Network Virtualization Server for Adaptive Network Control

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***Abstract*—This paper considers the virtualization technologies of an optical network infrastructure and the design of related systems. The objective of our research project is i) to develop a network virtualization server that providing the functionality of virtualizing optical network resources and ii) to demonstrate the network infrastructure accommodating multiple service networks using in conjunction with existing GMPLS technologies. In this article, we introduce the network virtualization technology on an optical network infrastructure and also present the design of a server platform and the specification of an inter-system interface.**

I. Introduction

Considering the increasing variety of network services and customer needs, optical network infrastructures should support the extensibility that enables rapid provisions of diversified service networks. Network virtualization is one key technology for this purpose. Here, network virtualization is a mechanism for running multiple networks, which are customized to a specific purpose, over the shared infrastructure[8]. However, existing virtualization technologies assume a packet-based network as the infrastructure , which may deteriorate network performance and stability due to interference by other service networks. To avoid this issue, we consider WDM (Wavelength Division Multiplexing)-based network virtualization with adaptive network control, as shown in Fig. 1. Here, resources on the optical network are shared by multiple virtual networks, but each of wavelength channels is dedicatedly allocated to one virtual network, which corresponds to one service network.

Resource contention resolution and dynamic topology optimization mechanism are essential for achieving the stable and efficient accommodation of multiple virtual networks. Multiple virtual networks share common network resources, which can cause unexpected resource contention among virtual networks. The resource contention mechanism adequately resolves the contention among virtual networks and maximizes the performance and stability of multiple virtual networks. Moreover, the network infrastructure should provide enough robustness under unpredictable network condition changes. The network should accommodate unexpected traffic demand changes due to the dissemination of new emerging network services and also topology changes caused by equipment failures or disasters. The dynamic topology optimization mechanism adaptively reallocates network resources in each virtual network in accordance with environmental changes such as traffic demand variations and network failures.

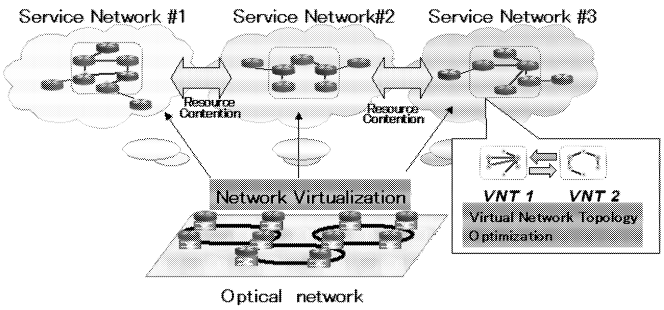

Fig. 1. Optical network accommodating multiple service networks

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II. Network virtualization

Considering an optical network infrastructure accommodating various diversified service networks, the network is expected to have the following properties; i) traffic demand is highly fluctuating and unpredictable and thus ii) a congested link in the network is erratic over the time. By introducing adaptive network control into the network infrastructure, the infrastructure can efficiently accommodate such unpredictably fluctuating traffic demand. In addition, by multiplexing multiple service networks on the common infrastructure, we can achieve the efficient resource usage of the infrastructure. The key lies in network virtualization technology with adaptive network control.

A. Concept of VNT

We assume that a network consists of electronic IP routers and optical cross-connects (OXC), as illustrated in Fig. 2. Note that we mainly consider IP as an upper layer in this paper, but the same discussion can be applied to Ethernet or any packet/frame-based interface. Each port of edge IP routers is connected to an OXC port. Traffic that is carried on the network between IP routers is carried over WDM links. A wavelength path is established between two IP routers by configuring OXCs along the route between the routers. The path is terminated at the transceiver of the last IP router, and the path is handled as an IP link in the IP layer network.

A set of wavelength paths forms a VNT, and traffic between two routers is routed on top of the VNT using MPLS explicit-routing technology. The VNT provides connectivity among IP routers for efficiently handling IP-layer traffic demand. By adequately configuring VNT, we can accommodate unpredictably fluctuating traffic or improve reliability upon network failure. Thus, VNT is a useful tool for achieving sophisticated traffic engineering within a service provider's network.

Dynamic topology optimization (also called as VNT reconfiguration) is able to optimize network resource utilization considering all layers, rather than optimization at each layer independently. IP routes and OXCs are managed and operated under the traffic engineering server considering network resources of both layers [6], [7]. The server computes path routes across different layers and control paths upon requests from users and operators. The server dynamically reconfigures an IP network topology that consists of several optical paths, VNT, according to traffic-demand fluctuation and network failure.

B. VNT-based Network Virtualization

VNT is one of the key technologies for realizing network virtualization on optical network infrastructures. Fig. 3 illustrates an overview of the virtualized optical network. Optical network resources are shared by multiple virtual networks; but virtual networks are isolated and separated by dedicatedly allocating a whole channel of WDM-based links to some virtual network. This can adequately avoid performance degradation due to performance inference by other virtual networks. Dynamic topology optimization on each virtual network is carried out based on VNT technology. Each VNT is controlled and managed in accordance with operational requirements and traffic demand of each virtual network. For a given traffic-demand matrix, we can compute an optimal VNT that minimizes network-resource consumption while satisfying the requirements of an virtual network.

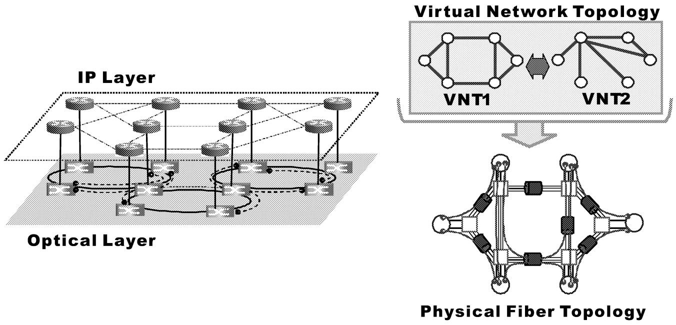

Fig. 2. Optical network infrastructure consists of IP and optical-layer networks. A set of wavelength paths, VNT, forms a logical topology of the IP network. VNT is reconfigurable in response to traffic-demand changes or network failures for achieving better network performance.

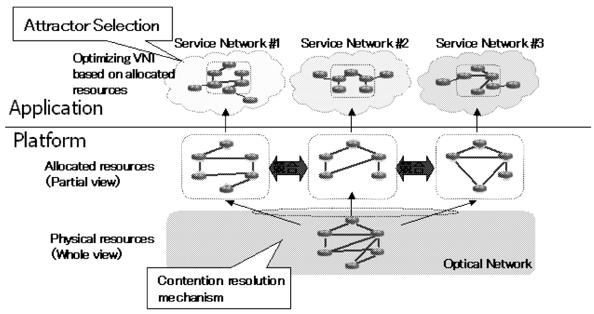

Fig. 3. Overview of network virtualization in optical network infrastructure.

Several studies have investigated VNT design algorithms [1]. However, we need to consider unpredictable traffic demand changes in computing a VNT. Conventional VNT algorithms are not suitable for this purpose. We thus developed a new VNT control algorithm that can provide the adaptability for network status changes while maintaining the almost same optimality as existing algorithms. The algorithm is called as an attractor selection-based VNT control algorithm [2].

C. Resource contention resolution

In Fig. 1, network virtualization is applied to the optical network infrastructure, where resources of the network are virtually separated and a part of the resources is allocated to three service (virtual) networks (1, 2 and 3). Each service network performs adaptive network control and dynamically reconfigures its VNT in response to network environmental changes such as traffic demand changes and network failures. Occasionally, resource contention among multiple service networks inevitably occurs due to the limitation of network infrastructure resources. For resource contention resolution, our approach does not require any direct interaction between a pair of virtual networks. The optical network infrastructure computes adequate resources to each virtual network by considering past and current traffic demand. Network resources in the infrastructure are shared by multiple VNTs, each of which is exclusively allocated to a virtual network. The server just informs residual resources to a virtual network in order to maximally utilize network resources for better performance of each virtual network while avoiding the exhaustion as well as contention of infrastructure resources. In this way, the server indirectly performs resource contention avoidance in coordination with network control of virtual networks. We believe our approach can avoid unnecessary communications between virtual networks, which improves the robustness of the total systems.

Main features and advantages of our proposed architecture, network virtualization on the optical network infrastructure, can be summarized as follows;

- By slicing resources on optical network infrastructure and allocating some of them to each virtual network exclusively, the infrastructure accommodates multiple virtual networks,
- Because each of wavelength resources is dedicatedly allocated to some virtual network by a control server, we can achieve fair resource allocation without causing unexpected resource contention among virtual networks.
- To improve the robustness and resource efficiency of a network infrastructure under environmental changes, resource allocation to virtual networks and a virtual network topology configuration are dynamically reoptimized.

III. Network Virtualization Server

A. System Architecture

Here, we present the design of a network virtualization server platform that provides resource contention resolution and dynamic topology optimization mechanisms. The system architecture is illustrated in Fig. 4. For efficient software development and flexible modification of network control algorithms, we deploy a vertically separate system architecture. The system composes of a server platform and an application server; the server platform provides network virtualization with a resource contention resolution and common network control and management function such as topology information collection and GMPLS network control; the application is tailored to provide a dynamic topology optimization function. The server platform provides network status information to the application over an open XML-based interface. Note that network status information highly depends on deployed protocols and network equipment, which complicates the development of algorithms on the application. Thus, the server platform converts such physical information into logical information.

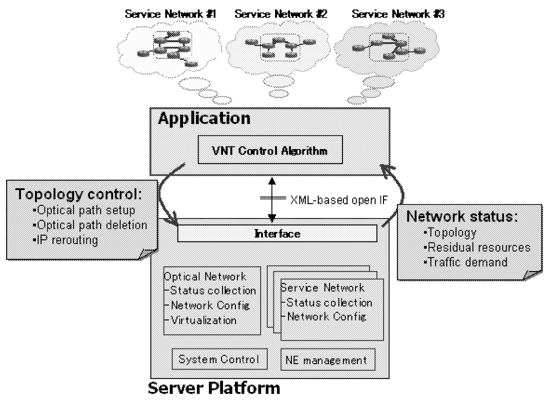

Fig. 4. Proposed system architecture.

In addition, the server platform provides a resource contention resolution mechanism, where the platform computes adequate resources to each virtual network by considering past and current traffic demand. The server platform just informs residual resources to a virtual network. In this way, the server platform indirectly execute resource contention avoidance in coordination with network control of service networks.

B. Adaptive network control mechanism

As for the application, our research group has developed attractor selection-based VNT control mechanism, which is inspired by biology [2]. The mechanism has been being implemented on the application server. The attractor selection-based VNT control adapts to environmental changes by selecting attractors using stochastic behavior, deterministic behavior, and simple feedback. The dynamic system that is driven by the attractor selection uses noise to adapt to environmental changes. In the attractor selection, attractors are a part of the equilibrium points in the solution space in which the system conditions are preferable. The basic mechanism consists of two behaviors, i.e., deterministic and stochastic behaviors and can be formulated as shown in Fig. 5.

In order to apply the attractor selection to VNT control, we consider the gene regulatory and metabolic reaction networks as optical and service overlay networks, respectively. The relationship is illustrated in 6. In this model, we would like to improve the performance of virtual networks by adequately configuring VNT. The important thing here is how to model a VNT control mechanism and select appropriate parameter and function in the basic formulation

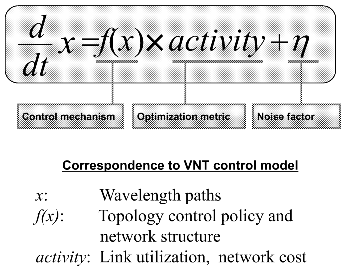

Fig. 5. Basic formulation of attractor selection-based control.

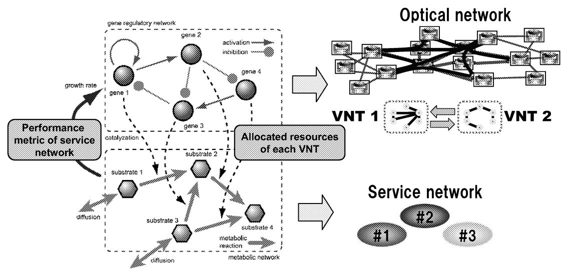

Fig. 6. Application of attractor selection to VNT control.

of attractor selection. In the formulation, x is an variable, thus we would like to improve a performance metric by finding better solution x. In the network model, variable x corresponds to a link resource or a wavelength path in the optical network. Next, function $f(x)$ is related to control mechanisms or protocols in the optical network. More specifically, $f(x)$ represents a topology control policy for an efficient and stable network control. The term *activity* is defined as a performance metric and corresponds to the throughput of virtual networks or link load in the optical network. Finally, the term η expresses stochastic behavior of the attractor selection and is important to ensure the environmental changes and avoid stacking local optimum. For the detailed formulation, please refer to [2].

C. Interface Specification

Here, we describe an application-program interface (API) of our proto-type server platform. In order to enable adaptive network control, the platform provides the following interface to its application. The interface is summarized in Table I. The application obtains network status information which includes network topologies with residual bandwidth for both optical and virtual networks and traffic matrix information of each virtual network through this API. Furthermore, the application orders network configuration changes by setting up or deleting Layer 1/MPLS paths. For the simplicity of an application server design, the server platforms conceals protocol-dependant information such as IP addresses and GMPLS-related parameters, and the application just handles a logical common network model which is independent of network protocols and layers. By combining above APIs, an application can carry out adaptive network control without GMPLS-related control function.

TABLE I
Server-application interface.

No.	API name	Description
1	Network status information notification	Inform information about network topology with residual resources, optical paths and packet layer routing.
2	Traffic information notification	Inform information about measured traffic matrix.
3	Resource allocation	Perform resource reallocation to service networks, and request additional resources by service networks.
4	L1/MPLS path control	Request the establishment or deletion of Layer 1 or MPLS paths.
5	Status change notification	In case of network status changes (e.g., failure or congestion), the server notify network status changes to an application.
6	Utility	Send Logs.

IV. Related Work

In this section, we refer to related work regarding network virtualization technologies. Recently, several projects have intensively conducted research and development of network architecture that provides network virtualization based on an overlay network, especially in North America. CABO [8] is one major test-bed on network virtualization and they provides to their users a part of underlay network resources as virtual nodes or links.

PlanetLab [9] is also known as famous testbed on network virtualization. PlanetLab develops and operates overlay network which are physically constructed over IP networks. In PlanetLab, virtualized resources are a set of Linux PC servers and they enables virtualization through software technologies. which restricts network performance (e.g., throughput and latency).

To solve performance issues, Turner *et al.* have studied performance improvement by hardware technologies [10]. They combined Linux PC server with network processors and implements performance-critical services like packet processing function onto network processors. Though their approach scales well and achieves much better performance compared to existing projects, they just offers a service network over conventional packet networks. This implies that different service network shares the common packet network and the performance of service networks is restricted by existing packet network technologies.

In existing research projects such as CABO and PlanetLab, a common packet network infrastructure accommodates multiple service networks, which deteriorates network performance and stability due to interference by other service networks. In our architecture, by slicing resources on optical network infrastructure in the unit of wavelength and allocating some of them to each service network exclusively, which leads to improved robustness and resource efficiency of a network infrastructure under environmental changes. This is main advantages of our proposed architecture.

V. Conclusions

This paper presented the design of a network virtualization server platform with attractor selection-based network control. We believe an adaptive network control mechanism improves the stability and flexibility regarding bandwidth utilization as well as a network operation. This paper is mainly focused on the architectural considerations. Our future work will include the development of the server platform in conjunction with resource contention resolution mechanisms.

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References

[1] B. Mukherjee, et al., "Some principles for designing a wide-area WDM optical network," Networking, IEEE/ACM Transactions on vol. 4, no. 5, pp.684-696, Oct. 1996.

[2] Y. Koizumi, et al., "Application of Attractor Selection to Adaptive Virtual Network Topology Control," in Proceedings of BIONETICS 2008, Nov. 2008.

[3] K. Shiomoto, E. Oki, W. Imajuku, S. Okamoto, and N. Yamanaka, "Distributed virtual network topology control mechanism in GMPLS-based multi-layer/region networks," IEEE Journal of Selected Areas in Communications, vol. 21, no. 8, pp. 1254-1262, October 2003.

[4] K. Shiomoto, E. Oki; D. Shimazaki, T. Miyamaura, "Multi-layer traffic engineering experiments in MPLS/GMPLS networks,", Page(s): 291-293, BROADNETS.2007, September 2007.

[5] J. Wey et al, "Network control and management for the next generation Internet," IEICE Trans. Commun., vol. E83-B, no. 10, October 2000, pp. 2191-2209

[6] E. Oki, J.L. Le Roux, A. Farrel, "Framework for PCE-Based Inter-Layer MPLS and GMPLS Traffic Engineering," IETF draft, draft-ietf-pce-inter-layer-frwk-04.txt, July 2007. (work in progress)

[7] E. Oki et al., "PCC-PCE Communication Requirements for Inter-Layer Traffic Engineering," draft-ietf-pce-inter-layer-req-05.txt, July 2007. (work in progress)

[8] Nick Feamster, Lixin Gao and Jennifer Rexford, "CABO: Concurrent Architectures are Better Than One", http://www.nets-find.net/Funded/Cabo.php

[9] "PlanetLab", http://www.planet-lab.org/

[10] J. Turner, et. Al., "Supercharging PlanetLab - A High Performance, Multi-Application, Overlay Network Platform,"in Proc. of ACM Sigcomm 2007, Kyoto, Japan, August 2007.