Flexible Virtualized Optical Transport Networking Technology

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Abstract

Network and computing resource sharing technology, such as network virtualization and cloud computing, is becoming more important for further reductions in capital and operating expenditures or further improvement in availability. We are researching a flexible mechanism for partitioning optical transport network resources and dynamically allocating them to diversified services or applications with isolated controllability. This article introduces the basic concept and research status of flexible virtualized transport networking technology, which enables service and application layers to control the network topology or path bandwidths in response to environmental changes such as disasters or unexpected traffic fluctuations.

1. Introduction

As communication services tend to become more diversified and require more bandwidth, the amount of traffic and its variation in time and space are increasing continuously. The amount of traffic that the carrier networks receive from Internet access services, video-on-demand services, and datacenter clouds has reached 100 Gbit/s per point of interface and may fluctuate enormously depending on social conditions or human behavior. Meanwhile carrier networks are required to be more sustainable against large-scale network failures or disasters because they act as lifelines; in other words, they must have a mechanism for rapidly recovering by reconfiguring residual resources in the event of large-scale failures as well as a hitless protection scheme against small failures or system maintenance. So future networks should handle unexpected traffic fluctuations or failures. One of the key schemes for this purpose is network resource virtualization, which shares network resources among multiple services or users and flexibly allocates them in the event of environmental changes. As for computing resources, flexible resource sharing and control technologies, such as server virtualization and cloud computing, have already been developed. Now flexible resource sharing and dynamic control schemes, including the optical transport or packet forwarding layer, are expected for the purpose of rapid adaptation to huge traffic fluctuations or disasters. This article introduces basic concepts and technical issues of the flexible, virtualized transport networking technology that NTT Network Service Systems Laboratories is researching.

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2. Technology trends for flexible network resource operation

Carrier service networks are generally composed of multilayer network resources, as shown in **Fig. 1**, such as the optical transport layer (fibers and cross connects (XCs), which may be optical XCs (OXCs), time division multiplexing (TDM) XCs, or multiprotocol label switching transport profile (MPLS-TP) XCs), the address or flow-based routing layer (Internet protocol (IP) routers, flow routers, and Ethernet switches), the session control layer (computing resources), and the application cloud layer (also computing resources). Each user session goes through the resources from the optical transport layer to the session control layer and finally reaches the application

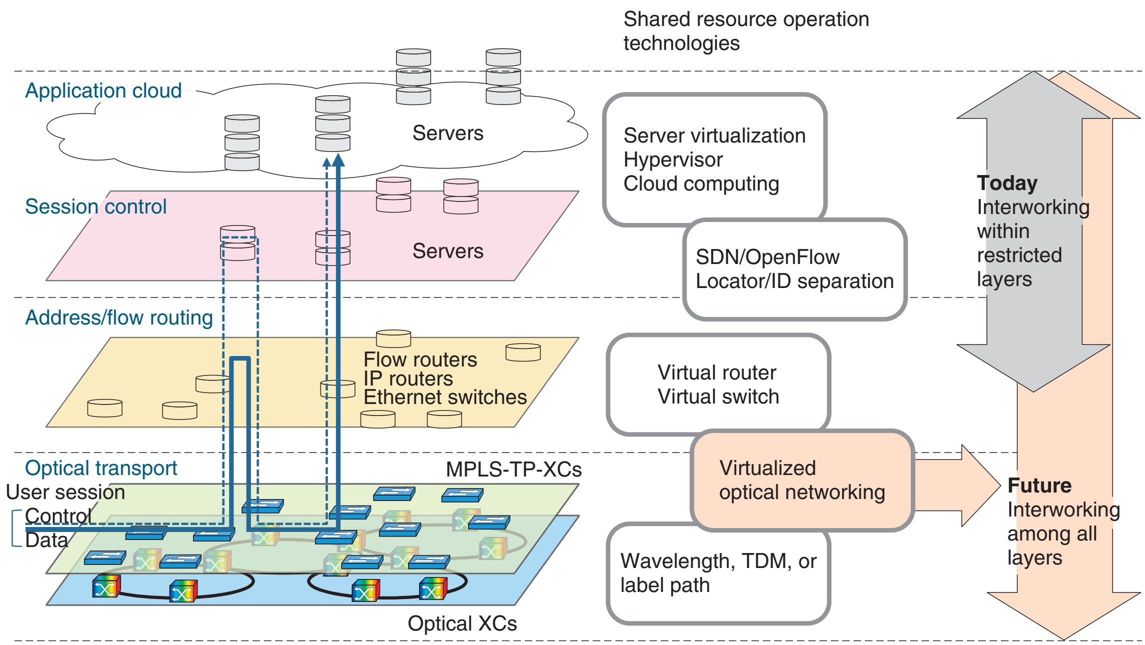

Fig. 1. Overview of virtualization technologies.

cloud in the case of server-client applications. In many cases, the resources of each layer are operated independently on the basis of the resource operator's policy, and multiple upper-layer resource operators utilize different elements of common lower-layer resources, or an upper-layer resource operator integrates multiple lower-layer resources managed by different resource operators. When the scale of traffic fluctuation or assumed failure is relatively small, it is sufficient for each operator to increase or decrease its own resources according to its long-term traffic forecast and request and get fixed-sized resources statically from the lower layer resource operators.

To handle large environmental changes, however, dynamic resource reallocation or exchange within each layer and coordinated resource control across multiple layers will be necessary. Network virtualization can be understood as a technology that enhances the controllability or operational flexibility of those multilayer common resources. Recently, many technologies related to network virtualization have been proposed or developed. Their basic functions can be categorized into three groups.

(1) Physical resource partition, isolation, and flexible allocation: server virtualization, hypervisor, virtual router/switch, virtual path/channel, and wavelength/timeslot path
(2) Simple unified operation for diversified resource elements: cloud computing [1] and virtual chassis
(3) Flexible, coordinated control for logically defined resources: software defined network (SDN) [2] and locator/identifier separation (LISP).

Network virtualization integrates these three functional aspects for the purpose of resource utilization efficiency promotion, simplified network design and operation, rapid new service delivery, and enhanced network service sustainability and availability.

ITU-T SG13 (International Telecommunication Union, Telecommunication Standardization Sector, Study Group 13) has discussed basic concepts for future networks since 2009. It regards network virtualization as the most important issue and has standardized a basic framework recommendation ITU-T Y.3011 [3].

An overview of current virtualization technologies in terms of network layers is shown in Fig. 1. (1) Partitioning technologies and (2) unified-operation technologies in each network layer are being improved continuously. Recently, studies of integrated operation of various layer resources and cross-layer networking have increased. Some examples are SDN, OpenStack, or OpenFlow, where applications or computing resources control packet switching functions actively and operate multilayer resources

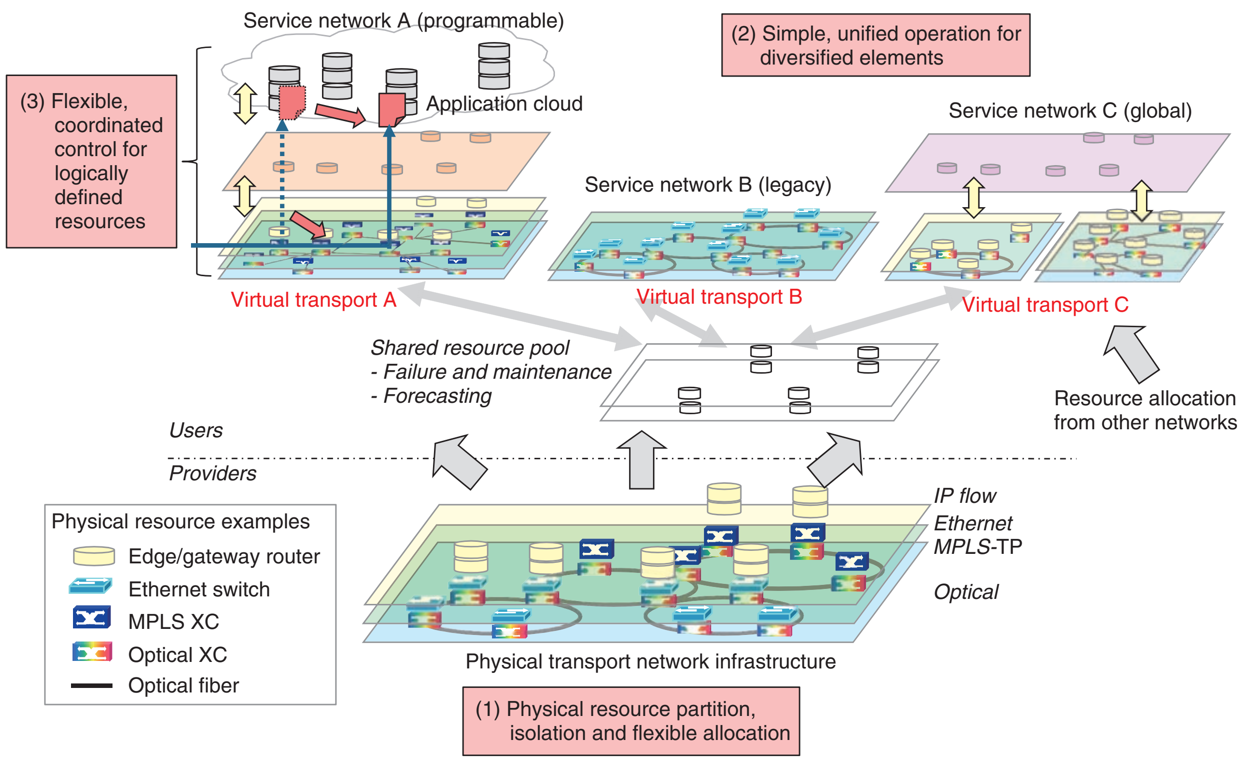

Fig. 2. Basic concept of virtualized transport networking.

flexibly. But current proposals are restricted to controlling traffic locally within datacenters or between datacenter locations. When software migration between datacenters causes a large variation in traffic amount or when the amount of traffic exceeds the thresholds in some core network parts, then wider cross-layer networking, such as dynamic reallocation of transport layer resources or rapid rerouting in the IP/Ethernet networking layer, is necessary for network service sustainability.

Therefore, future networks must be able to handle unexpected traffic variation, disasters, or rapid service creation by using cross-layer network resource control. One of the key schemes is to make overall network resources into a resource pool shared by multiple users and to optimize the amount of resources allocated to each user flexibly according to environmental changes, so that each user reconfigures its own network to retain optimal connectivity or service quality. It is also important for the lower-layer resources to provide controllability or programmability for the service or application layers, which integrate and control all of the allocated resources according to their unified operation policies. SDN concepts should be extended in terms of overall network layer interworking.

3. Flexible, virtualized transport networking

3.1 Fundamental concepts

To date, the optical transport infrastructure has had little relationship with IP routers, Ethernet switches, and computing resources. The former (the infrastructure) sets up and provides each wavelength path or MPLS path to the latter (routers, switches, and computing resources), from which service networks are formed. In the future, the former is expected to provide a virtual transport network comprising a logical system and logical link resources to the latter, and the latter are expected to control the transport network according to their own schemes for flexible adaptation to environmental changes. The basic concepts of flexible, virtualized transport networking [4] are shown in **Fig. 2**. Fibers, wavelengths, network systems, and related control functions are logically partitioned to generate a shared resource pool commonly available to users, and they are allocated to users as virtual transport resources. Each user integrates the virtual transport resources with its own resources and operates the overall service network according to its own networking policies and schemes. This dynamic, optimized resource allocation via the shared resource pool enhances the following network performance attributes.

- sustainability against unexpected traffic fluctuations or large-scale network failures
- rapid delivery of new advanced services
- cost reduction by optimization of the overall resource deployment including standby or forecast resources
- enhanced availability through additional shared standby resources

Appropriate resource abstraction capability, controllability, and programmability via various kinds of resource control interfaces enhances the following usabilities for virtual transport users.

- high value-added transport service creation and lineup
- simple and efficient network design and operation on the users' own networking policy
- integrated, flow-through operation for virtual transport resources and users' specific functions

To achieve the above concepts, we are now researching two technical issues to enhance the flexibility of optical transport networking: (1) shared resource management and an isolated control mechanism and (2) controllability and programmability for computing or packet processing layers. These are explained in sections 3.2 and 3.3.

3.2 Shared resource management and isolated control mechanism

To achieve both dynamic resource allocation via the shared resource pool and isolated resource control, which enables each user to access only allocated resources and prohibits users from accessing non-allocated resources, it is necessary to establish a model for managing partitioned logical resources and a mechanism for controlling resource access rights. The resource management model that we are proposing for both transport system resources (OXCs, MPLS-XCs, Ethernet-switches, and IP routers) and transport media resources (fibers, wavelengths, and packet labels) [5] is shown in **Fig. 3**. Both system and media resources are logically partitioned and each logical resource has an attribute indicating the users permitted to use it. Basic resource isolation can be achieved by a network virtualization platform that verifies the consistency between users' control commands and logical resource access rights. Dynamic resource allocation among users via the shared resource pool can also be achieved by controlling logical resource access right properly.

3.3 Controllability and programmability for computing or packet processing layers

The network virtualization platform aggregates logical resources assigned to each user and presents them to users as a virtual transport network at an appropriate level of abstraction. Since each user will operate the virtual transport network according to its own scheme, each virtual transport network should provide conformity and controllability to the user's operating environment. The ranges of virtual network topologies and operating schemes are also shown in Fig. 3. Virtual transport network A is used as sets of fixed paths connecting user systems, and B acts as one large virtual switch, communicating with user systems via some control-plane protocols. C acts as a switch network, supervised and controlled via some management-plane protocols. The network virtualization platform understands the correspondence between virtual transport resources and logical resources, and it optimizes the abstraction level according to the users' specifications. The platform also supports users' graphical user interfaces and application programming interfaces, which enable them to request additional virtual resources or virtual topology reconfiguration, and it emulates a virtual control & management plane to provide conformity to each user operating environment.

4. Proof of concept

4.1 Network virtualization platform prototyping

To confirm the feasibility of flexible resource allocation and controllability of the optical transport infrastructure, we implemented prototype software for the network virtualization platform [6]. We chose to use a platform architecture with a physical network manager separated from each virtual network manager on the following basis.

- centralized resource management and configuration to isolate physical system control efficiently
- abstraction of detailed network information at the physical network manager for each user to manage virtual transport easily
- independent functional extensibility and programmability for each user to develop virtual transport control applications that support new traffic engineering technologies.

For functional extensibility and programmability,

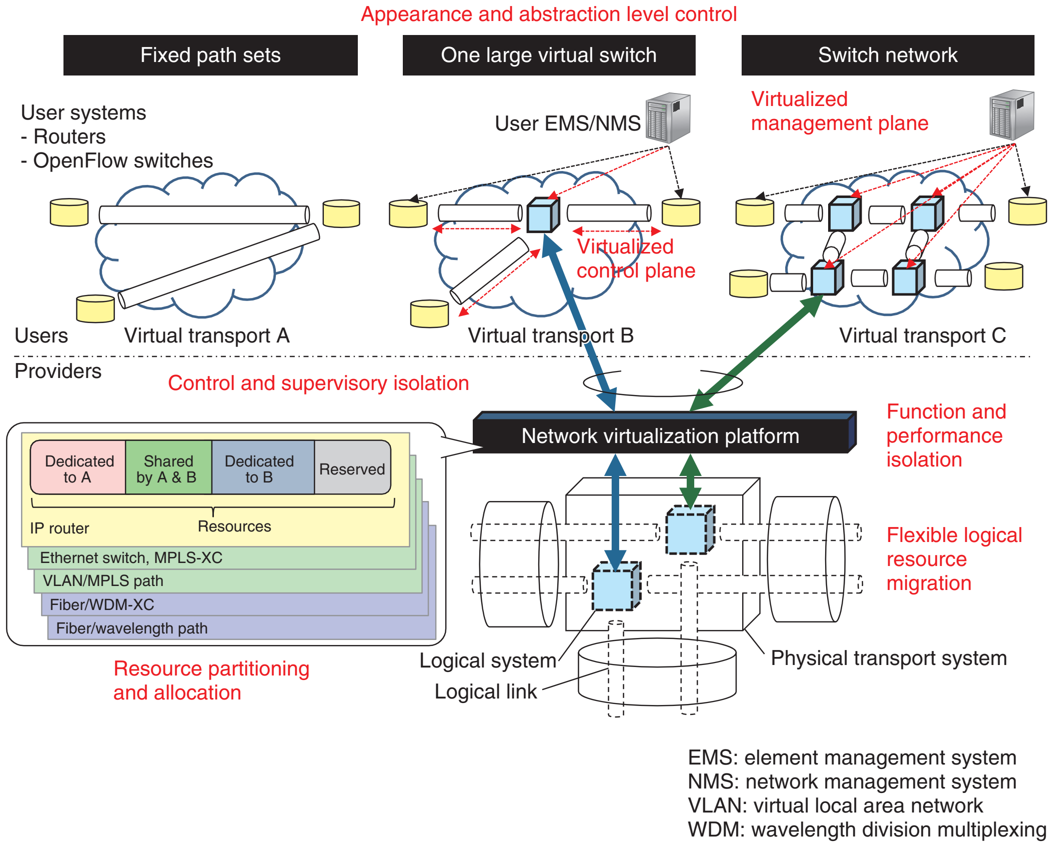

Fig. 3. Resource management, isolation, and controllability.

the virtual network manager has fundamental automatic network operation functions and can be easily connected to upper-layer functions. For example, it has a network reconfiguration function that optimizes the virtual transport topology and performs routing according to traffic demand and minimizes the amount of resources while keeping the communication quality and reliability [7]. Cross-layer and flow-through operation can be easily demonstrated by simple software modification, which directly reconfigures the topology or bandwidth of the virtual transport network when triggered by services or applications for example [8].

4.2 Proof-of-concept on national testbeds

With the abovementioned prototype software, we have been demonstrating shared resource networking and cross-layer operation with applications of the optical transport network on national testbeds, such as JGN (Japan Gigabit Network) [9], [10]. An experimental setup for global-scale virtual transport networking at SC11 (Supercomputing 2011), held in Seattle in November 2011, is shown in **Fig. 4**. The prototype software partitioned JGN-X (X: extreme) and provided virtual transport networks for multiple experimental groups, each of which successfully configured its virtual transport network independently. We also demonstrated global transport path networking technology across Japanese, American, and European testbeds for the first time in the world and showed the feasibility of global-scale virtual transport networks. The prototype software established bandwidth-guaranteed paths across multiple testbeds via the network service interface protocol, which is currently undergoing standardization, and constructed a global-scale virtual transport network. Using broadband video streams transmitted from Osaka to Seattle and London to Seattle, we also demonstrated the transmission performance attributes for actual application traffic and the feasibility of flexible path route selection according to the transmission quality of each testbed and available time zones.

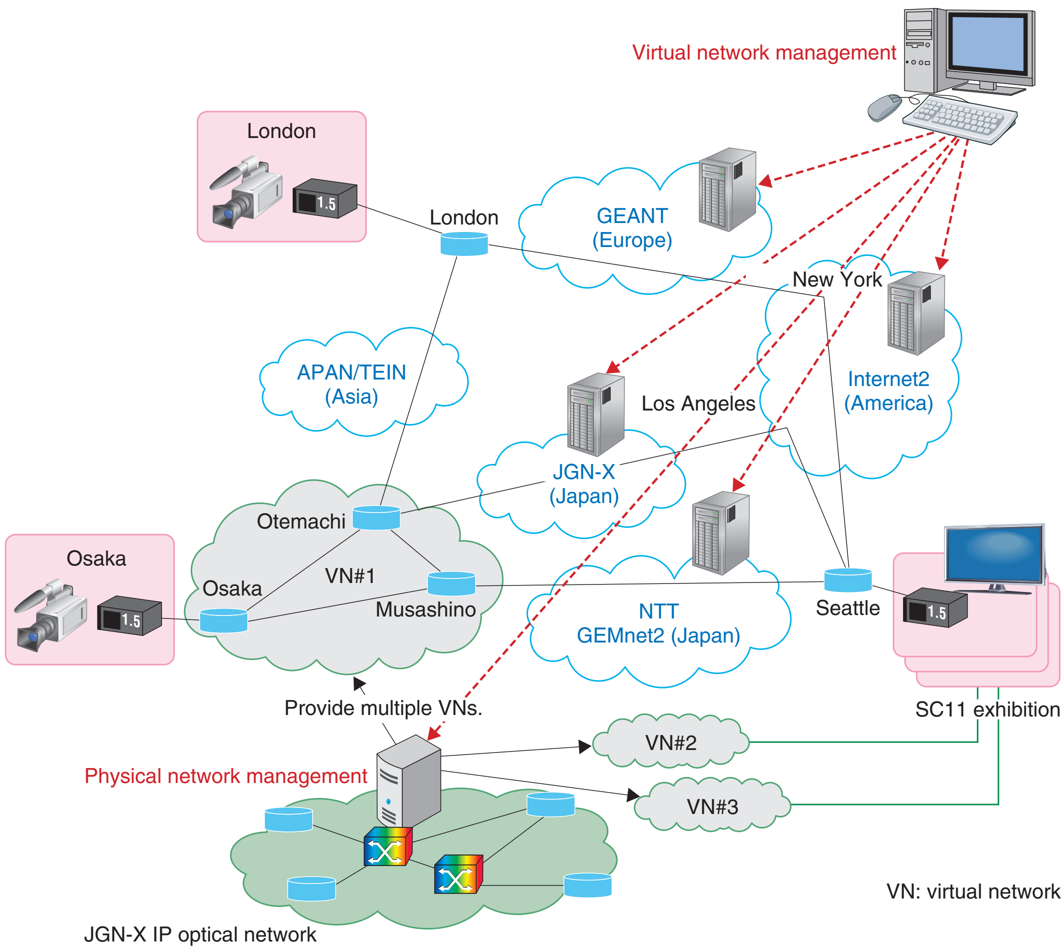

Fig. 4. Proof of concept on national testbed.

We have submitted reports of these JGN experiments to ITU-T SG13 Q.21 as use-case contributions and we are contributing to agreement on the basic framework recommendation Y.3011.

5. Conclusion

We introduced the basic concepts and technical issues of flexible, virtualized transport networking technology and also mentioned our network virtualization platform prototyping and proof-of-concept activities on national testbeds. In the future, we will promote research and development of the technical issues mentioned in section 3, establish and spread the network virtualization concepts by demonstrations on national testbeds, and continue contributing to standardization.

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