'loose coupling' approach.

This paper proposes a framework for internetworking the heterogeneous high-performance networks based on the reality discussed above. One of the common characteristics of these networks is use of centralized controllers or schedulers to provision circuits. The examples include NSF DRAGON's NARB [6], DoE ESNNet and Internet2 Abilene's and OSCARS/BRUW [8], CA*net 4's UCLP [9] and SURFnet's DRAC [10]. All have started or plan to provide Web services for users to request circuits within their network domains. Web services emerge as a technology that describes a standardized way for integrating web based applications on the Internet [14]. The technology allows organizations to communicate data without intimate knowledge of each other's IT systems. It appears to be a technology acceptable for networks that want loosely coupled internetworking. The focus of this paper is to introduce a Web Services Control Plane (WS-CP) into the heterogeneous internetworking context. The technology provides the common language and open, standard tools for heterogeneous networks to collaborate on extensive internetworking issues.

The proposed framework is extended from the GMPLS Control Plane (GMPLS-CP). It captures the basic GMPLS functionalities in dealing with multilayer, multi-domain heterogeneous networks and translates such functionalities into Web services notations. Both GMPLS-CP and WS-CP (essentially any control plane for multi-layer networks) should have the following key features:

- **Routing** - distribution of "data" between networks. The data that needs to be distributed includes reachability information, resource usages, etc
- **Path computation** - the processing of information received via routing data to determining how to provision an end-to-end path. This is typically a Constrained Shortest Path First (CSPF) type algorithm for the GMPLS control planes. Web services based exchanges might employ a modified version of this technique or something entirely different.
- **Signaling** - the exchange of messages to instantiate specific provisioning requests based upon the above routing and path computation functions. This is typically a RVSP-TE exchange for the GMPLS control planes. Web services based exchanges might employ a modified version of this technique or something entirely different.

The internetworking framework will also incorporate a distributed resource and service discovery mechanism as well as a common Authentication, Authorization and Accounting (AAA) structure, which are the norm for typical Web services applications and will in turn enhance the existing GMPLS-CP.

The remaining paper is organized as follows. Section II describes the proposed framework for heterogeneous internetworking. Section III presents the design details of a WS-CP under the framework. Section IV discusses the implementation strategies and considerations. Section V concludes the paper.

II. FRAMEWORK FOR MULTI-LAYER HETEROGENEOUS INTERNETWORKING

In this section, we present an architectural description of the framework for multi-layer heterogeneous internetworking.

A. Overview

Our design philosophy for this framework is two-fold. First, the framework should encompass both the tightly coupled GMPLS-CP and the loosely coupled WS-CP. Second, it has a service-oriented architecture. The framework is built over a suite of Common Internetworking Infrastructure Services (CIIS). The CIIS provides a secure communication infrastructure for both GMPLS-CP and WS-CP. It includes a Registration and Discovery component to publish a network's routing, path computation and signaling capabilities to other networks in unified Web service definitions. The Mutual Trust and Policy Exchange components provide common Authentication and Authorization services between networks. The Context Management component provides the mechanism for multiple networks to co-schedule and co-provision services in a transaction style and avoid conflicts. As in a Service-Oriented Architecture (SOA), the CIIS components can be easily implemented based on the standard Web services specifications. For example, the Registration and Discovery component can be based on the OASIS Universal Description, Discovery and Integration (UDDI) [18] or the Globus Monitoring and Discovery Service (MDS) [20] and the security components can be based on the OASIS Web Services Security (WSS) standards [14]. The standard Simple Object Access Protocol (SOAP) [16] will be used for inter-network control plane message exchange. More discussions on CIIS design will be presented in Section IV.

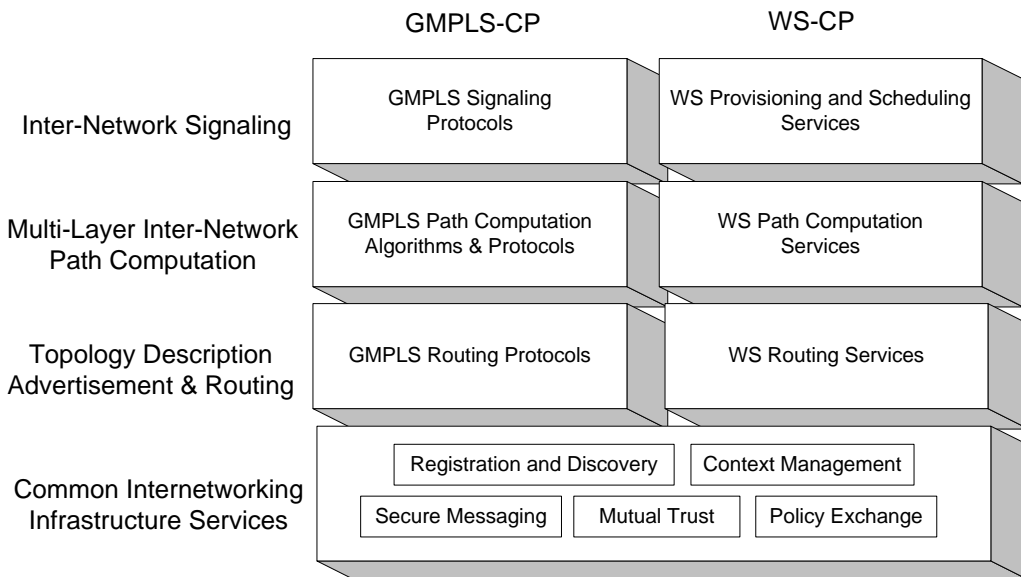


Figure 1: A Framework for Multi-Layer Heterogeneous Internetworking.

Figure 1 shows the relationships between the building blocks of the proposed internetworking framework. The framework is extended from the established GMPLS-CP technologies. Above the CIIS foundation are three hierarchies of functionalities that are translated from the corresponding GMPLS technologies, including (1) multi-layer network topology description, advertisement and routing, (2) multi-layer inter-network path computation and (3) inter-network signaling. Heterogeneous networks that adopt the entire GMPLS-CP stack can have a tightly coupled internetworking. Examples are the Internet2 HOPI and the NSF DRAGON networks. Non-GMPLS networks or networks that deny tightly coupled internetworking due to administrative reasons can adopt a full or partial WS-CP stack. By partial WS-CP stack, we refer to a hybrid internetworking model that uses WS-CP routing and GMPLS-CP signaling.

To support the WS-CP stack, we introduce the following components into the peering network controllers.

- Web service for traffic engineering (TE) aware topology and resource description, advertisement and query
- Techniques for performing path computation based on Web service based topology descriptions
- Web service for circuit service description and query, supporting both on-demand and advance scheduled services
- Distributed end-to-end service discovery with embedded multi-layer multi-domain routing capability
- Web service based inter-network signaling

Design details for the WS-CP will be presented in the next section.

B. Topology Description, Advertisement and Routing

The starting point for multi-layer heterogeneous internetworking is to summarize the traffic engineering (TE) topology of individual networks and advertise the topologies on a global scope. Unlike the IP-layer internetworking that uses BGP for distribution of reachability information, the multi-layer networks need to disseminate some TE attributes, such as link bandwidth information and switching capability description, beyond their local domains. The participating networks only expose a summarized view of their domain topologies in order to both reduce routing overhead and hide interior network details. This dictates a two-hierarchy routing architecture. In the higher level, a summarized or abstract global topology is used for end-to-end inter-network routing. The higher-level routes can then be expanded by individual networks with lower-level details based on the detailed, local topology information.

As a reference GMPLS-CP design, the NSF DRAGON network uses Network Aware Resource Broker (NARB) [6] in each network domain to summarize its intradomain TE information and advertises an abstract topology to other domains. An instance of link-state routing protocol is responsible for flooding the abstract topology information at the interdomain level. NARB in each domain can therefore construct a global topology with summarized TE information. Meanwhile, one instance of link-state routing protocol, say OSPF-TE, runs inside each domain, responsible for flooding physical TE information in an intradomain scope, which allows NARB to construct a local domain topology with detailed TE information. This solution can be easily extended to the heterogeneous internetworking environment by mapping ‘domain’ to ‘network.’

Similar topology description, advertisement and routing functionalities must be defined in the WS-CP using Web services. In particular, an Extensible Markup Language (XML) description of the multi-layer network topology is required. Based on a common XML Schema Definition (XSD) [15], a network resource

description language is desired for the participating networks to describe and advertise their TE topologies towards a summarized global view. In the WS-CP, the inter-network topology advertisement and routing functions are exposed as Web services, defined by Web Services Description Language (WSDL) [17] and published via the Registration and Discovery service in the CIIS. Other networks can query the summarized network topology on demand via the published Web services, which realizes a loose coupling way of topology advertisement as against to the way in GMPLS that topology information is continuously flooded via OSPF-TE or other routing protocols.

C. Multi-Layer Multi-Domain Path Computation

Multiple constraints in multi-layer networks compose a very complex computation space. The multi-domain heterogeneous internetworking environment makes the problem further complicated. There is no standard path computation method or algorithm available for such networks. Nevertheless some common logic can be used to tackle the problem. Firstly, each participating network should obtain a summarized global view of all the network topologies as well as a detailed view of its own local topology and convert and maintain the topologies in an internal TE database. Secondly, each participating network should have a dedicated Path Computation Element (PCE) [13] to compute end-to-end path under plural TE constraints. Thirdly, a collaboration mechanism must be used for participating networks to complement one another's path computation results with further details. With such collaboration, a complete routing path can be assembled with sufficient information for the signaling procedure to set up an end-to-end circuit.

In the NSF DRAGON and Internet2 HOPI GMPLS-CP, both networks have their PCE, called Resource Computation Element (RCE) that maintains a TE database synchronized to interdomain and intradomain OSPF-TE. RCE uses a 3-Dimension Resource Computation Model (3D RCM) to facilitate sophisticated path computation under the three broad types of constraints: multi-layer TE constraints, time scheduling constraints and AAA policy constraints [7]. One collaboration method DRAGON and HOPI network use for interdomain (or inter-network) path computation is called Recursive Per-Domain (RPD) scheme. In RPD, the source-domain RCE initially computes an end-to-end path using both the summarized global topology and the detailed source-domain topology, which results in an explicit route with strict (or physical) hops in the source domain and loose (or abstract) hops in other domains. Each RCE asks its next-domain RCE to expand the remaining loose hops. The expanded strict hops are recursively appended to the strict hops in the previous domains until an all-strict-hop explicit route is obtained.

Similar logic can be adopted by the WS-CP. Actually the whole path computation core can be reused. The WS-CP needs the following additions. The XML formatted topology description metadata should be translated into the internal PCE TE database and kept updated. An intradomain (or intra-network) path computation Web service should be provided by each participating network to assist collaborative end-to-end path computation. The supported collaboration capability for inter-network path computation should be explicitly published by each network. RPD is just one option. Since the Web services based topology description and advertisement provides more flexibility in locating global resources, one possibility is to expand the summarized routing paths from several downstream networks in parallel.

D. Inter-Network Signaling

Once an explicit route is obtained, a signaling procedure will be kicked off to set up the circuit. This is the physical provisioning phase, in which GMPLS-CP and WS-CP behave differently. In GMPLS-CP, a signaling protocol, e.g. RSVP-TE, will be invoked to allocate and associate resources along the routing path across multiple network layers and domains. GMPLS-compatible equipment can automatically adapt traffic from one network layer to another, e.g., from PSC to TDM and from L2SC to LSC, based on the

generalized label switching architecture. This could be done in a contiguous way at the network boundary if the adjacent switches are fully interoperable at the signaling level. Two networks by different system vendors or of different carriers may not interoperate in a contiguous way even if they are both GMPLS networks. They can use the Optical Internetworking Forum's (OIF) External Network Node Interface (E-NNI) signaling protocols [12] to stitch their segments of Label Switched Path (LSP) into an end-to-end one.

In the WS-CP, the loosely coupled networks do not send signaling messages across networks to create the end-to-end circuit. Instead the involved networks on an explicit route will participate in a co-provisioning procedure. To do that, each network needs to expose their provisioning capability as Web services under a common service definition. The distributed provisioning services can be requested by the originating network controller to create a sequence of path segments. The originating network controller or service requestor will be responsible to maintain the provisioning context via the Context Management service and assemble the segments into an end-to-end circuit. GMPLS signaling protocols such as RSVP-TE use soft-state messages to keep an established circuit alive until it is torn down or some error occurs. A similar keep-alive mechanism should also be provided by the WS-CP.

One challenge for the WS-CP signaling or co-provisioning is that there is no standard way to stitch the heterogeneous path segments from different networks. Without a GMPLS-style switching architecture, most routers and switches cannot perform inter-layer adaptation automatically. For example, a Juniper IP router cannot determine how to map an Ethernet VLAN from one link to an IP MPLS tunnel in another unless it is manually configured using some vendor-specific feature, such as Circuit Cross Connect (CCC). Therefore, such adaptation capability also needs to be explicitly exposed as Web services for other networks to use under unified definitions.

In inter-network signaling, we only consider on-demand provisioning. A great number of applications require advance reserved or pre-scheduled circuits. WS-CP should of course provide advance scheduling in the form of Web services. This simply adds a co-scheduling phase before the signaling phase. We leave this topic to be discussed in other papers.

III. WEB SERVICES BASED INTERNETWORKING AND CONTROL PLANE DESIGN

The internetworking technologies in the GMPLS-CP stack are currently available via the established IETF standards as well as some experimental implementations such as the NSF DRAGON open-source GMPLS stack. Their counterparts in the WS-CP stack have yet to be developed. In this section, we explore the technical details for design of the WS-CP based on the standard Web services technologies.

A. WS-CP Architecture

Figure 2 shows a high-level overview of the WS-CP architecture from an individual network perspective. Each network has a centralized controller that supports a set of core networking functions that are based on GMPLS or non-GMPLS implementations. These network control or management functions have been explained in Section II. A WS-CP reuses these functions by wrapping them with a Web services layer. Some core networking functions may not be directly mapped into Web services notations and translation is required. For example, a Network Description Language (NDL) [23] can be used to translate between the XML metadata that describes the network topologies based on the W3C Resource Description Framework (RDF) [21] and the internal TE data that are typically structured for a link-state routing protocol. Some functions may have to be added in the networks that do not have a control plane. Each network should also implement the CIIS services that build a common shared secure communication infrastructure with other networks.

Each network registers with UDDI as a unique organization and publishes the internetworking related Web services in common WSDL definitions. An alternative to UDDI is the Globus MDS. The UDDI can be on a commercial server or a shared private one that is available for all the participating networks. A network can find other networks by searching the UDDI server. A more reliable way is to allow two adjacent networks to exchange their UDDI keys and the CIIS Registration and Discovery service provides a *getNetworkList* operation to populate all the known UDDI keys to other networks. Any participating network can use the *getNetworkList* operation recursively to get all the UDDI keys, which lead to the Web services published by all other participating networks.

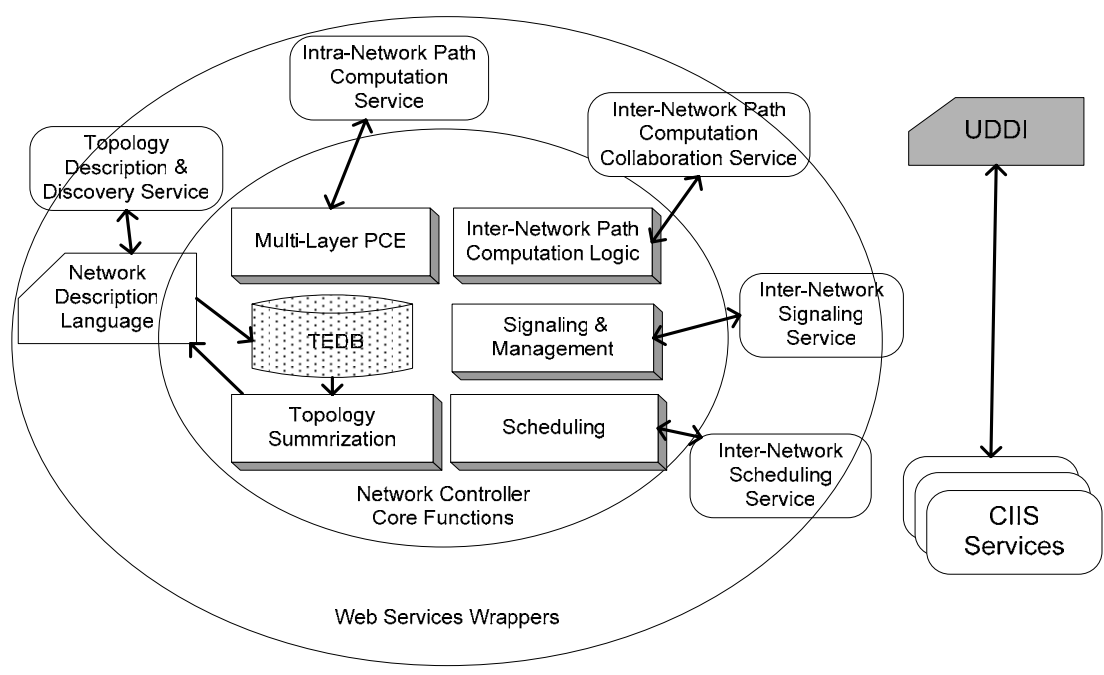


Figure 2: A Web Services Based Internetworking Control Plane Architecture.

The WS-CP internetworking starts with the participating networks invoking one another's Topology Description and Discovery service. A circuit provisioning process starts with the source network obtaining a high-level explicit route to the destination based on the global topology view. Then the Inter-Network Path Computation Collaboration service can be invoked to determine the inter-network path computation method and coordinate the physical provisioning procedure. The Intra-Network Path Computation service is used to expand the high-level explicit route with local details in other networks. The Inter-Network Scheduling service is an interface to local network scheduler for advance circuit reservation while the Inter-Network Signaling service is the interface to the local network signaling or management module. Details of individual Web services included in the WS-CP architecture are described in the following subsections.

B. Topology Description Service and Inter-Network Topology Discovery

A network topology can be described using a common network topology description language. One example is the University of Amsterdam's NDL [22] that currently supports a single TDM layer and is in progress towards a multi-layer schema. The topology description service definition consists of the following operations.

A *getNetworkTopology* operation returns the full description of domain topology in NDL format.

`<wsdl:operation name="getNetworkTopology">`

A *getNetworkRouterList* operation returns the full or partial set of router IDs in the network.

`<wsdl:operation name="getNetworkRouterList">`

A *getInterNetworkLinkList* operation returns the inter-network link descriptions.

`<wsdl:operation name="getInterNetworkLinkList">`

A *getAdjacencyNetworkList* operation returns a list of links that point to the Topology Description services in the adjacent domains or networks. The operation can be used to recursively explore the entire inter-network topology.

`<wsdl:operation name="getAdjacencyNetworkList">`

To reduce the overhead, a *getNetworkTopologyDelta* operation can be used to only retrieve the updated portion of a network topology.

`<wsdl:operation name="getNetworkTopologyDelta">`

C. Intra- and Inter-Network Path Computation Services

The Intra-Network Path Computation service definition has the following operations.

A *getPathComputationResult* operation supports both persistent path computation for regular provisioning and time-constrained path computation for advance scheduling. The operation returns an explicit route description or an error message. In addition, an *Adaptation Description* for ingress and egress links should also be returned, given that a multi-layer path computation is requested. The *Adaptation Description* will provide further information to form the appropriate signaling service request, which we will discuss in the next subsection.

`<wsdl:operation name="getPathComputationResult">`

A *getPathComputationResultAndHold* operation will place an exclusive lock on the resources along the resulting explicit route. This is useful for two-phase provisioning that firstly makes sure the resource availability and avoids race condition.

`<wsdl:operation name="getPathComputationResultAndHold">`

A *revokePathComputationResult* operation will delete the exclusive lock and release the held resources.

`<wsdl:operation name="revokePathComputationResult">`

The Inter-Network Path Computation service has the following operations.

A *getInterNetworkPathComputationCapability* operation queries the inter-network path computation schemes supported by other networks.

`<wsdl:operation name="getInterNetworkPathComputationCapability">`

A *createInterNetworkPathComputationSession* and *deleteInterNetworkPathComputationSession* operations are used to create and delete an inter-network path computation context.

`<wsdl:operation name="createInterNetworkPathComputationSession">`

<wsdl:operation name="deleteInternetnetworkPathComputationSession">

A *getRecursivePathComputationResult* operation perform a RPD path computation as explained in Section II.C. Other inter-network path computation operations will also be defined in future.

<wsdl:operation name="getRecursivePathComputationResult">

D. Inter-Network Signaling Service

The Inter-Network Signaling service definition has the following operations.

A *getSignalingCapability* operation returns the type of signaling method and inter-layer adaptation method supported by the network.

<wsdl:operation name="getSignalingCapability">

A *createPathReservation* operation creates the physical path segment based on the explicit route in the path computation results.

<wsdl:operation name="createPathReservation">

A *createAdaptationCrossConnect* operation performs additional work for non-GMPLS ingress and/or egress switches to create internal cross-connects and adapt traffic between network layers.

<wsdl:operation name="createAdaptationCrossConnect">

The *confirmPathReservation*, *deletePathReservation*, *reportPathReservationError* and *refreshPathReservation* operations perform path reservation confirmation, deletion, error report and refreshing in a way analogous to what RSVP-TE does in the GMPLS-CP.

<wsdl:operation name="confirmPathReservation">

<wsdl:operation name="deletePathReservation">

<wsdl:operation name="reportPathReservationError">

<wsdl:operation name="refreshPathReservation">

VI. IMPLEMENTATION STRATEGIES AND CONSIDERATIONS

In this section, we discuss the implementation issues for existing networks to participate in heterogeneous internetworking under the proposed framework.

A. Control Plane Implementation Strategies

The proposed internetworking framework provides three options for control plane implementation, including GMPLS-CP, WS-CP and hybrid-CP. Internetworking via GMPLS-CP is a good choice for the networks that have implemented the full GMPLS routing and signaling stack. They will need to expose their summarized TE topologies to each other via a common link-state routing protocol, which is separated from their interior routing protocols. Also either a contiguous or E-NNI-style GMPLS signaling protocol must be supported across their network boundary. Currently, the Internet2 HOPI and NSF DRAGON networks have GMPLS-CP internetworking built on the common DRAGON GMPLS Software Suite. Internetworking via a GMPLS-CP provides precise low-level control and very fast provisioning speed. However, the networks with GMPLS-CP have to implement a basic set of WS-CP features in order to interoperate with the networks that use WS-CP. In other words, when heterogeneous internetworking is desired, GMPLS-CP should be wrapped in a Web services layer as depicted in Figure 2. Such wrapping can be relatively easily implemented in the GMPLS networks which usually have the full set of built-in core functions required by the WS-CP as described in Section III.

For the networks that only use a central controller for networking monitoring and provisioning, the WS-CP implementation is a natural choice. This is particularly true for those that rely on Network Management Systems (NMS). WS-CP carries more control overhead and is slower than GMPLS-CP but it is less equipment and protocol dependent. A tradeoff between GMPLS-CP and WS-CP is the hybrid-CP. Some networks are actually constructed with routers and switches that can support GMPLS signaling by simply turning on the related features or upgrading controlling software. They may choose a hybrid-CP with the WS-CP routing and path computation and the GMPLS signaling. They could therefore minimize the development cost and enjoy the benefit of fast GMPLS signaling. It is worth noting that unlike a fully GMPLS-capable network, such networks must extend their internal control code to implement the logic for multi-layer, inter-network topology discovery and path computation.

B. CIIS Implementation Considerations

The security related CIIS services such as secure messaging, mutual trust and policy exchange can be implemented under the WSS architecture. Security is the common concerns for all the networks participating in heterogeneous internetworking. Many such networks are also committed to the emerging distributed and grid computing technologies such as Globus and are willing to adopt and promote the standard WSS architecture. We believe that there will be sufficient standardization and development tool support for the relevant implementation.

The implementation of Registration and Discovery service can be based on the mature UDDI technology or the Globus MDS technology. Additional logic will be added for recursive exploration of the entire internetworking environment and for automatic service registration and notification of service changes. The Context Management service may be based on the Web services Transaction (WS-Transaction) and Coordination (WS-Coordination) specifications [24]. Since these specifications are designated for e-Business transactions, some simplification can be expected in actual implementations.

B. Performance Issues

Performance is a common concern on the implementation of a WS-CP. Traditionally a network control plane is considered as a plane of fast lanes for control messages to flow. The XML-formatted topology description metadata could be bulky in size and take a lot of computation cycles to translate. The new WS-RDF specification allows for retrieval of a selective portion of metadata each time so that the communication and processing overhead can be greatly reduced. The real challenge is to define a well formatted resource description structure such that a set of related network resources, e.g. the TE links within a specified area and/or in a specified layer, can be quickly located and retrieved.

Another issue is that the current Web services lack a 'push' style of information exchange mechanism. Resource and service information is located in the service provider's site and explicitly queried and 'pulled' by users into their domain. There is no way to realize the information 'push,' which is the norm in the GMPLS-CP routing advertisement, e.g., OSPF-TE flooding, and signaling, e.g., RSVP-TE messaging and error notification. This is one of main reasons that WS-CP is slower than GMPLS-CP. Fortunately, the development of Web services 'push' technologies has already been in progress. The work is being reflected in the specifications, such as WS-Notification and WS-Eventing [25]. Such technologies will be included in the WS-CP in future as the heterogeneous internetworking framework evolves.

V. CONCLUSIONS

In this paper, we addressed the problem of internetworking heterogeneous high-performance networks. We proposed a framework for multi-layer heterogeneous internetworking that encompasses both GMPLS-CP and WS-CP. The proposed WS-CP provides a loosely coupled internetworking solution for heterogeneous networks that cannot support direct interoperation due to technical and administrative reasons. The WS-CP is built over the standardized Web services for multi-layer, inter-network topology description and advertisement, routing, path computation, and signaling as inspired by GMPLS-CP. We believe that both GMPLS and Web services will be the proper technologies in such internetworking while the latter will be more widely accepted. Some implementation strategies and considerations were also discussed in this paper.

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