# Multilayer Coordination Technologies for Next-generation Core Networking

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**Abstract**

In this article, we introduce multilayer coordination technologies, which provide various advantages such as improved efficiency of network operation, fast and stable failure recovery, and efficient use of network resources. The rapidly increasing bandwidth requirements of IP traffic mean that networks based on optical technologies in conjunction with IP routing technologies will provide the backbone of the next-generation Internet. One of the major issues is how to construct an optical-technology-based backbone network that provides economical transport of large-scale IP-based packet traffic while achieving high reliability and multi-QoS (quality of service) support. These objectives can be achieved using multilayer coordination technologies.

## 1. Introduction

Broadband Internet access services such as ADSL (asymmetric digital subscriber line) and FTTH (fiber to the home) are becoming more and more popular in Japan. The traffic volume imposed on core networks has been rapidly increasing because of the increasing number of broadband subscribers as well as advances in broadband access technologies. The increasing bandwidth requirements for IP traffic mean that optical-technology-based networks will provide the backbone for the next-generation Internet. One of the major issues is how to construct an optical-technology-based backbone network that can economically transport large-scale IP traffic. To achieve economical transport of high-capacity IP traffic while providing high reliability in the optical-based core network, our research group has proposed a next-generation Internet backbone architecture called a multilayer service network architecture that provides multilayer IP and optical network services [1].

A backbone network usually consists of multiple layer networks, and each layer network such as the IP, SONET/SDH (synchronous digital hierarchy), optical layers, is operated and managed independently. However, in the multilayer service network, network operation and control such as multilayer path setup and deletion are performed in an integrated manner by using GMPLS (generalized multiprotocol label switching) [2] technologies (**Fig. 1**). GMPLS extends MPLS (multiprotocol label switching) to support the dynamic provision of various layer paths including optical paths and provide network survivability through a protection/restoration technique. Though GMPLS can basically provide multiple layer path control in an integrated manner, the current GMPLS specification is mainly focused on controlling paths in each layer separately. On the other hand, multilayer coordination technology is defined as network control that enables us to achieve path establishment/deletion, failure recovery, and network re-optimization by coordinating multiple layer networks.

In this article, we describe three multilayer coordination technologies: i) dynamic path establishment, ii) failure recovery, and iii) advanced traffic engineering. These technologies offer various advantages such as improved efficiency of network operation, fast and stable failure recovery, and efficient use of network resources.

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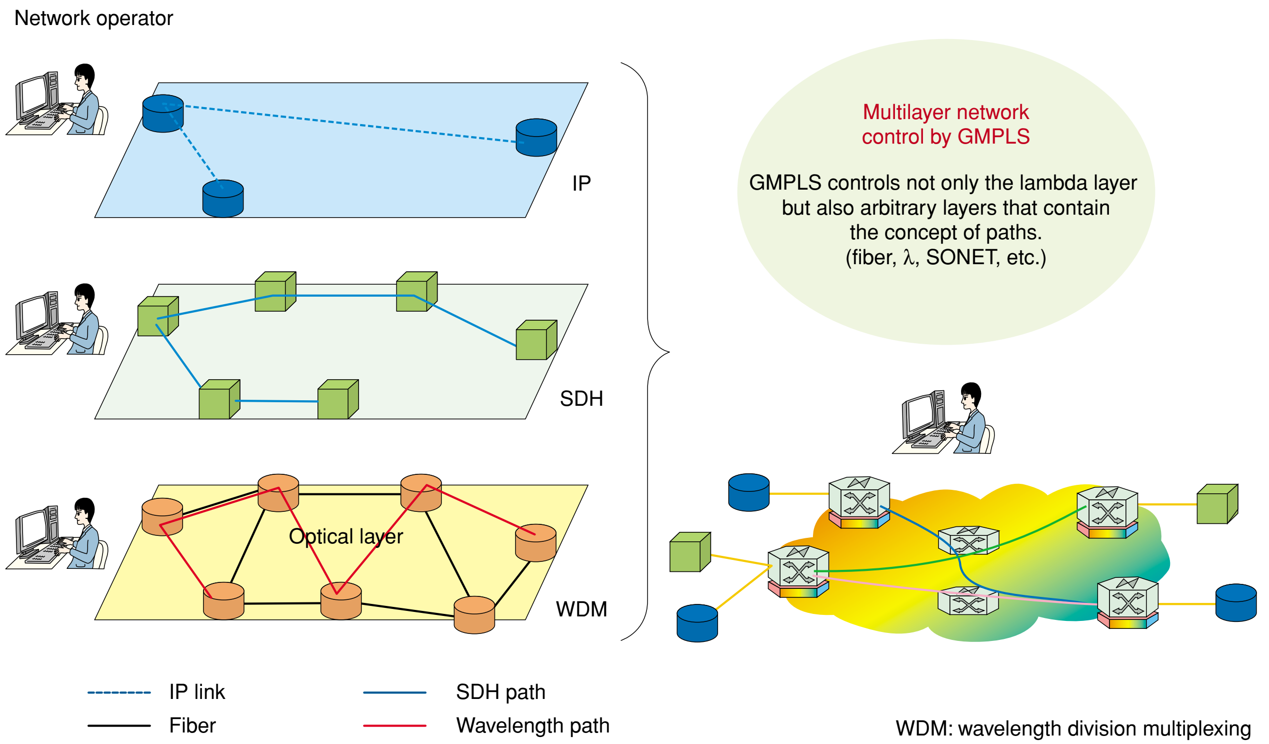


Fig. 1. Concept of multilayer network control.

## 2. Multilayer coordination technologies

### 2.1. Dynamic path setup using multilayer coordination

First, we explain how to dynamically set up a path using the multilayer coordination. In the conventional network, to establish a packet-layer path, a network operator must configure links connecting each pair of routers from the source to the destination in advance (**Fig. 2**). However, with multilayer coordination technology, if we fail to set up a packet-layer path on the route because of a shortage of resources or some other reason, the packet-layer control entity asks the optical-layer control entity to set up a wavelength path by coordinating the packet and optical layers. After a wavelength path has been established, a packet-layer path is established automatically over the wavelength path. In this way, we can operate networks more efficiently using multilayer coordination. In addition, the dynamic path setup technique lets us increase/decrease the number of wavelength paths connecting two sites according to the traffic demand. For example, such technologies can be used to provide a short-hold broadband path for data synchronization between two data centers located at a remote site or for high-quality video streaming services.

### 2.2. Stable and fast failure recovery through multilayer coordination

Second, we introduce a failure recovery technique based on the multilayer coordination. The multilayer service network is a converged backbone network that provides multiple layer services. Hence, it requires high reliability as well as high capacity and cost effectiveness.

A path protection technique has been widely used to enhance network-level reliability [3]. In this technique, a pair of paths is configured between the source and destination nodes. One path is used to transport traffic as the working path in the ordinary case. If any failure occurs on the working path, then the system will recover from the failure by switching over to the other path. In the case of a fiber cut, it is much quicker to switch paths than repair the faulty fiber itself, so the path protection technique can increase network reliability.

The multilayer service network can utilize multilayer paths. Let us consider the case where a failure recovery function is provided in each layer. If any failure occurs in some layer, then the failure recovery functions of more than two layers can work to recover from the failure, which may cause network instability. To avoid this problem, in a multilayer service network, fast failure recovery is performed stably by using multilayer coordination when a failure occurs.

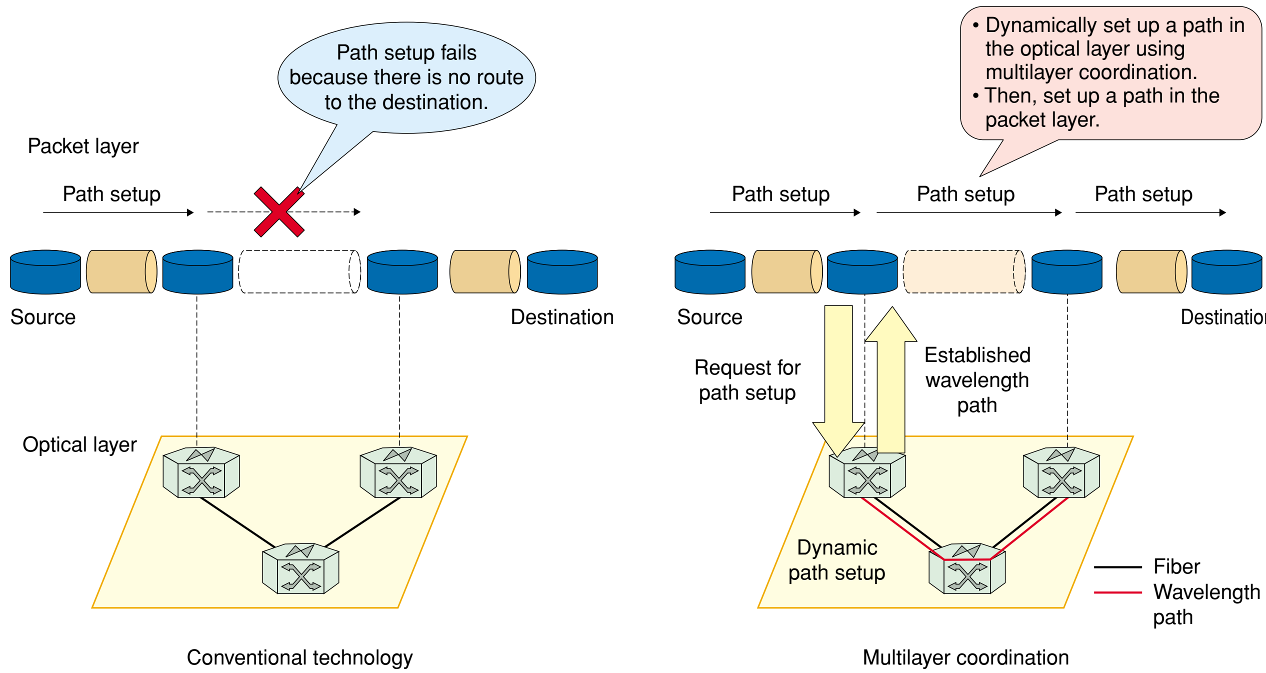


Fig. 2. Dynamic path control achieved by multilayer coordination function.

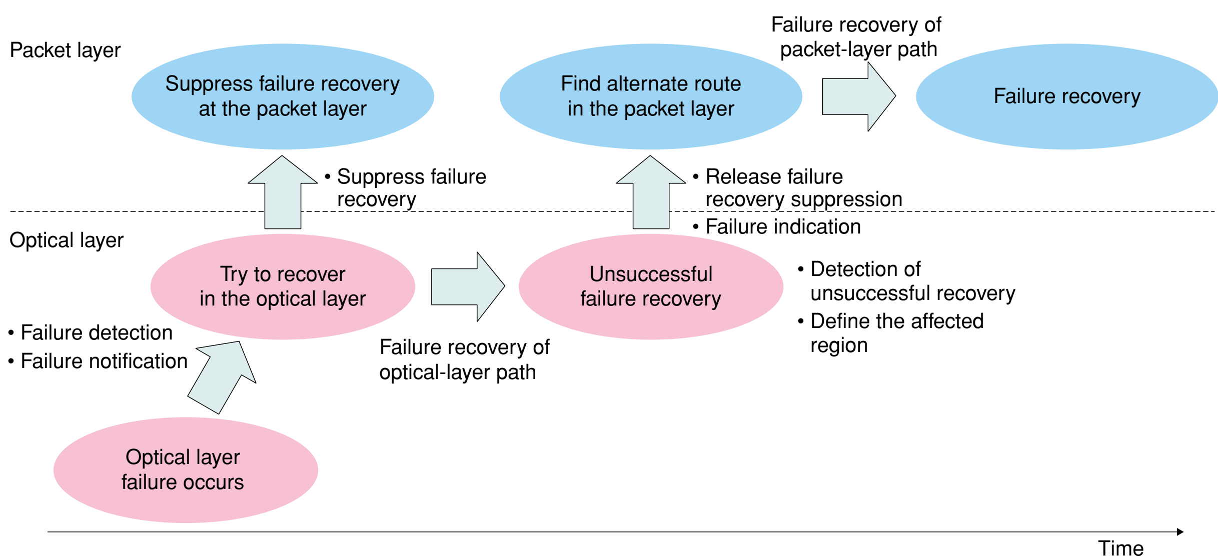


Fig. 3. Failure recovery through multilayer coordination.

A flowchart of recovery by multilayer coordination is shown in **Fig. 3**. If any failure occurs in the optical layer, the failure detection function in the optical layer finds the failure and the path protection function in the optical layer performs recovery. When performing path protection, the optical layer sends a request to the upper layer to suppress its recovery process in order to make the recovery stable. Here, note that we need to consider the following cases for a highly reliable network design: protection in the optical layer may fail to restore the network if the failure turns out to be multiple simultaneous failures (i.e., two or more links or nodes go down at the same time) or if we use a protection method that does not reserve the bandwidth of backup paths in advance. In such cases, the optical layer should immediately report the failure occurrence to the packet layer. Upon receiving the failure notification, the packet layer recovers from the failure using its path protection mechanism, and finally the service is resumed. By introducing multilayer coordination into failure recovery, we can i) recover from a failure without causing instability and ii) handle various types of failures like simultaneous failures, which we cannot do without multilayer coordination.

### 2.3 Advanced traffic engineering

Finally, we explain advanced traffic engineering techniques based on the multilayer coordination, which enable us to design a cost-effective network topology while maintaining high reliability under various network conditions.

#### 2.3.1 Dynamic path optimization considering reliability

Advanced traffic engineering lets us create a cost-effective core network through optimized path computation and dynamic path control. The key to achieving efficient use of limited network resources lies in the multilayer routing calculation function. In the conventional network, path computation is performed based on information about a single layer network. However, in the multilayer network, path topology can be optimized using multilayer information, including the packet- and optical-layer topologies and the traffic demand of the upper-layer network, to achieve efficient use of network resources. Here, the term ‘optimization’ is defined as designing the optical- and packet-layer network topologies with minimal resources while satisfying the bandwidth requirement of service networks.

**Figure 4** illustrates an example of a network providing advanced traffic engineering. In this example, we assume a centralized control model where a path calculation server collects information about network resources. After computing the optimized path topology for each layer, this server sends the route information of each path to nodes in the network. Finally, the network is optimized through dynamic path control at each node using GMPLS signaling. This technique provides the following advantages:

i) efficient use of network resources achieved by dynamic path optimization and
ii) survivable network layout with consideration of upper-layer restoration.

For example, traffic demand in the network fluctuates over time because of temporary increases in traffic caused by streaming distribution of a concert, disasters, and different behavior of users during the day and at night. Advanced traffic engineering lets us reduce the redundant resource usage by optimizing the path topology according to the change in traffic

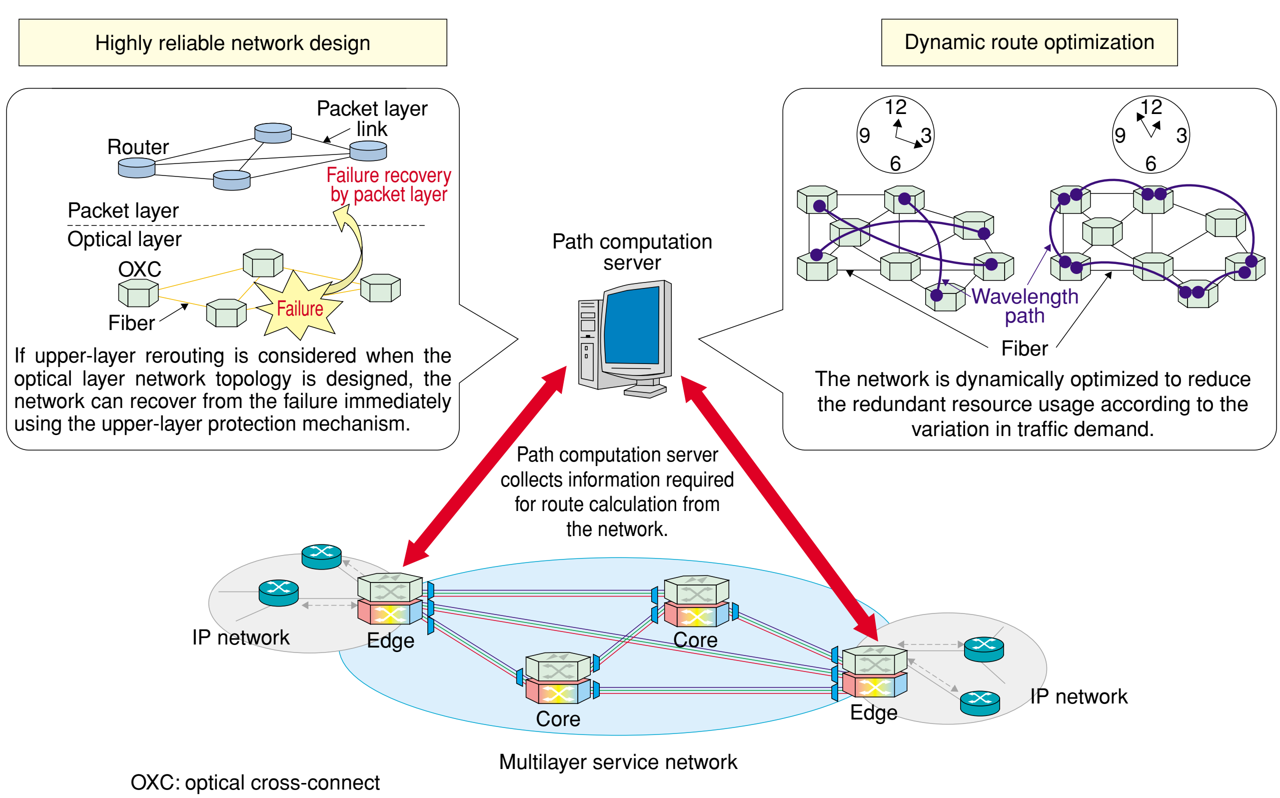


Fig. 4. Example of a network providing advanced traffic engineering.

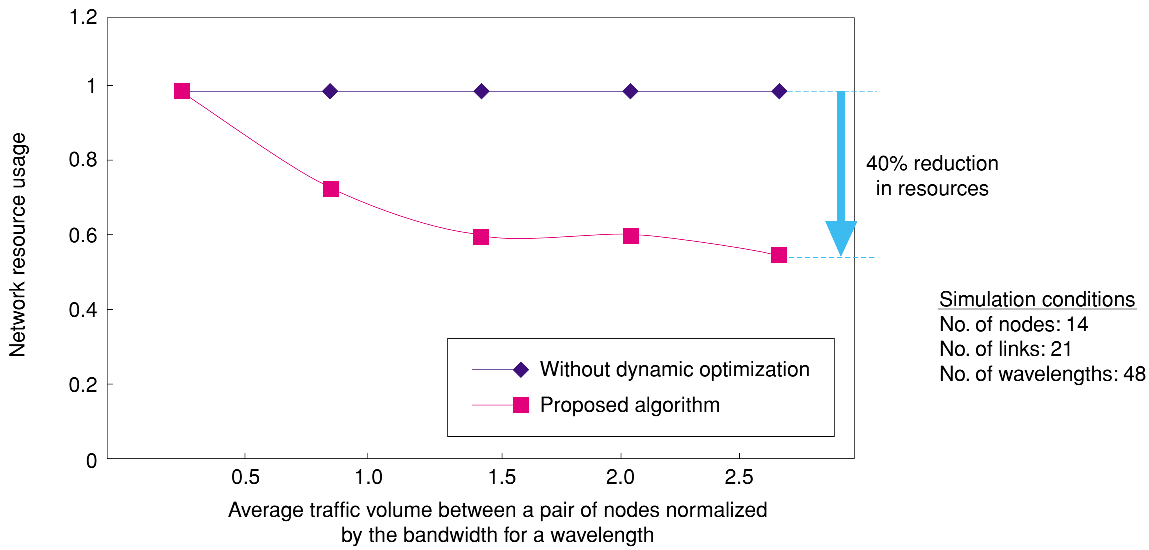


Fig. 5. Reduction in resource consumption achieved by the proposed method.

demand.

In NTT Network Service Systems Laboratories, we have developed various route optimization algorithms and efficient methods for collecting network resource information [4], [5]. Here, we briefly review related work and show the superiority of our scheme compared with conventional schemes. As multilayer survivable layout algorithms, Sasaki and Su [6] proposed multilayer network design algorithms to maintain IP layer connectivity after a single fiber link failure. We extended their algorithms to support dynamic reconfiguration of the network topology according to the variation in IP-layer traffic demand. In some simulation configurations, our scheme [4] decreased network resource consumption by about 40% compared with the fixed topology (**Fig. 5**).

### 2.3.2 Improving the network scalability

To support the advanced traffic engineering technique, a path computation server in the multilayer service network needs to collect much more information than in a conventional single-layer network. The load on the server tends to increase as the number of nodes or paths in the network grows. This results in such instability that it has a longer path computation time or topology reconfiguration time. To solve these problems, we have developed a new architecture and algorithms for collecting network resource information. The basic process of the scheme [7] is as follows. First, the path computation server selectively collects the subset of network resource information from the network. Then the server infers the complete resource information using the information collected in the previous phase and stored in the database within the server. Finally, the server computes the optimized route based on the presumed information. In this way, we can reduce redundant message exchanges between the server and network, which leads to improved scalability.

Some simulation results for our scheme are shown in **Fig. 6** [7]. The proposed scheme produced an almost ideal optimized topology while reducing the total volume of control messages by more than 60%. Note here that network scalability is mainly determined by the volume of protocol-related messages, so our scheme can improve the scalability of network optimization. These results show that our approach of inferring the traffic demand can produce an almost optimal network topology.

## 3. Conclusion

NTT Network Service Systems Laboratories is researching and developing a multilayer coordination function that will enable us to construct an economical and highly reliable network and promoting the standardization and globalization of the network architecture and related protocols.

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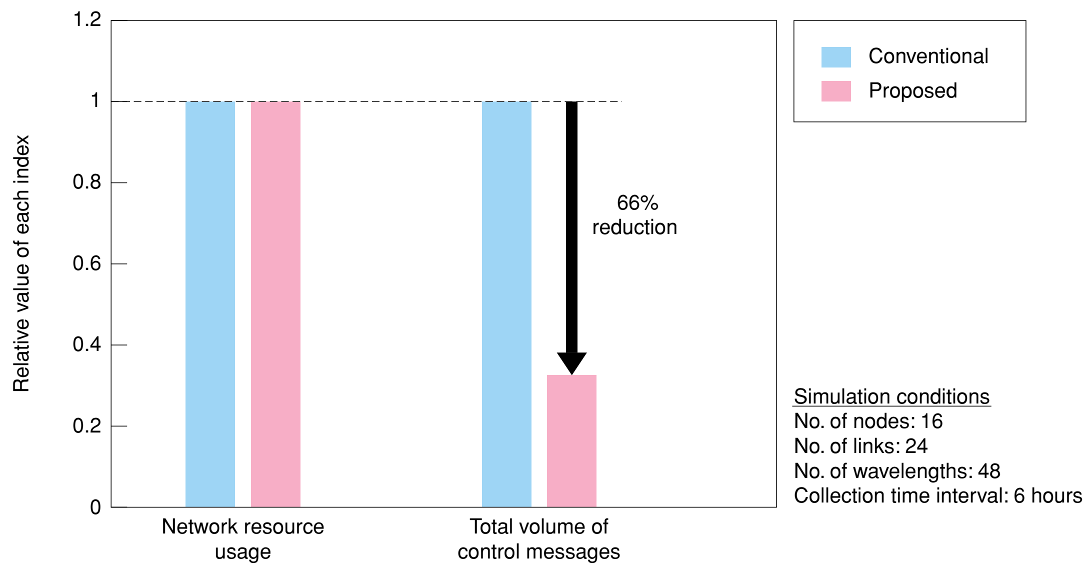


Fig. 6. Performance of the proposed method in terms of efficiency and scalability.

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