Optical-Label Switching, MPLS, MPLambdaS and GMPLS

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ABSTRACT

This paper discusses the new architecture and protocol of Optical-Label switching in light of its interworking with MPLS and MPLambdaS networks. The dynamic and agile characteristics of Optical-Label switching indicate its support of diverse QoS, CoS, and ToS services while interoperating packet and circuit switching. Optical-Label switching routers employ time, space, and wavelength domain switching for contention resolution, and they interface with MPLS, MPLambdaS, or any client networks with proper signaling such as extension of GMPLS.

Keywords: Optical Internet, IP, WDM, MPLS, Optical-Label Switching, Wavelength Conversion

I. Introduction and Motivation

It is now a cliché to refer to an ‘explosive’ or ‘exponential’ traffic growth in the Internet. It is also a given fact that the core of the Internet is employing multiwavelength optical networking technologies. Only several years ago, implementation of a ‘Next-Generation Network’ was much debated among computer, telephone, and cable networking communities without reaching any consensus. In the meanwhile, the data traffic has continued its ‘exponential’ growth consistently over the past three decades since the birth of the Internet. This trend was not realized as ‘explosive’ until in 1997 when it became evident that the data traffic will surpass the telephony traffic by year 2001. Internet service providers and telecommunications service providers both realized the obvious need for a scalable networking technology to meet this ever-growing demand. Fortunately and fortuitously, the multi-wavelength networking research was continuing its remarkable progress especially with new enabling technologies such as optical fiber amplifiers. A number of commercial optical networking system announcements coincided with all-optical testbed demonstrations by the DARPA (Defense Advanced Research Program Agency) sponsored MONET (Multi-wavelength Optical Networking) [1, 2] and AON (All-Optical Networking) [3] projects in 1997 and the European Commission KEOPS (KEys to Optical Packet Switching) [4] in 1998. The commercial development and deployment which started in 1997 concentrated only point-to-point scalable capacity with multi-wavelength optical networking. This initial phase of optical networking is often referred to as the first generation optical networking. With the availability of optical fiber amplifier technologies, the first generation optical networking was an immediate success owing to its obvious merits; gracious capacity increase by adding a wavelength at a time without having to install additional fibers. The optical networking research led by MONET, AON, and KEOPS went far beyond the first generation optical networking. The MONET project emphasized the reconfigurable aspect of all-optical multi-wavelength networking and investigated the viability of transparent networking. Such wavelength routing and reconfigurabilities are the bases for ‘the second generation optical networking’. The reconfiguration can be applied to each wavelength without involving any electronics in the data plane. Therefore the second generation optical networking supports format and protocol transparency, and provides optical communication circuit path called lightpath by properly configuring the optics within the optical network elements. While the benefit of transparency is still in debate, the second generation optical networking clearly simplifies hardware in the data plane, and its commercial deployment is currently in progress. The KEOPS project, on the other hand, emphasized optical packet switching. This readily interfaces packetized data with optical wavelengths, and allows flexible granularity beyond the resolution of a wavelength. Optical packet switching [5] facilitates the convergence between telecommunications and computer communications, and will be the bases for ‘the third-generation optical
networking.’ Compared to electronic-packet switching, optical-packet switching achieves lower power consumption, especially when higher line rates and larger switching connectivities are considered.

While it is evident that optical networking, currently evolving from first-generation to second, is likely to continue its evolution towards the third generation optical networking in the near future, the network evolution can be facilitated if the networking technology provides interoperability across multiple generations. In 1997, the author and his colleagues at Bellcore proposed [6] a new networking concept, ‘Optical-Label Switching’, which allows seamless network evolution from circuit-switching to packet-switching. Optical-Label switching allows routing and switching based on short ‘optical-labels’ which include information related to source, destination, traffic engineering, priority, time-to-live, etc. The optical-label switching can be applied to a packet, a flow of packets, a burst, and a circuit, and thus it interoperates with a wide range of switching technologies. Since its first introduction, the optical-label switching technology has made a remarkable progress in all aspects. We have designed a scalable and modular optical label switching router architecture that achieves contention resolution in time, space, and wavelength domains [13]. We have also created an optical-label switching networking architecture that is hierarchical and scalable. Finally, we have experimentally demonstrated very-high speed optical-label switching and routing with optical label-swapping [14, 15, 17].

In the year Optical-Label switching made a key progress towards the Optical Internet, the data networking also made a progress in simplifying protocols and adding a rich set of routing and traffic engineering capabilities. Many of these technologies are based on a set of common ideas. They all use a label swapping technique for forwarding data, the same technique that, not coincidentally, is used to forward data in ATM switches. Unlike ATM, however, all the techniques strive to maintain the control paradigm of the Internet Protocol suite. They use IP addresses and standard Internet routing protocols such as OSPF and BGP. Thus in many respects they combine the best of ATM (fast, simple forwarding) with the best of IP (ubiquity, scalability, flexibility). Historically, the notion of ‘IP Switching’ started from Ipsilon, and soon followed by Tag Switching by Cisco and Aggregate Route-based IP switching (ARIS) by IBM. The set of approaches collectively use equivalent of label switching technologies. A label is simply a short, fixed-length identifier that is used to forward packets. A label switching device will usually replace the label in a packet with some new value before forwarding it on to the next hop. For this reason, the forwarding algorithm is often called label swapping. The label switching device called label switching router (LSR) can run standard IP control protocols to determine where to forward packets. The Internet Engineering Task Force (IETF) has officially met to establish a standard in this area, and has adopted the phrase Multiprotocol Label Switching (MPLS) to refer to these techniques in 1997.

While it was a coincidence that both MPLS and Optical Label Switching were born in 1997 with a notion of label based forwarding, Optical-Label switching specifically attempted the integration of optical networking and data networking, while MPLS itself was initially oblivious of optical networking. In order to address multi-wavelength optical networking, a recent IETF draft on ‘MPLambdaS’ reported an approach to the design of control planes for optical crossconnects (OXC), which leverages control plane techniques developed for MPLS Traffic Engineering. MPLS is a viable technology for integrating or enhancing IP/ATM networking, and MPLambdaS combines the MPLS control plane with the WDM transport layer.

MPLambdaS was successful in integrating MPLS and WDM, but there are a number of important shortcomings when next generation optical networking is considered. First, MPLambdaS assumes circuit switching in the optical layer and excludes the possibility of optical packet switching. While the optical circuit switching by the MPLS control plane is widely acceptable today, future networking is expected to exploit advanced optical technologies for packet switching directly at the optical layer. Second, the current MPLambdaS architecture treats wavelength conversion in a rather awkward fashion. The recent IETF drafts on MPLambdaS state that OXCs can include wavelength conversion, but they discuss no concrete schemes for implementing wavelength conversion. Wavelength conversion is an important capability in resolving packet or circuit contentions not available in conventional data networking. The contention resolution in Optical-Label Switching discussed in this paper utilizes a powerful combination of deflection in time [8, 9], space, and wavelength [10, 11]. Third, the MPLambdaS fails to accommodate label-merging and label push/pop operations. This is related to the fact that wavelength conversion is not sufficiently supported, hence labels or wavelengths cannot be merged into a label or a wavelength.
This paper introduces new aspects of Optical-Label Switching, shows a scalable architecture, proposes a scheme for its interoperation with MPLS and MPLambdaS, discusses optical-label switching network emulation, and experimentally demonstrates optical-label switching and routing.

II. Optical Label Switching AND MPLS

1.1. A. Optical-Label Switching Architecture

The key underlying networking concept behind Optical-Label Switching is an efficient and transparent packet forwarding method using an optical-label switching mechanism which can co-exist with legacy WDM technology on the same fiber. Fig. 1 depicts the underlying concept for a fast connection setup and Fig 2 illustrates an example of a Next Generation Internet Network Element (NGI NE) or an optical-label switching router (OLSR). New signaling information is added in the form of an optical signaling label which is carried in-band within each wavelength in the multi-wavelength transport environment. The optical-label containing routing and control information such as the source, the destination, the priority, and the length of the packet, will propagate through the network along with the data payload. Each optical-label switching router will sense this optical-label, look-up the forwarding table, and take necessary steps to forward the packet. During this processing and switching time, the packet is delayed by the optical fiber loop at the transport-input interface before entering the switch fabric. The goal is to reduce the need to manage the delay between the optical signaling header and the data payload if the optical-router itself provides the optical delay necessary for the short time required for setting the switch states within each network element. If the packet is to be routed to a wavelength/path where there is already another packet being routed, the optical label switching router (OLSR) will seek routing by an alternate wavelength, by buffering, or by an alternate path. This space, time, and wavelength domain contention resolution is a key to implementing optical-router without heavily relying on time-buffers as conventional electronic routers do.

Fig 1. Fast connection setup using the optical signaling header for the accompanying data payload [6,7]. Optical Label Switching Routers (NGI NE) with Label-Processing interfaces quickly read the header and route the packet. If there is switching contention on the preferred path, the NGI NE will attempt to route using an alternate wavelength, to delay the transport, or to route with an alternate wavelength.

The OLSRs are enhanced with two types of label-processing modules to efficiently handle bursty traffic. The first type of modules (LP-CI) interface between the client interfaces of OLSRs and the client machines (e.g. IP routers) to encode optical signaling labels onto the packets added into the network, and to remove optical signaling headers from the packets dropping out of the network. In the language of Multi-Protocol-Label-Processing (MPLS), the LP-CI is considered as an ‘Edge Router’, whereas the rest of the optical-router is considered as a ‘Label Switching Router (LSR)’. This edge router can be either all-optical or optoelectronic, but flexible buffering and grooming capabilities can facilitate handling of diverse traffic patterns. From this respect, optoelectronic routers can be more useful than the all-optical
version especially because the capacity and the connectivity requirements are reasonably low compared to the core part of the OLSR. The second type of label-processing modules (LP-TI) taps a small fraction of the optical signal from the Input Transport Interfaces (TI), detect signaling label information, and relays the appropriate commands to the switch fabric in the OLSR after looking up the forwarding table. The fiber delay is placed at the TI so that the packet including the header and the payload reaches the switch fabric after the switching occurs. This fiber delay will be specific to the delay associated with the combined time delay of header detection, table look-up, and switching. The targeted goal is to accomplish this in ~100 nsec with a ~20 m fiber delay. Alternately, the power tap in LP-TI can be replaced by a frequency selective tap in order to separate the optical-label from the data payload to facilitate label-swapping. In the later section IV we experimentally demonstrate such label-swapping using fiber-Bragg grating based frequency selective filtering to separate the optical-label. On the other hand, label-swapping adds cost and complexity to OLSRs. Later in this section, we introduce a new hierarchical networking architecture that can scale without label-swapping, while providing traffic engineering features of MPLS.

OLSR requires no optical-to-electrical, electrical-to-optical conversion of the data payload at the core, and the data plane is completely transparent to protocol and format of the data payload from end-to-end. Further, optical-label switching accommodates data packets of any length, flows of an arbitrary number of packets, a burst of a long datagram, and even a circuit-connection. Highest degrees of interoperability is possible in optical-label switching. Optical-Label Switching dynamically supports various degrees of QoS (Quality of Service), CoS (Class of Service), and ToS (Type of Service) parameters. The priority based routing gives ‘Class of Service’. Higher priority packets are far less likely to be deflected in wavelength, in time, or in path than lower priority packets. The packet loss probability, latency, and bit-error-rate are also significantly lower for the higher priority packets as they attempt to occupy the preferred wavelength/time/path. Reference [12] shows the simulated results. While this priority based routing would be sufficient for the vast majority of traffic, some traffic may still require a guaranteed QoS rather than statistical and priority based CoS. Optical-label switching allows relatively rapid circuit connections with QoS upon-demand. ToS yet provides another criterion beyond CoS and QoS where differentiation between various types of services can be achieved regardless of priority and QoS parameters. For instance, telephone or video conferencing are examples of real-time interactive applications whose priority can be relatively low. The optical-label switching will have label-fields for CoS, QoS, and ToS parameters, and they can be dynamically accommodated such diverse needs using the signaling scheme discussed in a later section.

The optical-label utilizes subcarrier multiplexing to achieve encoding in the optical frequency domain. Fig. 2 shows the optical label and the data payload in (a) the time and (b) the frequency domain. The optical subcarrier multiplexing technique facilitates optical-label extraction, erasure, detection and rewriting either all-optically or with simple optoelectronics. On the other hand, introduction of ‘deterministic’ optical-labels will relieve the need for label-swapping at each node. The example of such a label is a destination oriented forwarding label like the IP header. Without label-
swapping, scalability of the network is limited to typically 1000 nodes. Introducing a hierarchy in the Optical-Label Switched networks allows scalability far beyond this limit. Each subnet and backbone network can reuse the labels without ambiguity in this hierarchical network. For a national network, imagine a network with a node or a post office at each representing a ‘zip-code’. The optical-label will contain the zip-codes of the source and destination encoded as abbreviated addresses. The addressing and the network architecture are both hierarchical in that the addressing within the zip code will be at the lower level or the subnetwork. At the boundaries of these subnets, the labels must be rewritten. The node at each zip-code corresponds to the LP-CI or the edge router, and it works like a post office where it combines each packet (envelope) with respect to the forward equivalent class (zip code) and with respect to priority (express mail, priority mail, first-class, and second-class). The congestion management and traffic engineering are achieved hierarchically in that the access network will utilize its own congestion management interfacing with that of a Supernet via the LP-CI. The lower hierarchy traffic is handled by the electronic MPLS network, whereas the higher hierarchy traffic handled by the Optical-Label Switching Supernet. The network management is also hierarchical in that detailed addressing within the same zip-code is transparent to that of the Supernet. Any ‘change-of-address’ is handled by the local postmaster who corresponds to the NC&M agent at the post office. If a sender omits a zip-code of the recipient, the packet can be either returned to the sender or it will be forwarded to a special post office which functions like a DNS (domain name server) where the name or the city name will be looked up to find a zip-code. This zip-code based hierarchical networking allows minimum complexity in forwarding while eliminating the need for label-distribution protocol and label-swapping. The routing is destination oriented while the best route is continuously updated by monitoring the network condition. Vast majority of the network traffic will benefit from this addressing scheme, and we will call this CLASS_A optical-label. Fig. 4. shows the structure of CLASS_A optical-label.

Fig. 3. Optical-Label classes. CLASS_A will be a simple destination oriented optical-label containing destination zip-code (~10 bits), source zip-code (~10 bits), priority (~3 bits), duration of the datagram (~8 bits), experimental (~3 bits), QoS (~3 bits), ToS (~3 bits), and Optical-Time-to-Live (~3 bits). CLASS_B will be a destination oriented optical-label with traffic engineering encoded by ~3 bits of TE. CLASS_C uses ‘Label’ rather than the destination oriented optical-label, and works similarly with MPLS requiring CR-LDP or RSVP-TE. CLASS_D is for circuit-switching in which OLSR will cease to switch packet-by-packet or burst-by-burst.

Often, there is a need for additional traffic engineering beyond the simple destination oriented packet forwarding. Fig. 3 shows CLASS_B, CLASS_C, and CLASS_D optical-labels for such purposes. The CLASS_B optical label uses the three experimental bits (EXP) for traffic engineering purposes for a given destination zip-code. Therefore, a number of different label switching paths can be defined for the same destination. The CLASS_C optical-label abandons the destination oriented forwarding, but relies on Label Switching Paths (LSPs) set up through CR-LDP or RSVP. The CLASS_D optical-label is for circuit-switching in which OLSR will cease to switch packet-by-packet or burst-by-burst,

\[ \text{CLASS}_A \]

<table>
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<tr>
<th>00</th>
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<th>Source</th>
<th>Priority</th>
<th>Duration</th>
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<th>QoS</th>
<th>ToS</th>
<th>OTTL</th>
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\[ \text{CLASS}_B \]

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<th>Source</th>
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\[ \text{CLASS}_C \]

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\[ \text{CLASS}_D \]

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<th>Exp</th>
<th>QoS</th>
<th>ToS</th>
<th>OTTL</th>
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Fig. 4. shows the structure of CLASS_A optical-label.
rather it will be attached to a circuit flow provisioned by the NC&M. The role of CLASS_D optical-labels are primarily for performance monitoring and other functions that are necessary even for circuit switched traffic. Circuit set-up and tear-off signaling will be handled by the NC&M but can be duplicated in CLASS_D optical-labels so that straight forward ‘set up’ and ‘tear down’ signaling (SET) can be sent to forwarding tables. For packet switching, Class_A will be dominantly popular format although Class_B and Class_C may be used. For burst switching, Class_C will be dominantly used, while Class_B and Class_A can also be used. Class_D will be for circuit switching with guaranteed QoS.

The OLSRs can avoid implementing label-swapping so long as Class_A , Class_B, and Class_D labels are used. Since the hierarchical addressing architecture supports scalability while using Class_A and Class_B labels, we contend that they can assume the roles of Class_C labels. When Class_C labels are used in a network populated with OLSRs with or without label swapping capabilities, either deterministic labels should be used or the OLSRs without label-swapping capabilities must rely on other OLSRs with label-swapping capabilities to achieve label-swapping.

These optical-labels will encapsulate the data payload which can be an IP or IP/MPLS datagram. Hence the data payload contains the IP header or the MPLS label that was used in the electronic networking, and the optical-label will be simply a representing label for the wide area optical networking adopting optical-label switching. Note that there are priority bits which represents CoS, as well as other bits for QoS and ToS. The CoS achieves priority based differentiated packet forwarding which is only relative and not a guaranteed quality. QoS bits are for guaranteed assurance of QoS parameters. ToS specifies the type of applications such as real-time, or soft-realtime. For instance, IP-telephony packets may have low priority CoS and allow high packet loss QoS, but will require real-time ToS. The above designations are only meant to be examples, and many variations are possible. For instance, Class_C and Class_D optical-label formats can benefit from those covered by the MPLS and MPLambdaS activities of the IETF.

Conventional packet-switched networks emphasized ‘self-routing’ that could rapidly route the packets based on the header contents. This method unfortunately lacked coordination between routers in order to achieve large network level performance. Circuit-switched networks used the NC&M to provision the connections that offered end-to-end QoS, however the connection setup typically took a long time ( >1 sec) to complete. In contrast, Optical-Label switched networks use an architecture involving both the NC&M and the label based signaling, which resemble the human nerve system where the brain (NC&M) and the reflex system (optical-label based signaling) cooperate to achieve the optimum functionality. Signaling (reflex system) through optical-labels quickly makes a routing decision based on the header content and the routing table, and provides the statistics of packet transport ( e.g. how long a packet of what priority is going from where to where through which port) for the NC&M (brain). On the other hand, the NC&M has its own capability to provision a circuit-switched service at much slower speed (~1 sec) than the packet routing performed by the optical-label-signaling (~100 nsec). The NC&M communicates with network elements through the Data Communications Network (DCN) on a supervisory wavelength outside the WDM wavelength band utilized for packet transport. Through the DCN, the NC&M monitors the network traffic conditions, updates the routing table to optimize the network performance, and even attempts to partially restore the fault in the network by correcting the routing table to route around the faulty nodes or links. This is the basis for auto-discovery, auto-configuration, and auto-restoration of the optical-label switched network. The two-tier architecture consisting of the NC&M and the label-signaling will be a basis for achieving rapid but coordinated forwarding of packets in light of the network conditions. From the viewpoint of today’s circuit-switched network, upgrading the network to an optical-label switched network is graceful in that modular upgrades and interoperability are offered in this two-tier architecture. The packet forwarding protocol will be adaptive and will perform the following functions: (a) measure network parameters (such as state of communication lines, traffic, delays, capacity utilization) (b) report the measured information to the NC&M for routing computation (c) compute forwarding tables at the NC&M (d) disseminate the tables to each OLSR in order to have packet routing decision at the OLSRs (e) gather traffic information from OLSRs so that NC&M will update the forwarding tables periodically (f) forward a connection or routing request from a client machine to the NC&M, and (g) forward routing information from the NC&M to the OLSR to be inputted in the optical signaling header. While similar adaptive schemes have long been implemented in the IP, optical label switching achieves this by help of optical-label based rapid signaling as well as the NC&M on the supervisory channel.
In case of switching conflict, the Optical Router can take one, or a combination of the following three choices: wavelength conversion, time-buffering, and path deflection. The new wavelength dimension available in optical routers opens new capabilities far beyond the conventional electronic routers which use buffers as primary tools for packet contention.

- **Wavelength interchange**, where a packet may be converted to an idle wavelength that would allow it to be forwarded onto the next hop. The alternative wavelength routing also achieves the same propagation delay and number of hops as the optimal case, and eliminates the difficulties in sequencing multiple packets. From this perspective, wavelength conversion is a very attractive solution compared to path deflection or time-buffering. The switching fabric scales with the degree of wavelength conversion.

- **Limited delay buffering**, where a packet may be routed through a fiber delay line and recirculated back into an input port of the same Optical Router. At that point, the header content will be read and routing will be attempted again. One interesting point here is that, unlike in the conventional packet switching, no precise bit or packet synchronization is necessary for the buffer. For that reason, the choice of the length of the delay line can be arbitrary, however, there will be a trade-off between the contention resolution efficiency vs. the minimum optical latency. Limited number of delay buffer lines will be incorporated in the Optical Router, and multiple wavelengths are accommodated in each delay buffer line. The optical label switching router includes both wavelength conversion and buffering so that packet wavelength can be converted to another wavelength if the buffer is occupied for the original wavelength.

- **Limited deflection routing**, where a packet may be deflected to a neighboring switching node from which it can be forwarded towards its destination. Care again must be taken to prevent a packet from being repeatedly deflected, thereby causing signal degradation, as well as wasting network bandwidth. The OTTL and Loop prevention schemes discussed above can be applied here.

- **Prioritized packet preemption**, where a newly arrived packet may preempt a currently transmitting packet if the arriving packet has a higher priority. This would be the last resort solution when alternate wavelength, buffering, or path deflection routings are not available. Higher layer protocol such as TCP, or NC&M can request retransmission of the packet if necessary.

**B. Interoperation with MPLS, MPLambdaS via GMPLSII**

Fig. 4 shows an underlying architecture for the Optical Internet Core assumed in this report. The NGI Supernet will interface with NGI Access Networks. These networks are currently categorized in terms of WAN, MAN, and LAN depending on the network architecture, and some of these networks will evolve to be NGI Supernets while some may remain as NGI access networks. The Supernet may evolve from conventional WAN or MAN, and it will typically
require a rapid transport of a relatively large datagram, a burst of packets, or a flow of many packets, in contrast to the NGI access network. When a user in one NGI access network exchanges packets with another user in another NGI access network through the NGI Supernet, it will be beneficial if the packets are ‘bundled’ as a flow, or combined as a burst. If the traffic load is very low, they may be transported as individual packets. It will be also beneficial if these packets, a flow of packets, or a burst of many packets, are differentiated in terms of their priorities for transport, so that the network capacity can be utilized economically. Such priority based transport supports differentiated Class of Service. If it requires a high degree of end-to-end, negotiated, and guaranteed Quality of Service, a circuit can be provisioned end-to-end.

A number of important issues related to NGI Supernet and NGI Access networks include end-to-end congestion management, traffic engineering, and traffic grooming. As Fig 4 illustrates, an effective solution includes introducing a hierarchical structure to all aspects. There will be independent but collaborating congestion managers and traffic engineering in both the access network and the Supernet, while assuring higher layer such as TCP to interact with them. Traffic grooming will occur at the interface between the access network and the Supernet. This hierarchical approach is highly effective since there is a strong contrast between the access network and the Supernet, especially because optics plays a key role in the Supernet.

In Fig 5, the access network routers (shown as diamonds) continuously communicate with each other using out-of-band signaling. This signaling allows not only a flow-control but also early detection of congestion or failures. Shown in solid arrows are packet transports and broken arrows are out-of-band signaling. The diamond attached to the Super User is an Edge router with a bandwidth aggregation capability interfacing with the Optical Router via a LP-CI. The LP-CI adds or removes the optical-labels needed for routing packets in the NGI Supernet. The Edge LAN router is also capable of routing the packets in and out of the super user.
Fig 6. Projected network evolution from conventional electronic networks to hierarchical networks including Optical Label Switching Supernet. (a) is a conventional IP overlay on an ATM network. (b) is a network evolved from an ATM backbone to an MPLS backbone in the network. (c) is a network where MPLS backbone has evolved to an optical-label switching network while the Electronic IP network has been upgraded to the MPLS network. (d) shows how optical label switching network can interoperate with MPLambdaS network and MPLS network at Transport or Client layers.
label switching. Thus we propose GMPLSII which convey necessary signaling parameters for Optical-Label Switching networks. Using GMPLSII, end-to-end signaling across MPLS, MPLambdaS, and Optical Label Switching networks will be possible.

V. Conclusion

Optical label switching provides many desirable features not readily available in conventional networks. It capability to achieve packet switching as well as burst or circuit switching imply seamless network upgrades and network interoperability. By designing a new signaling protocol similar to GMPLS, Optical-Label switching can interoperate with MPLS and MPLambdaS networks. Network emulation experiments showed priority based forwarding of packets with differentiated Class of Service. High speed optical-label switching and routing of optical packets with all-optical label swapping has been experimentally demonstrated.

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