4-3 Experiments of a Terabit-Class Super-Network

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We propose the cooperative multi-layered traffic engineering technologies. Our technologies are designed to achieve the scalability goal of the “e-Japan Strategy” of Ministry of Internal Affairs and Communications in which a terabit-class network can accommodate about 40 millions of broadband users. We report the experiments of the Terabit-class Super-network using prototype systems.

Keywords
Optical-path control, OUNI, GMPLS, Traffic engineering, Cut-through, CDN

1 Overview of research and development

The goal of the e-Japan Strategy of the Ministry of Internal Affairs and Communications is to construct a network environment capable of providing full-time, high speed Internet access to 30 million households and ultra-high speed access to 10 million households. To achieve this goal, it is essential to enhance the transmission performance and expand the endpoint capacity of IP networks.

Studies on optical-path transmission technologies are currently being conducted with the aim of enhancing transmission performance. Since optical-path transmission is a point-to-point transmission technique, it is necessary to develop dynamic control technologies for optical-path prior to its application to IP networks, which are point-to-multipoint transmissions. One of the technologies being focused on for such optical-path control technology is GMPLS (Generalized Multi-Protocol Label Switching), a signaling technology that makes use of IP addressing. In addition to the signaling technology, a variety of related technologies such as IP routing technology, etc. must be brought together in order to construct an IP network. In particular, it will become necessary to dynamically establish and/or remove optical paths and to optimize the optical-path configuration itself in response to variations in IP traffic or requests from applications, in order to achieve higher-speed IP network access.

As such, we herein propose cooperative multi-layered traffic engineering technologies as candidates satisfying the demands for the control technologies of the Terabit-class Super-network[1]. These technologies feature centralized control and management of the IP network, achieved by linking the layers between the application layer and the optical-path layer, which maximizes the total throughput of the entire network with the required minimum transmission resources.

2 The network architecture

The network tested in the experiment consists of the core network, access network, and control network, as shown in Fig. 1.

The core network has a layered structure in which the router network overlays the opti-

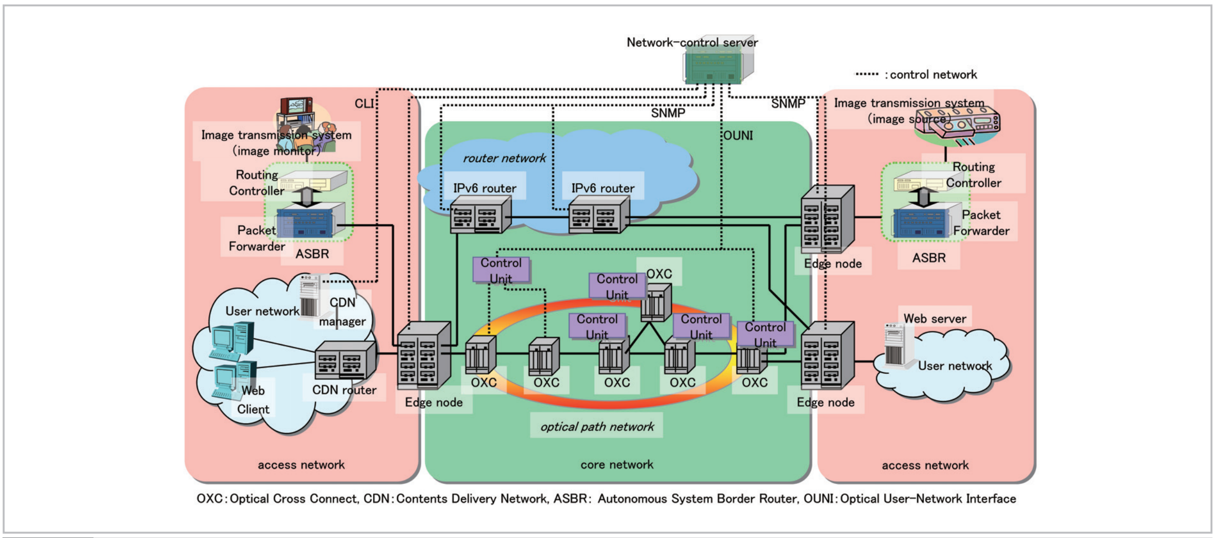

Fig. 1 *The network architecture*

cal-path network and connects the edge nodes, which accommodate the subscribed users. The optical-path network employs an optical router consisting of an OXC (Optical Cross Connect) and its control unit and is connected to the edge nodes using 2.4 G-POS (Packet over SONET). Here, two types of optical routers were used–a distributed control type router[2] and centralized control type router[3]. The router network consists of two IPv6 router units.

The access network consists of a CDN router[4], which carries out cache-hit judgment of web data[4], a CDN manager, which makes requests on the optical paths, a web server, and a web client terminal. Furthermore, a router with enhanced path-control functions [referred to as the ASBR (Autonomous System Border Router) in this paper] was also deployed[5] and connected to image transmission systems (image sources and image monitors). The 1000 BASE-SX was used for the connection between the edge nodes and the access network.

The control network consists of a network-control server, CDN manager, IPv6 router, edge nodes, and control unit of optical routers connected by 100 BASE-T. Here, the interface between the network control server and CDN manager was the CLI (Command Line Interface), and that between the network control server and IPv6 and edge routers was the SNMP. Furthermore, the connection between the network-control server and the control units of the optical-router was made by OUNI (Optical User Network Interface) by concentrating the control functions on the edge nodes performing the optical path controls as proxy functions on network-control servers[6].

3 Traffic-driven optical-path control experiment

The traffic-driven optical-path cut-through control technology optimizes the configuration of the optical paths between edge nodes so that the total throughput within the network is maximized based on information on traffic loads within the core network. The experiment was conducted in the following steps (see Fig. 2).

(1) First, we checked the image quality of the IPv6 transmission during nominal network conditions and the deterioration of quality during periods of router congestion.

In the experiment, the image transmission system under the ASBR was used to transfer an image through the IPv6 transfer path via the IPv6 router, and it was confirmed that the image quality was good, with no apparent image degradation. Then, an external load was placed on the IPv6 router to create a congested state, and it was confirmed that degradation

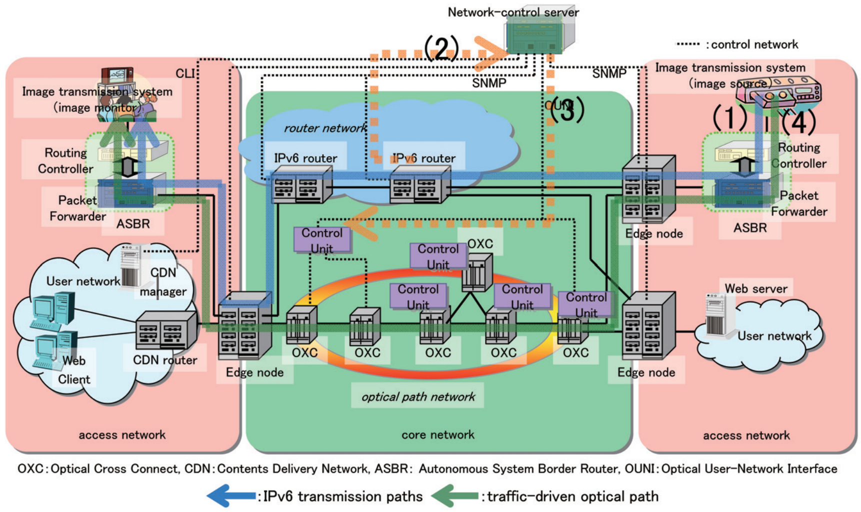

Fig.2 Outline of the traffic-driven optical-path cut-through control experiment

was observable in the images transmitted via IPv6 transmission paths.

(2) Next, we checked the traffic information collection, determination of the flow creating the congestion, and the identification of the edge nodes on both ends of the flow using the network-control servers implemented in the present study.

The network-control server collects the IPv6 router traffic information via polling at 30-second intervals, and the obtained traffic information is used to identify congestion in the IPv6 router as well as to identify the flow causing the congestion. Furthermore, the edge nodes on both ends of the flow were detected in order to execute the optical-path control described in a later section.

(3) Then, we examined the feasibility of improving the efficiency of network controls by establishing autonomously dispersed optical paths between optical routers, even for cases in which optical path allocations for the entire network are performed as a centralized function of the network-control server.

The network-control server makes a request to the control unit on the OXC adjacent to the edge routers detected above to carry out cut-through optical-path controls by OUNI. This triggers the autonomous cut-through optical-path establishment between control units on the OXC to be made by GMPLS optical-path establishment signaling based on the request. Figure 3 shows how the optical-path establishment signaling is made during this process. This is a screenshot taken by the GMPLS ATViewer[7] displaying the optical-path established when the OUNI signaling packet is captured in real-time.

(4) We investigated the effect of optical-path establishment on image data.

It was visually confirmed that the image quality recovered when the flow on the congested IPv6 transmission path causing the deterioration was switched over to the cut-through optical path established above. In this case, the image data was transferred to the established optical path in a little under one minute after congestion had been generated by applying the external load on the IPv6 router. However, it only took approximately 3 seconds to establish the optical path and switch over the traffic in the IP layer after the request was placed to establish an optical path.

The results of the above experiment verified the effective operation of the traffic-engineering control and optical-path control by the network-control server based on traffic load information.

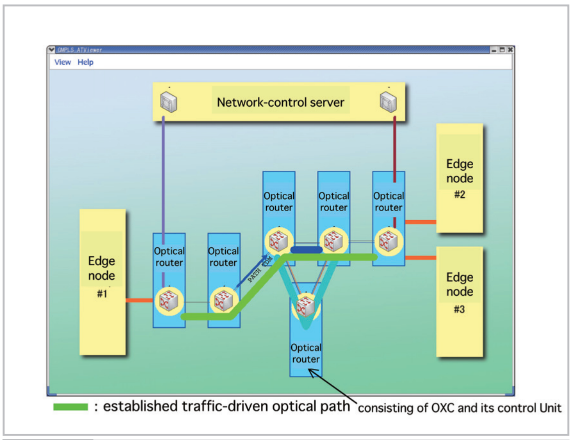

Fig.3 A screenshot displaying the condition of the optical-path established using GMPLS ATViewer

4 Application-driven optical-path control experiment

Application-driven optical-path cut-through control technology establishes optical paths between edge nodes to carry out data transmission in response to requests made by user applications. In the present experiment, large-volume data transmission via the optical-path network was enabled by making the CDN manager explicitly request the network-control server to establish/remove the cut-through optical paths according to the result of cache lookup at the CDN, as described above.

In this control scheme, a "policy control" is made, in which the application-driven cut-through optical path is given priority over a traffic-driven cut-through optical path. In this scheme, the application driven path is regarded as a "user service," and even when there are no unoccupied ports on an edge node, an application-driven cut-through optical path may be established by removing any pre-existing traffic-driven cut-through optical paths.

In order to achieve high-speed control, it is preferable to secure a certain amount of resources for application-driven cut-through optical paths. In such case, the remaining resources will be used by traffic-driven cut-through optical paths to maximize the total throughput of the entire network.

The experiment was conducted in the following steps (see Fig. 4).

(1) In order to create a state of competition between traffic- and application-driven optical paths, the traffic-driven optical path is first established and image data are then transmitted over this path. No image degradation occurred at this stage.

(2) First, we examined the optical-path establishment request made from the user application to the network-control server.

The web client sent a content request to the web server. Based on the request, the CDN manager requested the network-control server to establish an optical path between the transmitting and receiving ends according to the result of cache lookup.

(3) Next, we examined how traffic-driven

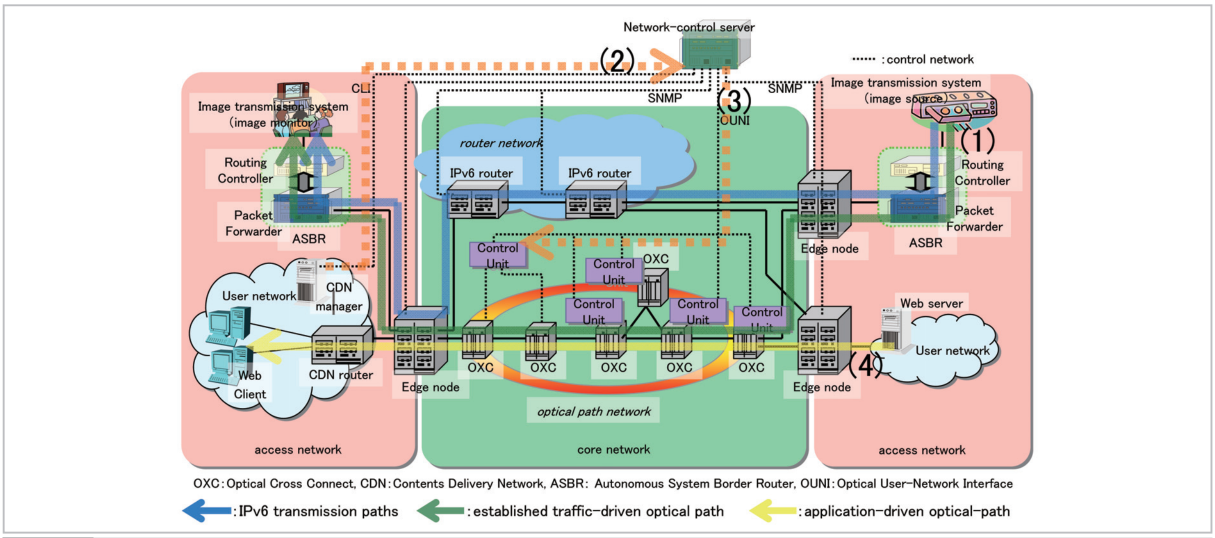

Fig.4 Outline of the application-driven optical-path cut-through control experiment

optical-path removal and application-driven optical-path establishment are controlled based on the policy control.

The optical-path establishment request from the CDN manager in the present experiment competes with the existing traffic-driven optical path currently transmitting the image, as described above. Therefore, on the basis of policy control, the network-control server switches the image transmission over to the IPv6 transmission path and removes the existing traffic-driven optical path according to the OUNI protocol. Here, the congestion of the IPv6 path was left untouched, and a visual confirmation was made of the image degradation.

Then, like the traffic-driven optical path, an application-driven optical path was established according to the OUNI protocol, and an IPv6 path was established on this optical path.

(4) Finally, we examined the condition of data transmission on the established application-driven optical path.

As stated above, it was visually confirmed that high-speed transmission of large-volume web data requested by the web client was made on this optical path based on the instructions from the CDN manager after the establishment of application-driven optical path. It took approximately 10 seconds for the removal of the old optical path and the establishment of the new one and the switchover of the traffic in the IP layer to be completed after the request had been placed for optical-path establishment from the CDN manager to the network-control server.

The cut-through optical path established as the application-driven path is removed by explicit request from the CDN manager after completion of the web data transmission. Then, a traffic-driven optical path was re-established by the traffic-engineering controls. It was visually confirmed that the image quality recovers when a new optical path is established for image transmission several tens of seconds after a request is made to cut the optical path after completion of the web data transmission.

The results of the above experiment verified the effective operation of the optical-path control by the network-control server based on requests from applications.

5 Conclusions

Experiments were conducted on the feasibility of adopting cooperative multi-layered traffic engineering technologies as control technologies for Terabit-class Super-networks, using a prototype. Through the present experiments, it was confirmed that the dynamic optical path controls for both of the proposed technologies–both the traffic-driven and the application-driven type–could be carried out in several tens of seconds. These results represent significant contributions toward the achievement of the scalability goals for the e-Japan Strategy of the Ministry of Internal Affairs and Communications.

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