

# Design Implementation of IPv6 services over GMPLS based IP/Optical Network

*Mallik Tatipamula and Francois Le Faucheur, Cisco Systems*

*Tomohiro Otani, KDDI*

*Hiroshi Esaki, University of Tokyo*

## ABSTRACT

In recent days, there has been considerable interest in deploying IPv6 based services. Trial and commercial IPv6 services [1, 2] offering has already begun, especially in Japan, Korea, China and other parts of the world. At the same time, many service providers have embraced Multi-Protocol Label Switching (MPLS) as the enabler for the required multiservice capabilities of their next generation packet network. Also, the widespread deployment of DWDM based optical transport systems in the core network to satisfy the tremendous need and increase in capacity demand, has led network planners to reconsider traditional approaches to “provisioning” and “network restoration” and plan integration of the optical layer into the MPLS infrastructure according to the emerging GMPLS technology. The purpose of this paper is to discuss next generation network architecture evolution and present a detailed architecture for transport of emerging IPv6 services and applications over next generation GMPLS multi-service backbone network. This paper also presents an implementation and demonstration of a new technique for IPv6 transport over GMPLS backbone network as well as interoperability verification of IPv6 and GMPLS using a GMPLS network test bed.

## INTRODUCTION

The current IP address space is unable to satisfy the potentially huge increase in the number of users or the geographical needs of the Internet expansion, let alone the requirements of emerging applications and services such as Internet-enabled personal digital assistants (PDAs), home area networks (HANs), Internet-connected transportation (for example, automobiles), integrated IP telephony services, IP wireless services, and distributed gaming. IPv6 is designed to meet these requirements and allow a return to a global environment where the addressing rules of the network are again transparent to the applications. A number of service providers [1, 2] in Japan have already started offering trial and commercial IPv6 services. Also several National Research Networks around the world consider IPv6 as a key technology for their next generation networks.

At the same time, many service providers have selected MPLS as the fundamental technology for their next generation packet network. A prime driver for this evolution is MPLS multiservice capability, which enables network operators to cope with the broadening of the IPv4 service offering (such as IPv4 VPN services) and at the same time allow many other services, which were so far supported on multiple technology specific networks, to be migrated to a single infrastructure. Examples of such services currently being migrated onto the MPLS multiservice infrastructure include ATM services, Frame Relay services, Ethernet services and PSTN.

Finally, the widespread deployment of DWDM based optical transport systems in the core network to satisfy the corresponding increase in capacity demand, has led service providers to reconsider traditional approaches to “provisioning” and “network restoration”. Consequently, they are considering, or are already planning, to push the infrastructure integration paradigm one step further by integrating the optical layer into the MPLS Control Plane based on the emerging Generalized Multi-Protocol Label Switching (GMPLS) technology [3]. GMPLS has emerged as a next generation networking protocol for providing an intelligent optical control plane for optical networks. GMPLS is considered to be a superset of MPLS, as it extends the forwarding and control planes to include not only packet based, cell based but also SONET, DWDM and fiber based network elements

The emerging Grid, Supercomputing and Ubiquitous applications and services, traffic growth and technological advancements (such as GMPLS, IPv6, etc.) are different forces that will drive the architecture and evolution of next generation networks.

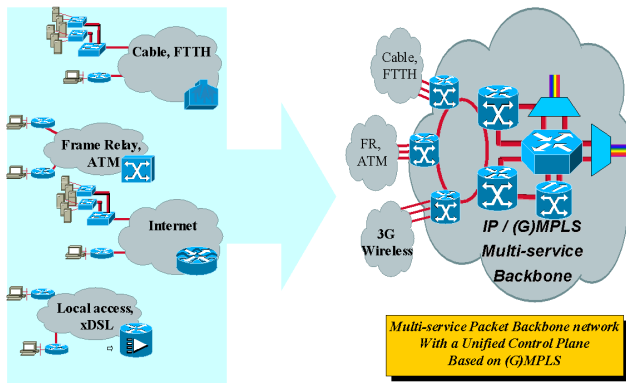
In this paper, we provide a brief introduction about network evolution towards an intelligent multi-service Optical network. A view of next generation network architecture based on IPv6 and GMPLS technologies is presented. We propose a specific method known as 6PE to transport new emerging IPv6 services and applications over next generation GMPLS based multi-service backbone networks. The detailed architecture of 6PE is discussed and early trial demonstration as well as

interoperability evaluation is presented. Finally a number of conclusions are proposed.

## NEXT GENERATION NETWORK EVOLUTION

### EVOLUTION TOWARDS MULTI-SERVICE OPTICAL PACKET BACKBONE NETWORK

The global telecommunication system is being transformed into a new network with a capacity many orders of magnitude greater than it used to be in early 1990s. Traditional telecom backbone network architecture is moving from a world of many separate backbone networks for voice (e.g., PSTN), data (internet, Frame Relay, ATM), radio and cable, into a world of a single high bandwidth multi-service packet backbone network as shown in Fig. 1.



**Figure 1.** Network evolution from multi-tiered backbone network to a single multi-service packet backbone network

The packet switched backbone that can handle and scale a wide variety of services is a key component in any multi-service backbone network. It should be able to carry different types of traffic that have diverse characteristics, e.g.,

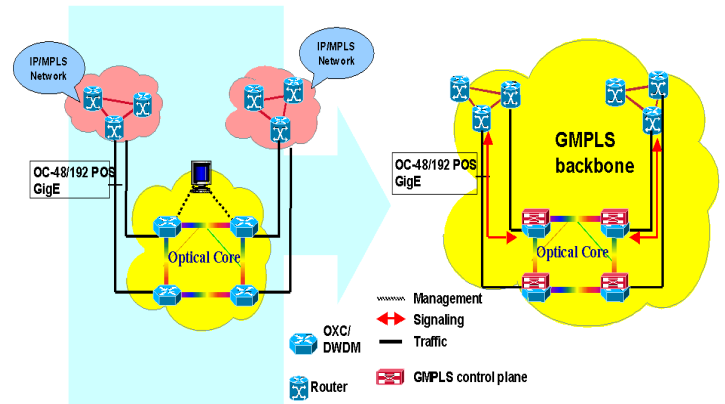
- Real-time traffic
- Internet traffic
- Enterprise communications
- Voice and video streaming

Such backbone networks must deliver true, carrier class resilience and serviceability, and support powerful IP border routing for peering with other IP networks. This type of multiservice packet backbone consists of routers running the MPLS protocol suite.

### NEED FOR OPTICAL INTELLIGENCE IN MULTI-SERVICE PACKET BACKBONE NETWORK

The core routers in multiservice networks are connected to a long haul DWDM network as shown in Fig. 2. Today’s DWDM network configurations are static using Element/Network Management Systems (EMSs/NMSs) as shown in Fig. 2a. Establishing a connection is a process involving many steps, which can take several months. The process is initiated by a series of administrative tasks to request the service that results in core networks becoming increasingly difficult to operate.

An intelligent Optical Control Plane based on GMPLS provides the ability to automate many of the optical network functions that are directly related to the operational complexities. These functions include rapid provisioning of bandwidth, service velocity, and automatic resource discovery. Traffic engineering parameters relating to optical protection support, available bandwidth, route diversity and quality of service, are distributed throughout the network allowing every node in the network to have full visibility and configuration status of every other node – ultimately making the optical network intelligent. Therefore, as service providers introduce new network elements into their networks, add/remove facilities, or turn up new circuits, the control plane will automatically distribute and update the network with the new information. The contrast today is that many of these upgrades and updates are performed manually and are operationally intensive. These features offered by an intelligent optical control plane are key for next generation multi-service backbone networks.



**Fig. 2a**

**Fig. 2b**

**Figure 2.** Evolution towards next generation GMPLS based Intelligent Multi-service Backbone network

Fig. 2b shows a next generation backbone comprising core routers connected with Intelligent Optical transport

consisting of Optical Cross connects with GMPLS control plane. Using a simple, network management system (NMS) based, point-and-click provisioning mechanism, core router will first signal a request for an LSP and, upon confirmation, dynamically set up the requested light path across the backbone network [4]. This is also known as a peer model, as OXC with GMPLS control plane acts as Labeled Switched Router, as discussed in next section.

### GMPLS

GMPLS [3] has evolved from MPLS - the original IETF standard intended to enhance the forwarding performance and traffic engineering intelligence of packet-based (ATM, IP) networks. GMPLS extends these switch capabilities so that it is not only packet switch capable (PSC), but also Time Division Multiplex capable (TDM), Fiber Switch Capable (FSC) and Lambda Switch Capable (LSC). In other words, MPLS is supported mainly by routers and data switches, however GMPLS can be supported by a variety of optical platforms including SONET ADMs, Optical Cross-connects (OXCs) and DWDM systems as shown in Fig. 3. This will allow an entire infrastructure, extending from routers to the OXCs, to utilize a common unified control plane based on GMPLS technology.

Regarding connection set up, while MPLS requires a Label Switched Path (LSP) between two end point devices, GMPLS extends this concept beyond simple point-to-point connections. In a GMPLS network it is possible to find and provision end-to-end paths that traverse different networks including optical domains with GMPLS control plane. Fig. 3 shows an example for the comparison of MPLS based LSR (Label Switched Router) and GMPLS based OXC, where Label could represent a Lambda or wavelength, as the incoming IP traffic from core router can be mapped directly into individual wavelengths (that are generally known as labels).

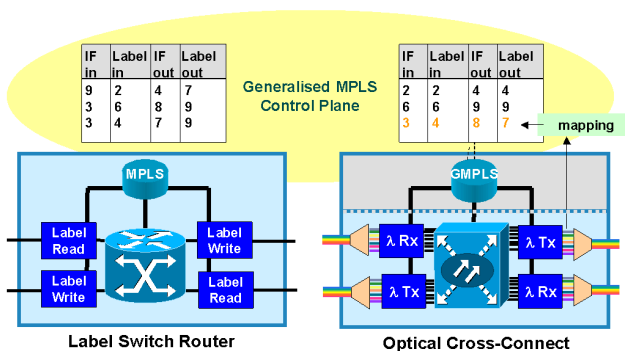


Figure 3. Comparison between LSR and OXC with GMPLS control plane

## A VIEW OF NEXT GENERATION NETWORK ARCHITECTURE

The emerging applications fueling demand for addresses include Internet appliances, Internet enabled wireless devices such as PDAs, home area networks, integrated telephony services, and net connected automobiles. In particular, “always on” environments for devices and applications that must be reachable by communication initiated externally, for example, as well as the shift in residential internet access to use broadband technologies such as DSL, cable modem or Ethernet-to-the-Home, preclude address conservation techniques such as IP address pooling/leasing. Also, the anticipated rollout of wireless data services is identified as a key IPv6 driver; this is reflected in the fact that the relevant industry standardization bodies, e.g., the 3<sup>rd</sup> Generation Partnership Project ([www.3gpp.org](http://www.3gpp.org)), Universal Mobile Telecommunication System (UMTS), and Mobile Wireless Internet Forum (MWIF), consider IPv6 as the foundation [5][6] for the future mobile/wireless IP services.

Aside from these applications that extend the Internet’s functionality for existing users, consideration must be given to the global population and the considerable requirements that for example, highly populous nations are starting to place on current Internet addressing.

Numerous network operators/service providers, especially in Japan [1, 2], have already started offering native IPv6 trials or commercial IPv6 services over their Broadband access networks such as DSL, Cable, Metro Ethernet, and 3G Wireless. Fig. 4 depicts the view of next generation network Architecture [7] with common multiservice backbone infrastructure supporting multiple broadband dual stack (IPv4/IPv6) based access technologies.

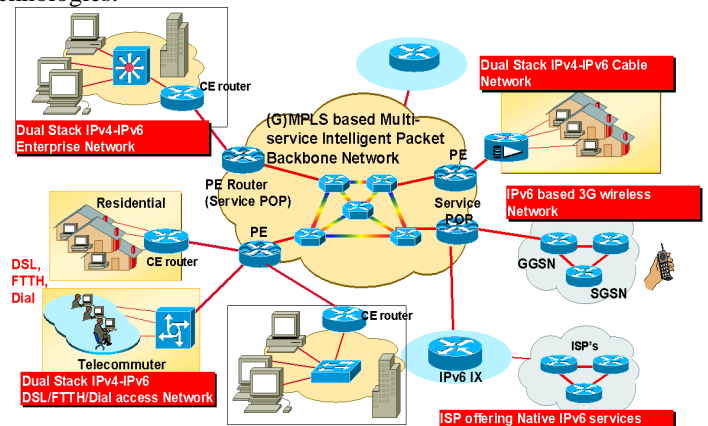


Figure 4. A view on Next Generation Multi-service Packet Backbone network architecture with dual stack (IPv4-IPv6) broadband access networks

### IPv6 DEPLOYMENT CONSIDERATIONS

Service providers running a GMPLS backbone already supporting multiple services may wish to add IPv6 services as well to their current service portfolio. However, this enhancement must satisfy a number of requirements, such as:

- The core network should not be impacted (i.e., no software upgrade, no hardware upgrade, no configuration change, no change in operations) so that the current stable and robust GMPLS core should not be put in jeopardy. Network stability and smooth migration with minimal impact on recently deployed or next generation backbone networks are key requirements for service providers/network operators as discussed in [8].
- Deployment should be scalable, so that no restrictions are imposed on the IPv6 services neither in terms of performance nor in terms of addressing, nor should extensive “tunnel” configuration be required.

Fig. 4 describes a view of next generation network architecture, offering IPv6 services in various access networks including 3G wireless (as described by 3GPP [5]) over a GMPLS based multi-service backbone network. Considering this next generation network architecture, the next section looks at how emerging IPv6 services can be transported over a GMPLS based Optical controlled network. The next section discusses the detailed design analysis for the “IPv6 Provider Edge Router over GMPLS” approach (referred as 6PE in rest of the paper) for IPv6 integration seamlessly into the multi-service Optical packet backbone networks based on GMPLS. Using 6PE, network operators can leverage GMPLS backbone network for offering IPv6 services over their access networks, meeting the requirements discussed above and in particular without any impact to their GMPLS backbone.

## IPv6 SERVICES OVER GMPLS BASED OPTICAL CONTROLLED NETWORK

IPv6 services over a GMPLS based Optical Controlled network can conceptually be supported in two different ways:

*IPv6 over (GMPLS Data Plane + IPv4-only Control Plane):* In this scheme, only PE routers (i.e., routers at the edge of the GMPLS cloud) need to support IPv6. The PE routers run a dual stack – IPv4 and IPv6. Such a PE is referred to as a 6PE. The IPv6 traffic received from the IPv6 network is transported towards the

destination IPv6 network using the GMPLS infrastructure in the core. Inside the GMPLS core (P Routers), all control protocols, including label distribution and Interior Gateway Protocols (IGPs) remain IPv4 based. OXCs (with GMPLS control plane) act as P routers inside the core, and they also remain purely IPv4 aware.

*IPv6 over (GMPLS Data Plane + IPv6 Control Plane):* In the GMPLS core, although forwarding remains IPv6-unaware (i.e. forwarding is purely label switching), the control plane protocols (IGP and label distribution) are IPv6 based protocols. This requires all edge (PE) and all core (P) routers to support dual stack (IPv4-IPv6), as it includes an IPv6 control plane.

This paper focuses exclusively on the first scheme relying on 6PEs at the edge of the GMPLS based optical controlled network since only this approach satisfies the operational requirements, as mentioned in IPv6 deployment considerations section, to not impact the GMPLS core. The following section provides detailed description on the 6PE architecture and procedures for transporting IPv6 over the GMPLS backbone.

### 6PE NETWORK ARCHITECTURE OVERVIEW

6PE enables IPv6 network islands to communicate with each other over Multi-service GMPLS based optical controlled backbone network using GMPLS LSPs (Label Switched Path) as shown in Fig. 5. The method relies on Multi-Protocol BGP extensions [9-11] for Provider Edge Routers (6PE) to exchange IPv6 reachability information along with a GMPLS label for each IPv6 address prefix announced. 6PE routers are dual-stack (IPv4 and IPv6).

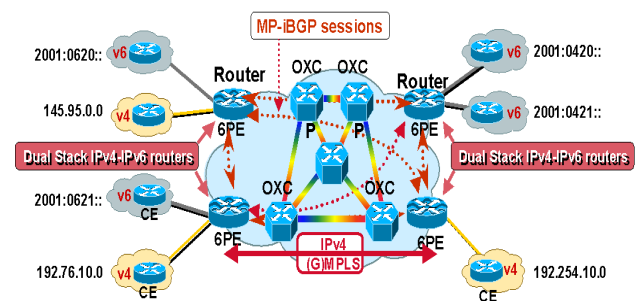


Figure 5. Logical view of 6PE connecting IPv6 islands over GMPLS backbone

In line with the GMPLS based optical network architecture described earlier, the 6PE approach relies on a hierarchy of labels imposed at the 6PE ingress router. The top label provides PE-to-PE connectivity inside the GMPLS backbone network: LDP (Label Distribution Protocol) or RSVP-TE (Traffic Engineering extensions to

ReSource ReserVation Protocol) distributes this label (referred to as the “top label”). The next label (referred to as the “bottom label”) is used by the 6PE egress router for IPv6 forwarding: it is distributed by MP-BGP (Multi-protocol BGP) in the “IPv6+label” address family.

Four types of routing interactions can be found on the path between IPv6 end devices, host A to host B, as shown in Fig. 6. Following steps are indicated as 1, 2, 3 and 4 in Fig. 6:

1. Host A and host B, running IPv6 application and IPv6 stack, is attached to Customer Edge (CE) Router (CE1 and CE2 correspondingly), in IPv6 cloud. IPv6 cloud is running an IPv6 Interior Gateway Protocol (IGP such as RIPng, IS-ISv6, OSPFv3).

2. IPv6 Customer Edge (CE) and 6PE routers exchanging IPv6 routing information through an IPv6 External Gateway Protocol (MP-BGP), Interior Gateway Protocol (IGP) or using static routes.

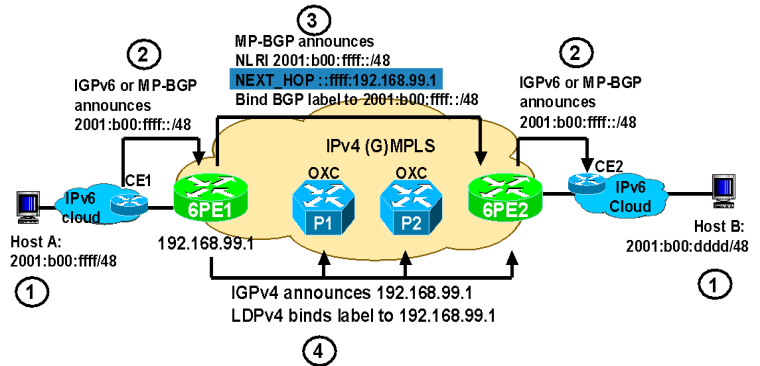
- The CE1 advertises the site IPv6 prefix of host A to 6PE1 using IGPv6, MP-BGP or static routes.
- The CE2 learns the IPv6 address prefix of host A from 6PE2 using IGPv6, MP-BGP or static routes.

3. 6PE routers (6PE1 and 6PE2) peering together through MP-BGP4 (or via a BGP Route Reflector) for exchanging IPv6 reachability over the GMPLS network and performing IPv6 forwarding.

- 6PE1 router announces its attached customers IPv6 prefix reachability to 6PE2 on the network using Multi-Protocol BGP extensions.
- IPv6 address prefix of the customer site (of host A) and corresponding label mapping (associated to IPv6 address prefix) is carried as a part of the Network Layer Reachability Information (NLRI) in the multi-protocol BGP extensions attributes [10, 11].
- Since the provider backbone is IPv4 only, the “NEXT\_HOP” [11] attribute in the announcement must include the IPv4 address of the announcing router, 6PE1. Because MP-BGP requires that the BGP next hop be of the same address family as “NLRI” in the multi-protocol extensions attributes, this IPv4 address of 6PE1 needs to be encoded into an IPv4 mapped IPv6 address [12]. This allows 6PE2 router to automatically learn the IPv4 address of 6PE1 and thus impose the corresponding MPLS IPv4 top label when

forwarding IPv6 traffic to customers connected to 6PE1.

4. GMPLS network, running an IPv4 Internal Gateway Protocol (OSPF or IS-IS) to establish reachability between 6PEs and an IPv4 label distribution protocol (LDP, TDP, RSVP) to distribute IPv4 labels.



**Figure 6.** 6PE Routing and Control Plane interactions for host B to learn routes to host A

IPv6 hosts, IPv6 routers in the IPv6 cloud and IPv6 CE routers are not aware that IPv6 packet forwarding occurs over GMPLS clouds. They operate in their regular IPv6 way. Similarly, P devices (be they P routers or OXCs) inside the GMPLS network are not aware that they are switching IPv6 packets, as they only use GMPLS forwarding, LDP or RSVP-TE for binding IPv4 labels and an IPv4 Interior Gateway Protocol (OSPF or IS-IS) to establish internal reachability inside the GMPLS cloud. Therefore, the 6PE feature does not impact these GMPLS core devices such as P routers, OXCs (acting as P routers), nor IPv6 hosts or IPv6 CE routers. Only the PE devices that actually connect IPv6 users need to be upgraded to support the 6PE functionality. Since forwarding in the core relies on regular IPv4 based GMPLS label switching, line rate performance is inherently available for IPv6 traffic as well. The 6PE approach is very scalable for the service provider since it does not require any tunnel provisioning or any configuration on a per-CE pair basis for CEs requiring communication (which “IPv6 over IPv4 tunneling” approaches involve): connecting a new CE only involves provisioning on the PE connecting this CE - this is sufficient for that CE to automatically obtain global reachability with all other CEs.

### 6PE CONTROL PLANE PROCEDURES

From the Control Plane perspective, the main principles of this method are:

1. The 6PE BGP routers are dual-stack (IPv6 and IPv4) and have a regular "IPv4 address" for peer communication through the IPv4 core.
2. Multiprotocol iBGP is used between 6PEs to exchange IPv6 reachability information. Thus, 6PE2 learns BGP Next Hop address of 6PE1 (as shown in Fig. 6) to reach a destination IPv6 subnet of host A. The BGP protocol encoding rules impose that this BGP Next Hop address be encoded as an IPv6 address. However, 6PE1 needs to convey its IPv4 address (192.168.99.1). Thus, 6PE1 actually embeds its IPv4 address in an IPv4-mapped IPv6 address (::ffff:192.168.99.1) and includes this in the BGP "Next Hop" field.
3. In order to resolve the recursion for an IPv6 destination subnet of host A, 6PE2 first converts the BGP next hop IPv6 address with an embedded IPv4 into an IPv4 address. Then 6PE2 resolves this IPv4 address using the IPv4 Forwarding Information Base (FIB) which provides the GMPLS label of the LSP that can be used to reach the 6PE1. We will refer to this label as the "IPv4 label". The IPv4 label has been populated in the IPv4 FIB through regular IPv4 GMPLS Control Plane procedures using IGPv4 and LDPv4 (or RSVP-TEv4). This IPv4 label is then stored as the top label along with the destination IPv6 subnet address in the IPv6 forwarding table of 6PE2.
4. Multiprotocol iBGP is used by 6PE1 to bind a label to each advertised destination IPv6 prefix as shown in Fig. 6. We refer to this label as the "BGP IPv6 label". 6PE1 creates an entry in its Label Forwarding Information Base (LFIB) for every BGP IPv6 label that identifies how to forward the corresponding IPv6 packets (e.g., forwards towards CE1).
5. The BGP IPv6 label is stored in the IPv6 forwarding table of 6PE2 as the bottom label in the entry for the destination IPv6 prefix of host A.

### Multi-Protocol BGP extension for "Labeled IPv6"

Multi-Protocol BGP already supports the IPv6 address family via the Multi-Protocol Reachable NLRI (MP\_REACH\_NLRI) and Multi-Protocol Unreachable NLRI (MP\_UNREACH\_NLRI) attributes.

6PE requires that Multi-Protocol BGP be further extended to be able to bind a GMPLS label to the IPv6 route as per [10]. The main aspects of this extension for

support of [10] are presented below with some implementation choices where appropriate:

### NLRI Format

The label binding information is piggybacked along the prefix advertisement in the same MP\_REACH\_NLRI attribute. The fact that the MP\_REACH\_NLRI contains a label is indicated by SAFI (Sub-Address Family) value of 4.

The NLRI for labeled IPv6 routes (used in "NLRI" field of MP\_REACH\_NLRI and in "Withdrawn Routes" field of MP\_UNREACH\_NLRI) contains one or more triple <Length, Label, Prefix>:

- **Length:** total length of the label plus prefix
- **Label:** carries one label, where:
  - Label value:** 20 high order bits
  - Unused:** 3 following bits set to zero
  - Bottom of stack bit:** low order bit
 ([9] Allows the Label field to carry multiple label values (that correspond to a label stack) but the 6PE only uses a single label value per NLRI)
- **Prefix:** IPv6 prefix of destination

### Withdrawing Routes and Binding

To withdraw a route and the associated binding, the BGP speaker uses the Withdrawn Routes field of the MP\_UNREACH\_NLRI attribute with a label value set to 0x800000 (in the NLRI field).

### Capability Negotiation

6PE extends BGP Capability Negotiation [14] for supporting "IPv6+label" capability in the following way:

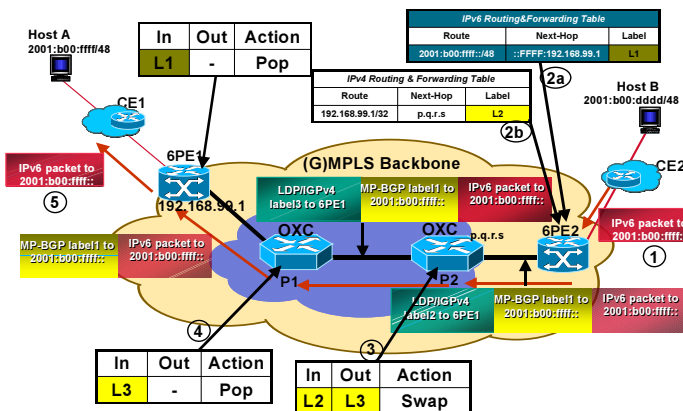
- 6PE advertises capability for "IPv6+label" to a neighbor when configured to do so for this neighbor
- 6PE also advertises capability for "IPv6" (i.e., unlabelled IPv6 packets) since there is a separate Capabilities Optional Parameters for each SAFI (Subsequent Address Family Identifier)
- If a neighbor has advertised "IPv6+label" capability, the 6PE will advertise all IPv6 routes as labeled routes
- If a neighbor has NOT advertised "IPv6+label" capability but has advertised "IPv6" capability, the 6PE advertises all IPv6 routes as IPv6 (unlabelled) routes to this neighbor. Note that if a 6PE receives unlabelled IPv6 routes, then the 6PE does not resolve the recursion and marks these prefixes as unreachable in the IPv6 routing table so that packets to this destination get dropped and not sent into the GMPLS cloud.

## 6PE FORWARDING PLANE PROCEDURES

Packet forwarding can take place after the control plane actions are performed, and the routing table and forwarding table have been populated as described above.

The main principles of the 6PE forwarding plane are:

1. As shown in Fig. 7, host B (attached to CE2 router) sends an IPv6 packet with destination IPv6 address prefix (2001:b00:ffff::) of host A.
2. Once 6PE2 router receives IPv6 packet from CE2, 6PE2 does a look up on IPv6 destination address prefix in the IPv6 FIB. As a result of this lookup, 6PE2 imposes two labels to the IPv6 packet and sends the packet to P2:
  - The bottom label, Label 1 (L1), is the “BGP IPv6 label”, bound by MP-BGP to IPv6 destination address prefix (2001:b00:ffff::), as explained in steps 4 and 5 in previous section.
  - As explained in step 3 of previous section, the top label, Label 2 (L2), was bound by LDPv4 (or-RSVP-TE)/IGPv4 to the IPv4 address of BGP next hop to reach 6PE1 through the GMPLS cloud.
3. P2, in turn, uses the top label, L2, when making its forwarding decision and forwards packet to P1 inside the GMPLS cloud. In other words, inside the GMPLS cloud, normal GMPLS label switching is used based on top IPv4 label, L2.
4. Since P1 is the penultimate hop with respect to the LSP associated with a route to 6PE1, P1 pops the top label, L2, before sending the packet to 6PE1.
5. When 6PE1 receives the packet, the BGP IPv6 label, L1, is used to do a lookup in the Label Forwarding Information Base (LFIB) that instructs 6PE1 on how to forward the packet (e.g., forward towards CE1).



**Figure 7.** IPv6 packet forwarding over GMPLS controlled Optical network

## 6PE SUPPORT OF IPv6 VPN SERVICES

In addition to IPv6 Global connectivity services (supported as described so far), Service Providers need to offer IPv6 VPN services. The prime driver for such IPv6 VPN services is the exact same need for isolation of end users intranets as sought with IPv4 VPN services. The potential use of non-global Site Local IPv6 Prefixes in enterprise networks is another driver for such IPv6 VPNs.

Extensions to the 6PE approach are being standardized in the IETF [13] for also supporting such IPv6 VPN services. This can be seen as combining the “IPv6 handling” of the 6PE approach described above with the “VPN handling” of BGP/MPLS IPv4 VPNs [3]. The major extensions to the 6PE approach described above are:

- Use of a different address family in MP-BGP advertisement, which is the labeled IPv6 VPN family (which allows disambiguation of non-global –and potentially overlapping-IPv6 addresses across VPNs)
- Use of the “Virtual Routing Forwarding (VRF)” concept of BGP/MPLS IPv4 VPNs [3] whereby each VPN has a separate set of routing and forwarding tables.

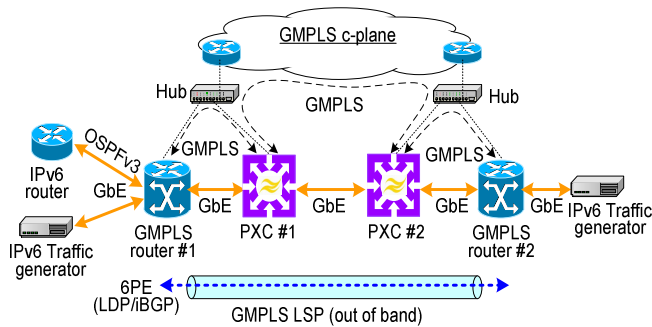
Again, when deploying such IPv6 VPN services, only PE devices that actually connect IPv6 VPN services will need to be upgraded. There will be no impact on the core. End users will benefit from the exact same set of features for IPv6 VPN services as for existing IPv4 VPN services while Services Providers will benefit from the exact same set of Operations, Administration and Maintenance (OAM) tools across IPv4 VPN services and IPv6 VPN services.

## INTEROPERABILITY EVALUATION

Multi-vendor interoperability in terms of GMPLS functions as well as IPv6 transport over GMPLS was evaluated. For this evaluation, an optical core network test bed, consisting of two GMPLS enabled IP/MPLS routers and two photonic cross connects (PXC) using all-optical three dimensional micro electro-mechanical system (3D-MEMS) switches, [15, 16] were used as shown in Fig. 8. The two PXC were connected by a Gigabit Ethernet (GbE) link, and each GMPLS router and PXC were also connected by a GbE link.

Moreover, IPv4 addresses were assigned to interfaces of PXC as well as routers in order to form GMPLS traffic-engineering (TE) links between a pair of interfaces. GMPLS OSPF-TE [17] information was exchanged using an Ethernet based GMPLS out-of-band control plane (GMPLS c-plane), indicating link attributes with a bandwidth of 1 Gb/s, the switching capability of lambda or

packet, and the encoding type of Ethernet. The ingress router initiated a GMPLS RSVP-TE [18] path message of a GMPLS LSP with 1 Gb/s bandwidth and Ethernet encoding and received the reserve message generated from the egress router, and as a result, the GMPLS LSP was successfully established via PXC's by a GMPLS out-of-band signaling mechanism. By using the created GMPLS tunnel as indicated in Fig. 8, non-GMPLS OSPF information came to be exchanged between routers by an in-band signaling mechanism and each router acquired a full routing adjacency.



**Figure 8.** Interoperability Evaluation Test bed configuration

Since PXC's within the GMPLS network are only IPv4 aware and only support IPv4 addresses, the 6PE method was utilized to transport IPv6 packets, by allowing GMPLS routers to be operated as an IPv6 edge. IPv6 addresses were assigned to the GbE interfaces connected to the IPv6 traffic generators and iBGP session was initiated over the GMPLS tunnel between GMPLS edge routers. IPv6 packets encapsulated by the IPv4 MPLS LDP label were successfully transported and confirmed by the packet generating tests.

In this setup, IPv6 routing interoperability between multi-vendor products was also evaluated. As shown in Fig. 8, an IPv6 router from a different vendor was attached to one of the GMPLS routers by a GbE link. By running OSPFv3 between the IPv6 router and the GMPLS router, they became an IPv6 routing adjacency, and as a result, the IPv6 reachability through the GMPLS tunnel could be confirmed from an IPv6 interface on the IPv6 router to an IPv6 interface of another GMPLS router by ICMP version 6. Thus, IPv6 and GMPLS interoperability was experimentally confirmed.

## CONCLUSIONS

Today service providers offer Voice, xDSL, Cable, Frame Relay, ATM, Ethernet, wireless packet data and IP services using an overlay of many different backbone

networks. This paper first briefly discusses current migration of carrier backbone networks toward a unified multi-service GMPLS network infrastructure. A view of such next generation network architecture is being presented to efficiently support both IPv4 and IPv6 centric data as well as multiservice traffic, with a common multiservice GMPLS based optical backbone network for various broadband access networks including xDSL, Cable, FTTH, Wireless etc. This paper describes the architecture and procedures associated with the 6PE (IPv6 Provider Edge) method for support of IPv6 services over GMPLS backbone networks. The 6PE method is very attractive to Service Providers migrating to multiservice GMPLS based networks because it achieves full IPv6 reachability in a scalable way, without any impact on the network core, and with line rate performance in the core. Also, the 6PE method is being extended so that IPv6 VPN services can also be added incrementally to the service portfolio with the same set of features and operational aspects as IPv4 VPNs.

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## BIOGRAPHIES

**MALLIK TATIPAMULA** [SM] (mtatipam@cisco.com) received B.Tech in Electronics and Communications Engineering from Regional Engineering College, Warangal, India and M. Tech in Communication Systems and High Frequency Technologies from Indian Institute of Technology, Chennai (Madras), India. He is currently a senior technical leader for advanced technologies in the Routing Technologies group at Cisco Systems. His expertise include VoIP, mobile wireless, optical networking, IPv6 and GMPLS technologies. He closely works with Service Providers and National Research Networks around the world in deploying these advanced technologies in their next generation networks. He has been with Cisco since 1998. Previously he worked at Motorola as a Principal Engineer, responsible for design of next generation wireless networks. From 1993-1997 he was with Nortel Networks, Ottawa as Senior Member of Scientific Staff, worked on Nortel's Optical and wireless products. He has over 12 years of experience in Telecom and Networking Industry. He is a senior member of IEEE and has served on technical program committees of several leading IEEE and SPIE international conferences. He appeared on Who is who in the world, Who is who in Engineering, Who is who in America. He offers courses at various leading universities, including a course on advanced Internet Protocols: Architectures, Standards and Applications at University of California, Berkeley extn.

**FRANCOIS Le FAUCHEUR** is a system architect at Cisco Systems working in product development in the areas of QoS and MPLS. He has worked for several telecom carriers in France and Australia on the development of enhanced services on ATM, Frame Relay, SMDS, and IP. He has an engineering degree in real-time data processing from the Ecole Centrale de Paris. He edits and coauthors many IETF specifications in the areas of MPLS and QoS, such as MPLS support of Differentiated Services, DiffServ-aware MPLS TE. He has also filed several patents in the areas of MPLS and QoS.

**TOMOHIRO OTANI** received the B.E., M.E. and Ph.D. degrees in electronic engineering from the University of Tokyo, Tokyo, Japan, in 1992, 1994, 2002, and Professional Engineering degree in electrical engineering from Columbia University, New York, in 1998, respectively. He is currently a senior research engineer of KDDI R&D Laboratories, Inc. In

1994, he joined Submarine Cable Systems Dept. of KDDI Corporation. In 1998, he became a research engineer of Optical Network Group in KDDI R&D Laboratories Inc. His research interests have been intelligent optical networks. He received the Young Engineering Award from the Institute of Electrical, Information and Communication Engineers (IEICE) of Japan in 1999. He is a member of the IEICE.

**HIROSHI ESAKI** received the B.E. and M.E. degrees from Kyushu University, Fukuoka, Japan, in 1985 and 1987, respectively. And, he received Ph.D from University of Tokyo, Japan, in 1998. In 1987, he joined Research and Development Center, Toshiba Corporation, where he engaged in the research of ATM systems. From 1998, he works for University of Tokyo as an associate professor, and works for WIDE project as a board member. He has been at Bellcore in New Jersey (USA) as a residential researcher from 1990 to 1991, and has engaged in the research on high speed computer communications. From 1994 to 1996, he has been at CTR (Center for Telecommunications Research) of Columbia University in New York (USA) as a visiting scholar. He is currently interested in high speed internet architecture, including MPLS technology, mobile computing and IPv6.