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Hybrid Circuit/Packet Technologies for Future Optical Internet

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Abstract: Dynamic capacity migration between circuit and packet networks is an unexplored topic, but it can be an effective way to improve network utilization. We discuss techniques for dynamic capacity sharing between circuit and packet services.

OCIS codes: (060.4256) Networks, network optimization; (060.4257) Networks, network survivability;

1. Introduction

The use of optical networks for supporting bandwidth-hungry services is an attractive proposition to ensure wide-area reach and huge amount of inexpensive bandwidth. Two services which are expected to be prevalent in future optical telecom backbone networks are packet/IP services and circuit/wavelength services (WL) [1]. Packet services including the traditional data services such as VPN, teleconference, data backups, etc. are accommodated over packet technologies and are well established in carrier networks. Wavelength services including bandwidth-intensive applications, such as terascale scientific experiments, characterized by strict QoS requirements, require circuit-switched technologies to deliver guaranteed bandwidth, and are managed directly at optical layer. Wavelength services currently contribute to a small fraction of carrier traffic today, but are expected to grow as applications such as e-science emerge [2, 3, 5]. So, important and timely research is needed to enable telecom carriers to design cost-effective hybrid circuit/packet networks by jointly supporting packet and wavelength services.

Hybrid circuit/packet networks consist of circuit networks co-existing with packet networks; generally the packet network is embedded on top of the circuit network. However, in certain cases such as DOE energy sciences network (ESnet) [3], the circuit network and the packet network are deployed side-by-side (e.g., they have common end-node sites and equipment), but they are logically separate and may have physically disjoint links.

In ESnet, the bandwidth partitioning between the two networks is relatively static. However, it would be very desirable to have dynamic partitioning of the bandwidth between circuit and packet networks, so that the bandwidth can be easily migrated from packet network to circuit network, and vice versa [5]. For example, traffic variations over a day can be exploited by accommodating large data transfers for terascale science applications during the night over the circuit network and leaving its exploitable capacity for packet traffic during peak hours of the day.

Wavelength circuits are often protected by dedicated backup circuits [4], which are generally idle and are unutilized unless there is a failure in the network. Especially with the upcoming deployment of 100G transmission systems, huge amount of backup resources will be underutilized. The network capacity can be better utilized if idle backup circuits of wavelength traffic can be loaned to packet services. We need a design approach that allows the idle wavelength backup capacity to be loaned to packet services without sacrificing the survivability of both services [4]. In this manner, capacity can be migrated from wavelength services to packet services. Similarly, capacity can be migrated from packet network to circuit network by loaning capacity over unused packet links for supporting wavelength traffic [5]. In Section 2, we present capacity migration from wavelength services to packet services in packet-over-circuit networks. In Section 3, we discuss capacity migration from packet network to circuit network.

2. Vertical Stacking: Packet Network over Circuit Network

In packet-over-circuit networks, a packet network is embedded on top of circuit network, e.g., an IP topology consists of IP routers interconnected by lightpaths, while physical topology consists of optical cross-connects / reconfigurable optical add-drop multiplexers connected by the physical fiber links. IP lightpaths are mapped over the physical topology. Network capacity can be better utilized if idle backup circuits of wavelength traffic can be loaned to IP/packet services [4]. In case of a failure (e.g., a fiber cut), IP demands over the backup circuit can be pre-empted and rerouted, while the backup capacity can be restored for serving the wavelength traffic. To reroute the IP traffic over alternate paths, the IP topology must remain connected at all times. Thus, only those backup circuits which do not disconnect the IP topology in case of a failure can be loaned.

We will explain an important concept used in selecting appropriate backups for supporting IP traffic using the illustration below [4]. Fig. 1 shows the IP topology to be supported over the physical topology. In Fig. 2, a sample six-node physical topology is given with two wavelengths/link. Note that, in Fig. 2, two wavelength (WL) circuits between 1-5 and 1-2 (marked by solid lines) have been already provisioned. The backup capacities for these WL paths are provisioned via routes (1-5-2) and (1-6-5), respectively (dashed lines). We observe that, for provisioning the IP demands 1-5 and 1-2, we can either use the backup paths in the physical topology if they are available, or we can establish new lightpaths. Figs. 3 and 4 describe two different solutions. In Fig. 3, both the backup wavelength circuits, (1-5-2) and (1-6-5), are used. If the physical link 1-5 fails, then both the backup circuit (1-5-2) and primary circuit (1-5) fail, which result in preemption of the IP traffic over the backup circuit (1-5). Hence, the solution in Fig. 3 does not provide a survivable mapping of IP connections, whereas the solution in Fig. 4, which uses only one backup wavelength circuit (1-5), is survivable. We need to consider failures of backup circuits not only due to failures of the links over which they are passing (backup circuit (1-5-2) in Fig. 3), but also due to failures of their primaries (primary circuit (1-5) and backup circuit (1-6-5) in Fig. 3) [4]. Thus, *a careful choice of backup circuits is crucial to ensure the survivability of IP topology*.

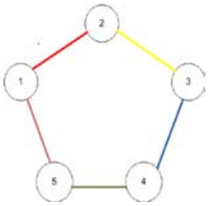

Fig. 1: Sample IP topology.

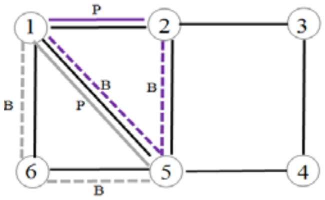

Fig. 2: Sample physical topology.

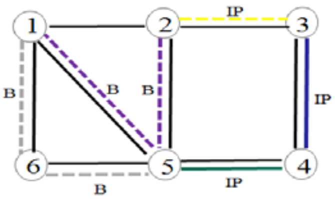

Fig. 3: Non-survivable mapping.

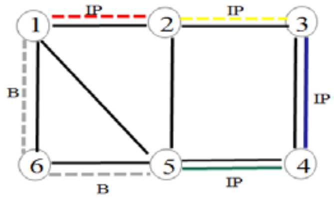

Fig. 4: Survivable mapping.

We assume that wavelength circuits are already assigned, and we formally state the problem as follows: Given a network topology, existing wavelength traffic, available wavelengths on each link, and IP layer demands, we need to assign lightpaths to the IP demands such that the overall cost (in terms wavelength usage) is minimized. The constraints are: (a) For every IP layer demand, either an existing idle backup circuit can be used or a new lightpath can be established. (b) Number of lightpaths on each link must be less than number of wavelength channels supported by it. (c) The IP topology must remain connected under all single link failures. Integrated approaches for jointly provisioning both IP and wavelength services at the same time can also be developed.

We conducted experiments using the 14-node, NSF physical topology (shown in Fig. 5) and regular IP topologies on top of them. We note that the cost savings are in the range of 44% to 70%, compared to no backup sharing. Figure 6 shows number of wavelength channels needed for the following three different cases. In Case I, there is no backup capacity sharing between IP and wavelength services. Cases II and III allow backup capacity sharing with and without survivability, and are similar to Fig. 3 and 4, respectively. We observe that there is a large saving in wavelength channel count in Cases II and III compared to Case I. Case I is the most expensive as new lightpaths are established for every IP demand. The percentage of cost savings in Cases II and III compared to Case I is on the order of 44% to 70%. Note that Case III can ensure survivability of the IP topology by incurring a small additional cost compared to Case II. More details can be found in [4].

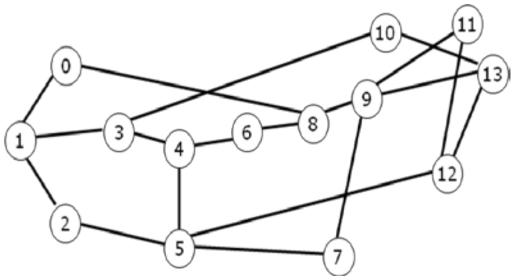

Fig. 5: 14-node NSF topology used in this study.

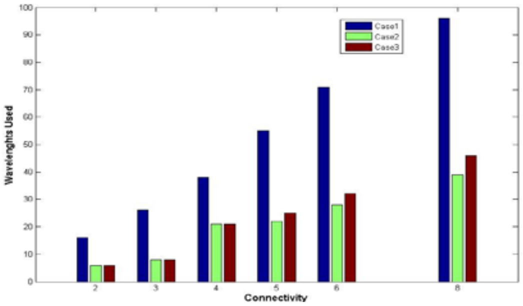

Fig. 6: Total number of wavelengths needed versus connectivity of the IP topology.

3. Horizontal Partitioning: Packet Network beside Circuit Network

Bandwidth can be dynamically migrated from one network to another. The circuit network in ESnet, known as science data network (SDN), provides dynamic and scheduled circuit services [3]. ESnet's SDN is based on traffic-engineered circuits that can be likened to a comparable dynamic wavelength circuit network in terms of end-to-end flow handling. In ESnet, the packet and circuit networks are physically disjoint. The SDN and packet network topologies in ESnet are shown in Figs. 7 and 8, respectively. When the capacity in the circuit network is exhausted, the excess capacity from the packet network can be borrowed [5]. While provisioning the wavelength services over the packet network, we need to ensure that services are not disrupted due to IP link failures.

Below, we describe a specific case of bandwidth migration from the packet network to circuit network. The scenario arises when we try to provision dedicated protections to all SDN reservations in ESnet [5]. We use a snapshot of the ESnet topology and traffic, focusing mainly on circuit network (SDN). The traffic consists of 15 active circuit services in the SDN network. The SDN topology comprises SDN nodes and logical links between those SDN nodes. The SDN nodes comprise optical crossconnects (OXCs) and routers. Note that these logical SDN links are mapped over a physical network of optical fibers by leasing capacity from Level-3 network [6]. There are 16 nodes in the SDN network. Every link in the SDN network is bidirectional and is of 10 Gbps capacity. The reservation requests are of 1 Gbps, 2.5 Gbps, and 3 Gbps capacity. The total capacity lit-up in the SDN network is 700 Gbps. ESnet [3] set up primary circuits for supporting these 15 reservations. The capacity used is 85 Gbps. The rest of the capacity is idle.

In our experiments, we want to protect these 15 SDN reservations by providing dedicated protection (since the network has a lot of excess capacity) [5]. We were able to protect 13 out of the 15 active SDN reservations with dedicated backup circuits, and only 218.5 Gbps out of 700 Gbps of SDN capacity is used. Note that there is only one logical SDN link connecting SDSC node to rest of the SDN network (Fig. 7), and 2 out of the 15 active reservations are to SDSC. Thus, it is not possible to provision backup circuits for reservation requests to SDSC with the existing lit-up SDN capacity. We also note that, by borrowing capacity from just two IP links, namely LASV-SDSC and SUNN-LASV, from the packet network (Fig. 8), we can ensure two-connectivity at SDSC and provide dedicated protection for all the active 15 wavelength service requests. In this manner, capacity can be migrated from packet network to circuit network for routing primary or backup wavelength circuits.

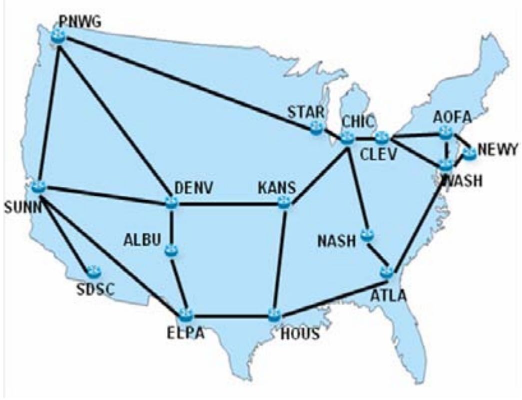

Fig. 7: ESnet Science Data Network (SDN) Topology.

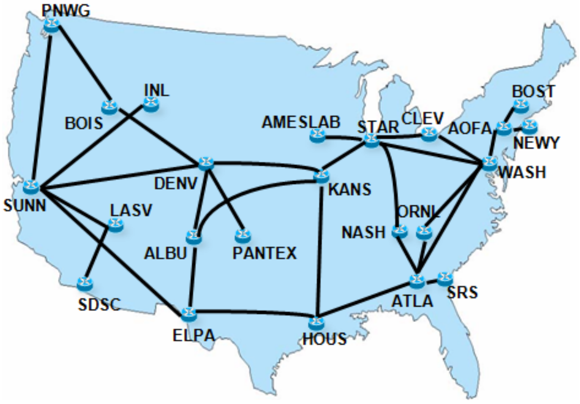

Fig. 8: ESnet Packet Network (IP) Topology.

4. Conclusion

In this paper, we discussed flexible capacity partitioning mechanisms in hybrid circuit/packet networks for supporting future Internet applications. The mechanisms result in significant cost savings in the range of 44%-70%.

References

[1] J. Simmons, *Optical Network Design and Planning*, Springer, 2008.

[2] A. Chiu et al., "Network design and architectures for highly dynamic next-generation IP-over-Optical long distance networks," *Journal of Lightwave Technology*, vol. 27, pp. 1878-1890, 2009.

[3] http://www.es.net/.

[4] C. S. K. Vadrevu and M. Tornatore, "Survivable IP topology design with re-use of backup wavelength capacity," *Proc. IEEE International Symposium on Advanced Networks and Telecommunication Systems (ANTS)*, IIT Delhi, India, 2009.

[5] C. S. K. Vadrevu, M. Liu, M. Tornatore, C. P. Guok, E. Chaniotakis, I. Monga, and B. Mukherjee, "Hybrid circuit/packet networks with dynamic capacity partitioning," *Proc. Third ITU-T Kaleidoscope Conference*, Pune, India, 2010.

[6] http://www.level3.com/downloads/Level_3_Network_map.pdf.