Customer-Controlled and -Managed Optical Networks

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Invited Paper

***Abstract*—There is a growing trend for many large enterprises and other users to acquire their own dark fibers and/or point-to-point wavelengths in condominium network architectures. These customer-owned and -managed networks have necessitated the development of a new set of optical network management tools and protocols. These tools and protocols are based on the new Open Grid Services Architecture and other space-based distributed protocols such as Jini and JavaSpaces that will allow end users to independently manage their own portion of a condominium wide area optical network. Participants in such a network will be able to perform their own restoral and protection, optical add–drop multiplexing, or cross-connect to other users on a peer-to-peer basis without signaling or requesting service from a centrally managed entity.**

***Index Terms*—Computer network management, Internet, optical communication, optical fiber communication, transport protocols.**

I. Introduction

TO DATE, the design and management of optical networks have largely been focused around two architecture initiatives for signaling and setup of optical circuits and/or virtual private networks (VPNs)—generalized multiprotocol label switching (GMPLS) [1] and automatically switched optical/transport network (ASON/ASTN) [2]. In addition, optical user network interface (O-UNI) [3] has also shown considerable promise as a client interface to request the setup of an optical circuit or VPN using either GMPLS or ASON/ASTN.

These technologies are well suited to traditional centrally managed hierarchical networks that are prevalent in today's telecom wide area network environment. However, a new type of network wide area architecture, often referred to as "customer-controlled and -managed networks" [4] is becoming increasingly common among large enterprise networks, university research networks, and government departments. Customer-controlled and -managed networks are radically different from the traditional centrally managed networks in that the enterprise not only manages and controls its own internal local area or campus network, but also controls and manages its own wide area optical network, assuming responsibility for direct peering and interconnection with other like-minded networks. As a consequence, traditional management and hierarchical optical network technologies, which are premised on central provisioning of optical VPNs to customers, are largely unsuitable for customer management of their own optical network.

There are basically two types of customer-controlled networks: metro dark-fiber networks and long-haul wavelength networks, more fully described hereafter.

A. Customer-Owned and -Managed Dark-Fiber Networks

Many schools, hospitals, and government departments are acquiring their own metro dark fiber. In Canada, for example, most universities have acquired dark fiber to provide their own metro network connectivity. Most of these institutions have participated in what are called "condominium" [5] dark-fiber networks so that they to can better manage and control their connectivity and bandwidth requirements. In condominium fiber networks cable installation and management companies, sometimes called alternate distribution companies (ADco) [6], build and maintain dark-fiber networks for a multitude of clients. The ADco's customers purchase individual strands of fiber within the fiber cable in a "condominium" arrangement similar in concept to condominium apartment buildings.

The big advantage of customer-owned metro dark-fiber networks is that the traditional "dollars per megabit" business model for bandwidth is largely replaced by the much lower cost for the one-time capital cost for the dark fiber and initial equipment outlay [77]. Thereafter, any increase in bandwidth only requires a simple equipment upgrade. Customers can take advantage of the inexpensive metro Gigabit Ethernet and more recently 10-Gb Ethernet equipment for lighting up the fiber. The cost of this equipment is generally far cheaper than traditional "carrier class" equipment operated by carriers. Most local area network (LAN) managers are familiar with Ethernet network management interfaces and the processes necessary to run the resulting network.

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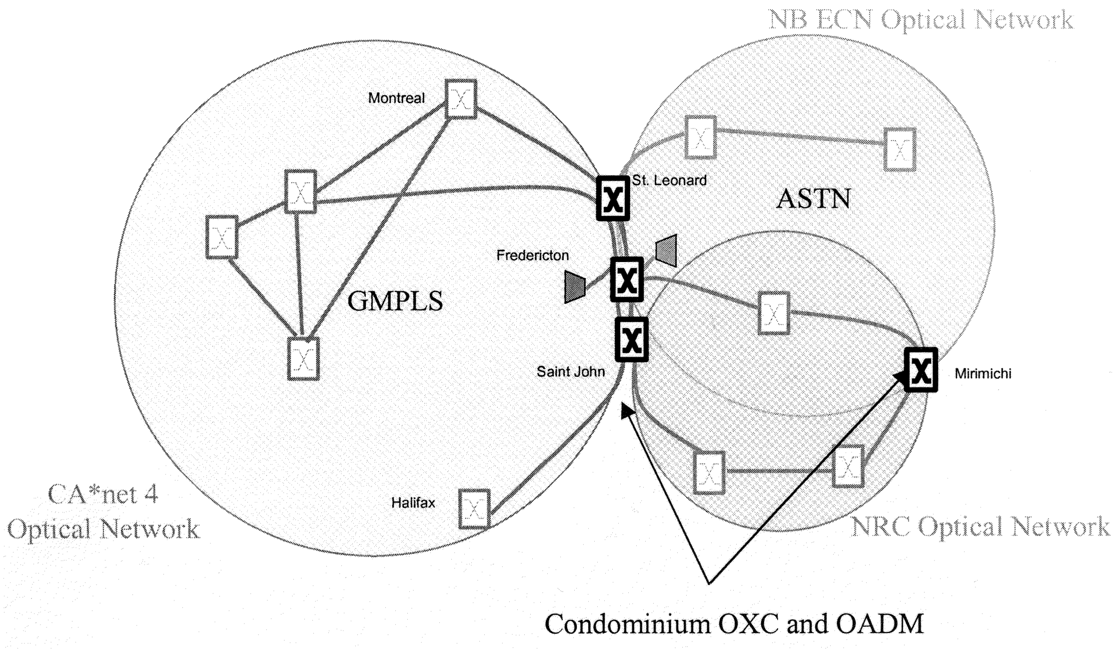

Fig. 1. New Brunswick, Canada, condominium optical network (simplified rendition for illustrative purposes).

B. Customer-Owned and -Managed Wavelength Networks

The advantage of customer-owned and -managed dark fiber in the metro area is now fairly well established. Until recently, the costs of deploying a long-haul optical network between metro areas was daunting for even large enterprise networks. In the past couple of years, however, the ready availability of long-haul dark fiber and the dramatic drop in the costs of long-haul optical equipment have allowed large Fortune 500 companies and a number of research networks to deploy their own long-haul optical network. In Canada, the Ontario and Quebec research networks ORION [8] and RISQ [9], respectively, are good examples of this model. Similar examples in the U.S. are the recent CENIC [10], I-wire [11], and National Light Rail [12] announcements. Recently Boeing, in partnership with Nortel, has announced a strategy to deploy its own national private optical network.

Many carriers are now selling or leasing point-to-point wavelength services to large enterprise and university research networks. A good example of this model is the Canadian national research network CANARIE's CA*net 4 [13], which has purchased point-to-point wavelengths from three separate carriers. The wavelengths terminate on CANARIE- owned and -operated optical add–drop and cross-connect equipment at various nodes across Canada.

In addition, some carriers are offering "condominium" wavelength solutions [14] where a number of clients share the capital costs of deploying an optical network. As a result, each client in the condominium consortium owns outright a set (or sometimes a band) of wavelengths. One of the drivers for new optical control and management systems arise from these condominium networks because, as much as possible, the participating clients want to independently manage their own optical add–drop multiplexing (OADM), optical cross-connect (OXC) to other clients, and offer optical VPN services to third parties.

An example of this style of condominium wavelength network is the proposed network for the province of New Brunswick, Canada, shown in Fig. 1. For this network, the carrier will provide a province-wide dark-fiber ring, and the various participants in the project will share the costs of the fiber and the purchase of the optical equipment to light it. Each participant will have their own set or band of wavelengths and be responsible for providing optical services to their own defined clientele. Therefore, each client needs to independently manage services on the common optical platforms such as the OADMs and OXCs.

II. The Drivers for Customer-Owned Networks

Through arrangements such as condominium dark-fiber and condominium wavelength networks, enterprises and university research networks can substantially reduce the cost of bandwidth, as it now largely becomes a capital cost [15], rather than an ongoing monthly service charge. This is particularly important where the demand for bandwidth increases significantly every year.

Customer-owned networks provide a second indirect cost savings through reduced Internet costs via remote peering and transit. Large enterprise or research networks can use customer-owned and -managed lightpaths to do direct peering with each other and, more importantly, set up lightpaths to popular no-cost peering exchanges [16]. Customer control of the cross-connect allows the user to change the peering relationship without having to contact a central management body or pay expensive Internet transit fees.

A third potential area for cost savings is in the elimination of expensive high-end routers and replacement of them with optical switches. There is a cost, however, in terms of network efficiency as the multiplexing benefit of the routers is lost. Therefore, it is a tradeoff between the cost of wavelengths versus the cost of routers. However, as networks become available with hundreds of wavelengths at 40 Gb/s or higher, the cost to terminate and route the traffic between wavelengths with routers will continue to escalate, whereas the cost of using optical switches to do the same task will remain essentially unchanged.

Customer-controlled and -managed networks also provide significant technical advantages, particularly in support of end-to-end (e2e) lightpaths and Quality of Service (QoS) for large file transfer, storage area networks (SANs), and the nascent grid services [17]. These applications require substantial bandwidth links, in the order of gigabits, that must be provisioned rapidly across multiple independently managed optical networks. To date, few commercial carriers offer intra-network optical VPN services with such capacity, and even fewer, if any, offer this capability across multiple independently managed networks.

III. The Technical Challenges of Customer-Owned Networks

With customer-controlled networks, it is quite common for a large enterprise or research network to purchase dark fiber and/or wavelengths from a number of independent suppliers as well as to participate in a condominium wavelength for some portions of their network. As a consequence, only the customer and no single carrier has total visibility of "their" network and can see all the network elements.

The traditional centrally managed hierarchical networking technologies such as GMPLS and ASON/ASTN assume that the carrier within its management domain has total visibility of all network elements and a common management system with a single interface to the optical equipment. This allows provisioning VPNs, as well as providing for restoral and protection services, etc. Clearly, this type of architecture is not practical with heterogeneous customer-owned and -managed networks. Although there has been recent work on developing inter-domain services, they assume a multiple independent network model of carrier-to-carrier signaling serving as proxy for the customer's request, rather than a customer at the edge negotiating directly with the separate independently managed networks.

Unfortunately, condominium wavelength networks and, to a lesser extent, condominium dark-fiber networks still require common equipment for the optical links across the network. It is neither practical nor cost effective to have independent optical repeaters, OADMs, and OXCs for each separate customer-owned wavelength. In customer owned networks, however, as much as possible, the owners of the individual wavelengths want to manage their own restoral and protection schemes and independently provide optical VPN services.

A simple example is the New Brunswick network cited previously where the CANARIE CA*net 4 network, being a national network, needs to have a separate restoral and protection scheme that is different than the New Brunswick regional network. As the commercial carrier does not have visibility into CANARIE's alternate routes, it cannot provide a traditional GMPLS restoral service. The CANARIE management system is the only one that has visibility and therefore needs access to the New Brunswick switches in order to facilitate a switch over in case of a fiber break or other outage. Similarly, the commercial carrier does not have visibility into the network topologies of the other participants. Therefore, the participants are in a better position, rather than the carrier, to decide on what is the optimum solution for providing optical VPN and restoral services.

IV. The CANARIE CA*net 4 Program

To date, no commercial technology allows multiple entities to manage portions of an OADM or OXC. The CANARIE CA*net 4 program [18] was funded by the Canadian government in December 2001 to build the world's first customer-controlled network. One of its key challenges is to address this management deficit. The basic premise of the CA*net 4 network is that participating regional networks, institutions, and ultimately researchers will be able to manage and control their own lightpaths across CA*net 4. More important, they will be able to independently manage the associated network elements that control the OADM and OXC functions associated with a given lightpath in order to provision their own optical services in support of bandwidth intensive applications, such as grids, and deploy their own restoral and protection schemes.

These network elements can be combined with network elements from other condominium networks or wavelength suppliers and integrated into the customer's network control and management system. Indeed the customer, rather than the carrier, may opt to deploy a GMPLS or ASON/ASTN optical signaling system or network management system that communicates with all of their network elements distributed across multiple independent networks.

In Fig. 1, a real-world application is shown with the New Brunswick condominium wavelength network [19]. Each of the participating parties already has an existing and/or planned optical network with their own independent network management system. To reduce costs, the parties want to build a condominium wavelength network and have common optical equipment for a particular route across the province. However, rather than add another network management system to manage the common OADMs and OXCs, it would be much more preferable to have each management system independently manage its portion of the "condominium" OADMs and OXCs as if they were part and parcel of their own network management system. This will allow each participating organization to do their own add–drop and network configuration.

V. Architecture for Customer Control of OADMs and OXCs

In October 2002, CANARIE issued a call for proposals for researchers and/or businesses to develop solutions that will allow customer control of individual cross-connects on an OADM or OXC to manage their given lightpath across the CA*net 4 network [20].

Early on, it was recognized that the problem of providing customer control of network elements was akin to similar challenges in managing distributed computing and or grids where there may be many independently managed computational

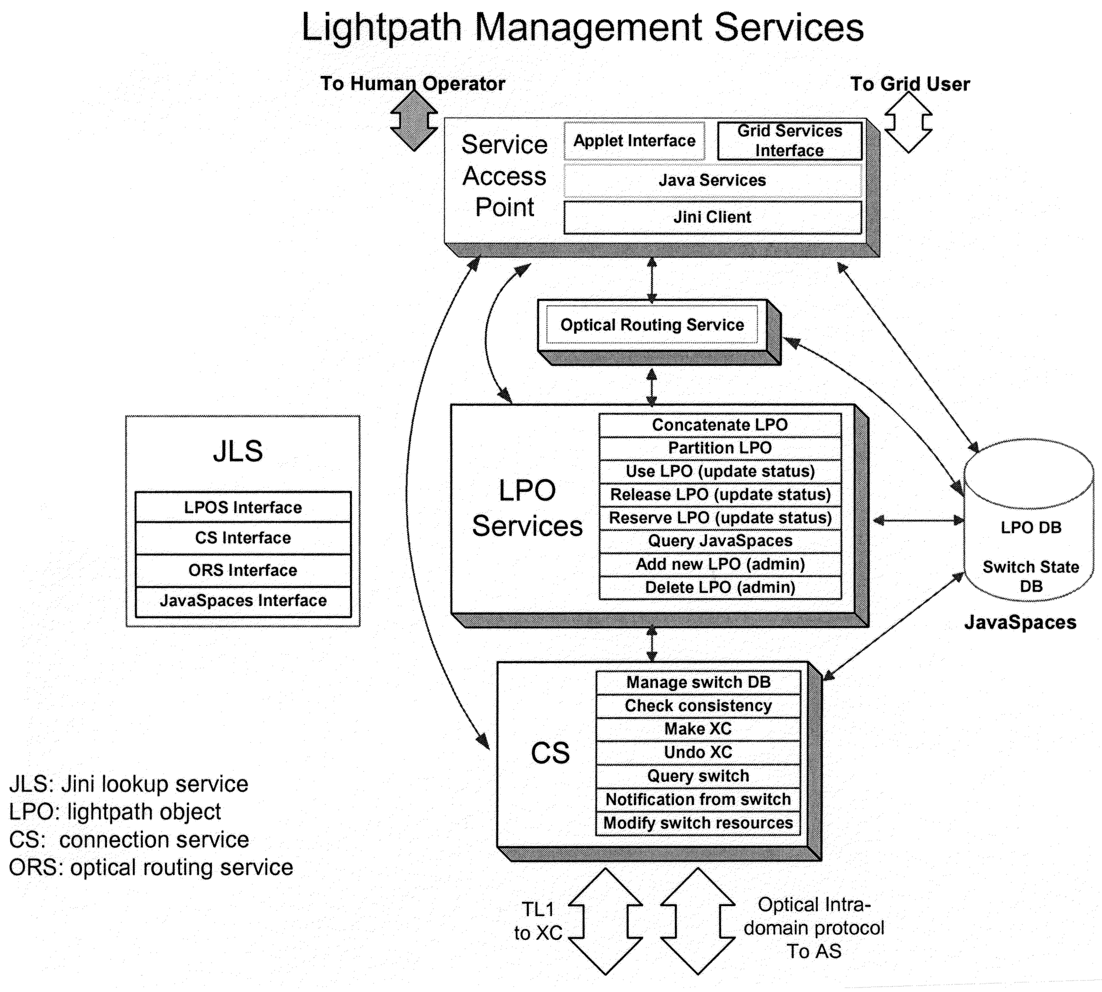

Fig. 2. Lightpath management architecture using Jini and JavaSpaces.

and instrumentation resources. Consequently, respondents to the call for proposals were asked to develop solutions based on technologies that were currently used for grids and other distributed applications.

The most common toolsets are space-based distributed systems using Jini [21], JavaSpaces [22], and Open Grid Services Architecture (OGSA) [23] based on web services. These two different approaches are described more fully hereafter.

A. Space-Based Distributed System for User-Controlled and -Managed Networks

A space-based distributed system fits well with the philosophy of user-controlled and -managed networks. Under such architecture, shown in Fig. 2, each user maintains a public space to advertise or publish its available resources that it is willing to share.

When a user wants to establish a connection, it searches other spaces for resources. The search may involve multiple independent spaces to which it has access. If resources are available, it will reserve them by taking resource objects from spaces. Switching or cross-connects can be activated by invoking the methods associated with the resource objects. The established connection can be further partitioned into multiple resources with smaller bandwidth allocations if the user does not need the whole bandwidth. Some of the partitioned resources or even the whole new connection can be re-advertised for sharing if the user creating them does not use them in a period of time.

“Federations” of users can be dynamically organized so that users can join federations as they see fit and withdraw from federations if necessary. A user can join multiple federations. Each user has its own tailored view of available resources. This allows independent users to collaborate with others in the same federation, even if they may not have formal bilateral agreements. This is distinguished from the conventional client–server architecture, which relies on passing messages directly between entities or invoking methods on remote objects and interacts based on service agreements. The communications between different users’ network management systems are loosely coupled through the use of spaces.

With federations, the resource heterogeneity issue is solved automatically. Spaces may advertise resources acquired from various sources, e.g., purchased dark fibers and/or wavelengths from a number of independent suppliers and condominium wavelengths. Users can utilize advertised resources from a variety of sources without distinction. In addition, control or management interfaces can be dynamically transferred to users. In this way, users do not necessarily have the knowledge

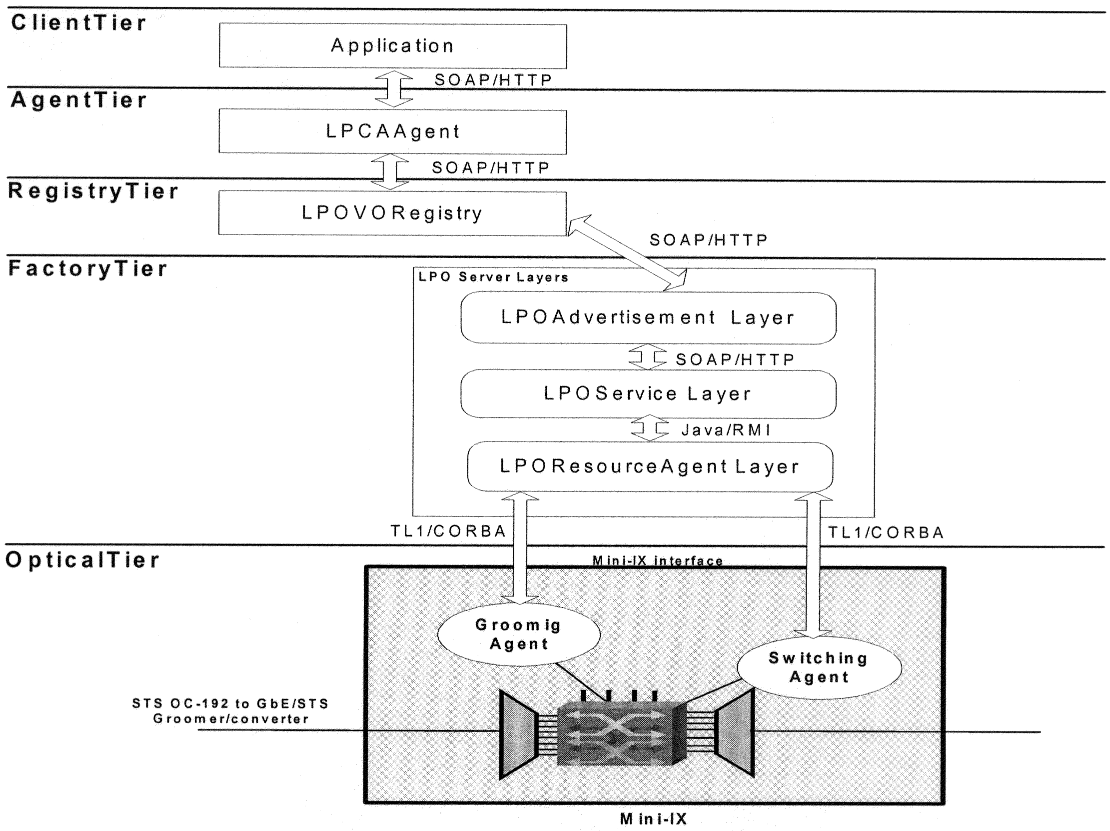

Fig. 3. Lightpath management architecture using OGSA.

about the control or management interfaces before using them. The owners of resources are free to update the control or management interfaces, without having to coordinate with potential users.

B. OGSA for User-Controlled and -Managed Networks

Another approach to user-controlled and -managed networks is to use the new OGSA being developed by the Grid Forum. The inter-domain lightpath optical management system (IDLM), shown in Fig. 3, is an example of this approach.

The IDLM is a multi-tiered service-oriented framework designed based on OGSA and implemented using Globus Toolkit v3 OGSA [24] as a development platform. To break down the complexity, maintainability, and sustainability of developing and operating this framework, it is conceptually divided this into the following five tiers:

1) client;
2) user agent;
3) registry;
4) factory;
5) optical.

Indeed, tiers of this framework are designed in a way that there are no direct dependencies between components of tiers, which are physically hosted on heterogonous distributed computing environment. As Fig. 3 illustrates in the conceptual architecture of IDLM, communication between software components is via Simple Object Access Protocol/Hypertext Transfer Protocol

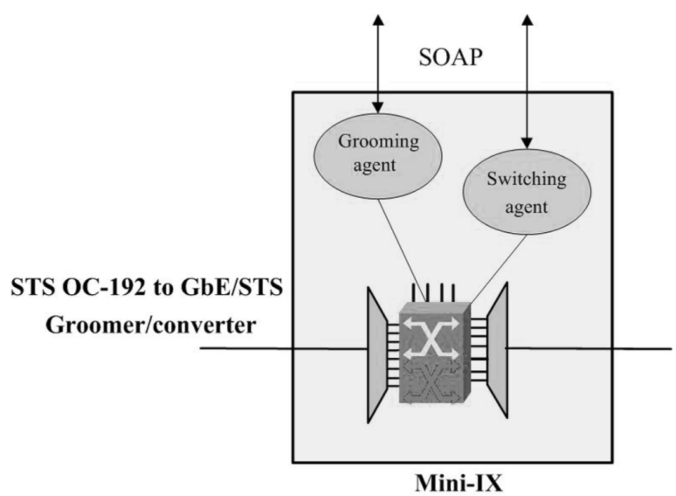

Fig. 4. Installing OGSI skeletons on optical switch.

(SOAP/HTTP) using well-defined extended Web Services Description Language (WSDL) Grid Web service interface [25].

Any given optical lightpath and its associated resource could be modeled as a Grid service in a service-oriented architecture such as OGSA. An end-to-end lightpath created by users of the network could be treated as a network-enabled entity, which provides a particular capability. These capabilities will be defined within a WSDL file, where a client of the lightpath service will be able to discover and invoke supported operations.

The factory tier is a network element (NE)-independent abstract layer, which will discover and register all provisioned

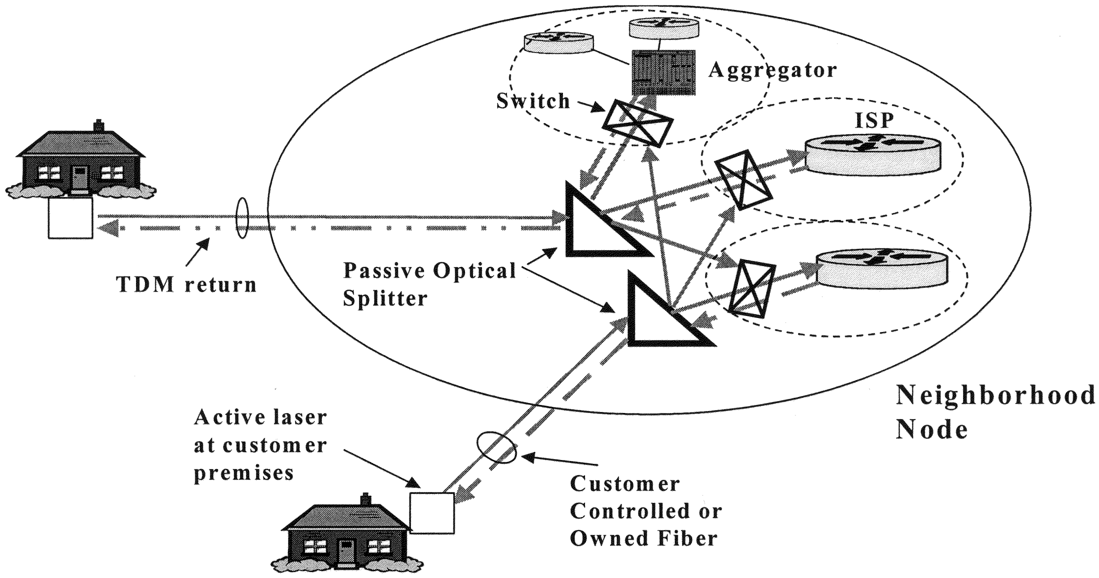

Fig. 5. RPON for customer-owned fiber networks.

end-to-end lightpaths for a given domain with dedicated grid service registry. Each registered service thereafter could be discovered and used by the clients.

The software components of the optical tier are Open Grid Services Infrastructure (OGSI) skeletons and run on an embedded grid hosting environment [26] installed on an optical switch. These skeletons are responsible to wrap native Transaction Language (TL) TL1 codes and provide location and platform transparency. Lightpath Object (LPO) services are instantiated on the optical switch and maintained via OGSI LPO service factories. Fig. 4 illustrates possible installation of skeletons on the grooming and switching agents.

VI. Future Research

A promising area of future research is to apply the concepts of customer-owned and -managed networks to the challenges of delivering broad-band in the last mile with multiple-facilities-based competitive service providers. One approach, called reverse passive optical networking (RPON) [28], extends the concept of customer-owned wavelengths into the last mile. An example of such an architecture is shown in Fig. 5. Rather than having the carrier own and manage the wavelengths to the customer premises, the customer owns and controls multiple wavelengths to a carrier-neutral meet-me point.

Passive optical networking (PON) [29] has been a technology that has been around for quite some time. The original purpose of PON was to provide low-cost customer premises equipment for fiber-to-the-home (FTTH) networks. A single laser beam originating from the carrier's central office would be split and be distributed to several homes using passive optical splitters (up to 32 in some cases). The single laser feed would be carefully modulated so that data for different homes would be included in separate time slots—time-division multiplexing (TDM).

With RPON, the active laser and possible dense-wavelength-division-multiplexing (DWDM) equipment is at the customer premises, and the passive optical splitters are located at the carrier neutral neighborhood collocation facility. The customer's signal is split amongst the various service providers. The service provider with whom the customer has entered a contractual relationship switches the feed into its facilities and generates a return signal using a dedicated wavelength or TDM time slot.

The customer controls and manages the link to the carrier-neutral facility and can then cross-connect to the service provider of his or her choice using the technologies described previously. With RPON moves, adds, and changes can be made with no truck rolls and completely at the customer's discretion.

Currently, the cost of lasers is still too expensive to make this a practical solution. However, with the advent of lower cost high-power vertical-cavity surface-emitting lasers (VCSELs), it is conceivable that this solution may be practical in a few years' time. More significantly, it is conceivable that the customer could operate a number of wavelengths and have a coarse or dense WDM connection to the carrier-neutral collocation facility.

The attraction of RPON and putting the active elements in the customer's premises is that now the customer can control the setup and tear-down of their own circuit-switched connections. For example, one TDM channel or wavelength emanating from the customer's premises could be used for connectionless packet service, while the additional channels or wavelengths could be used to support peer-to-peer connections.

For example, a customer may be interested in downloading a DVD movie file from a peer-to-peer content network, such as next-generation Morpheus or Kazaa. The connectionless TDM time slot would use a peer-to-peer search and discovery for the requested title, which may be located on a self-organizing server nearby on a neighbor's computer or several miles away at a service provider's hosting site. Once the appropriate file is located, the peer-to-peer application could then set up an end-to-end connection circuit using a separate time slot or wavelength for the multi-gigabyte or -terabyte file transfer using these customer-owned protocols described previously.

Because passive optics are used at the carrier-neutral facility, the end-to-end lightpath can be set up without making a signaling request to a central carrier. This is particularly advantageous if the self-organizing server with the requested title is on a neighbor's computer that is connected to the same carrier-neutral collocation facility. In that case, a peer-to-peer wavelength or TDM channel could be established between the two neighbors for the transfer of the requested file.

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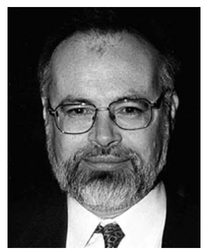

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