Bridge-And-Roll Demonstration in GRIPhoN (Globally Reconfigurable Intelligent Photonic Network)

Xiaolan J. Zhang[1], Martin Birk[2], Angela Chiu[2], Robert Doverspike[2], Mark D. Feuer[2], Peter Magill[2], Emmanuil Mavrogiorgis[3], Jorge Pastor[2], Sheryl L. Woodward[2], Jennifer Yates[3]

[1] *Department of Electrical and Computer Engineering, University of Illinois, Urbana–Champaign*
[2] *AT&T Labs-Research, Middletown, NJ* [3] *AT&T Labs-Research, Florham Park, NJ*
email: xzhang29@crhc.illinois.edu

Abstract: We describe a ROADM architecture for a dynamically reconfigurable photonic network and demonstrate the performance of a photonic-layer bridge-and-roll that could improve the operational flexibility of optical transport networks.

OCIS codes: (060.4261) Networks, protection and restoration, (060.4265) Networks, wavelength routing

1 Introduction

Traditional client-to-client wavelength path configuration in Reconfigurable Optical Add/Drop Multiplexer (ROADM) networks [1] requires a costly manual process to install transponders and attach them to both ROADM wavelength add/drop ports and client ports. Clients to the transport layer include IP routers, Ethernet switches, OTN switches, etc. The Globally Reconfigurable Intelligent Photonic Network (GRIPhoN) utilizes the reconfigurability of Fiber Cross-Connects (FXC) to replace the manual steps in provisioning new circuits. Technology advances of FXCs during the past ten years have greatly reduced the price per port. This enables greater dynamic reconfigurability in the photonic layer because large-scale networks with extensive use of FXCs can be built inexpensively. In these networks, any client is able to connect to any transponder, and each transponder can in turn transmit on any wavelength in any direction, all via remote control. These features eliminate error-prone human operations and produce cost savings and flexibility for future network products and services that require faster service provisioning, hitless reconfigurations, and graceful growth.

The GRIPhoN research testbed is a network resource management and operation platform capable of supporting advanced dynamic routing algorithms that incorporate customized cost models and network transmission limitations. GRIPhoN management software maintains a database to track the current availability of wavelengths, transponders (T/Rs) and regenerators (Regens) and supports a user interface to create/delete/reroute client-to-client direct or regenerated paths. To minimize service interruption during lightpath reconfigurations, GRIPhoN can execute Bridge-and-Roll (B&R) operations, a feature that can benefit many applications. For example, B&R can improve network availability by allowing client traffic to be moved hitlessly for scheduled maintenance or reversion from failure restoration (moving traffic from backup paths to repaired primary ones). B&R would improve on-demand wavelength services on the photonic layer since the network load can be balanced over time [2].

2 Photonic Layer Node Architecture

The node architecture in GRIPhoN is presented in Fig. 1. A commercial ROADM supplied by Fujitsu has full wavelength-by-wavelength connectivity among inter-node fiber pairs, as well as 100% add/drop capability. Two colorless FXCs are used to increase the path reconfigurability of the node. We have inserted a line-side FXC, L-FXC, between the wavelength MUX/DEMUX panel and the T/R/Regen bank of the Fujitsu ROADM. This enables colorless and steerable operation of the T/Rs. A client-side FXC, C-FXC, is inserted between the T/R bank and the client cards. This enables the client circuits to be dynamically reconfigured, and can enable sharing of T/Rs for on-demand services. The transmission port of each client card is connected to a 50/50 optical passive splitter. Automatic wavelength route reconfiguration and B&R are achieved in the GRIPhoN control software by coordinating changes in L-FXC, C-FXC and ROADMs in a series of operations described in the next section.

3 Bridge-And-Roll Implementation

The process of creating a long-distance wavelength path across multiple ROADMs via vendors' management systems can take minutes. Path reconfiguration using B&R in GRIPhoN reduces the service interruption by first creating a full new wavelength path (the "bridge") when the clients are still connected by the original

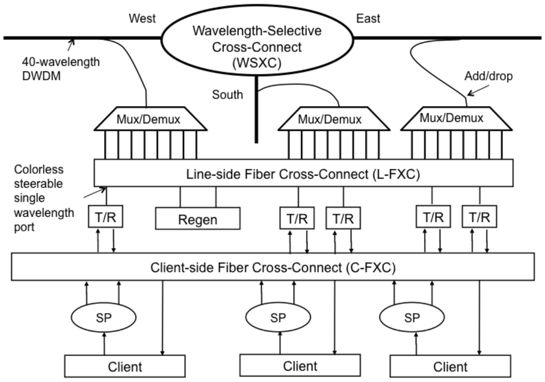


Fig. 1: Node architecture in GRIPhoN testbed. T/R is an optical transponder. Regen is a 3-R regenerator. Both T/R and Regen are 40-wavelength tunable. SP is a 50/50 optical passive splitter. For simplicity, each line above the T/Rs represents a fiber pair.

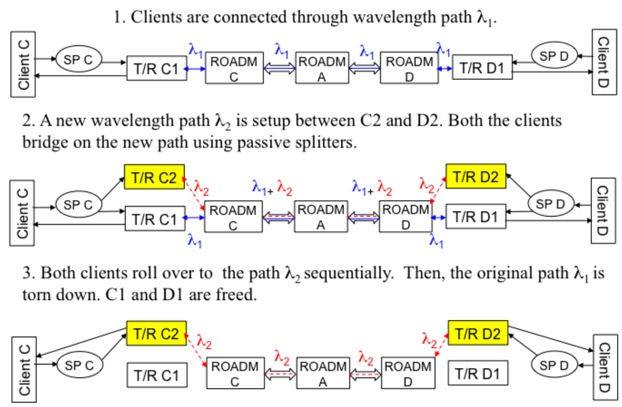


Fig. 2: An example of B&R to reroute a client path from wavelength λ_1 to λ_2. Each step is performed at each end. The same technique applies when switching regenerated paths.

path and then quickly "rolling" the traffic onto that path when ready. Appropriate L-FXC connections select the wavelength of the new lightpath. The "roll" migrates the client connections from the original T/Rs to the new T/Rs using the C-FXCs. This B&R procedure is illustrated in Fig. 2. Initially, client C and D are connected through ROADM C, A and D on wavelength λ_1. The process begins by remotely connecting the client "transmit" signals through the C-FXCs to a pair of additional T/Rs, C2 and D2, one at each end. Next, a new lightpath is established with wavelength λ_2 between C2 and D2. This process involves configuration of all ROADMs (C, A, D) in the route and the L-FXCs at node C and D. At this point, λ_1 is still the active path used by the clients. The "roll" step uses each C-FXC to quickly move the receiver connection of each client from the original T/R to the new one. The physical switching speed of the C-FXCs determines the duration of optical power loss at the client receivers. Now both clients communicate through wavelength λ_2 so the old path can be torn down and T/Rs C1 and D1 are available for other circuits.

In order for the B&R to work, the new path has to be resource disjoint to the old path. This imposes some limitations on choosing the new path. One free T/R at each node is required, and the FXCs must be large enough to serve all the clients (preferably by growing the FXC's as clients and T/Rs are added).

4 Management Platform Design

The GRIPhoN management platform supports automatic path creation, deletion and rerouting. The software consists of three layers of abstraction: The Routing Manager, the Link-routing Manager and the Device Manager (see Fig. 3). The lowest level is the Device Manager, which manages cross-connections through the ROADM network and its interfacing FXCs. The routing algorithm is customized to handle particular equipment constraints of the lowest layer of equipment (ROADMs and FXCs). The Link-routing Manager interprets and models the topology into a logical (graph-theoretic) network model that enables the Routing Manager to take advantage of general network routing techniques. Furthermore, the logical network model defines essential network resource usage information and creates simple logical queries and commands for the higher layer software modules. Such abstraction suppresses low-level hardware implementation from high-level routing functions. For example, this approach allows standard "shortest-path" routing algorithms to be easily enabled. For more advanced capacity-sensitive routing, we define a cost model and employ a "reachability matrix", i.e., an array that specifies which node pairs can be supported by regen-free paths from the given equipment characteristics, fiber characteristics, and topology. Finally, the Routing Manager processes high-level routing requests from users. For path creation between two clients, the Routing Manager finds the least-cost, available path on the logical topology and sends commands to the lower-layer software modules to create the connection. To reroute an existing connection to an alternate path (e.g., fiber-diverse from the existing path), the Routing Manager finds the least-cost alternative path and the lower layer software modules reroute the clients from the old path to the new paths via B&R.

NThA1.pdf

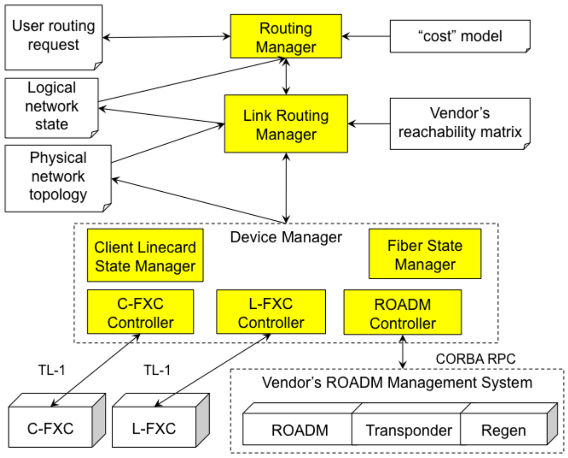
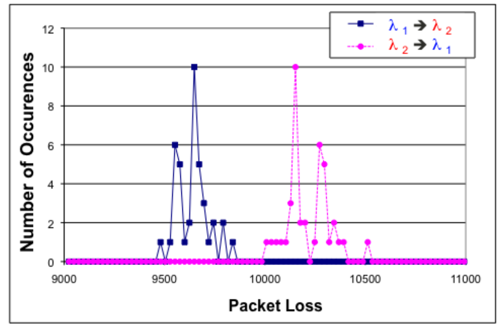


Fig. 3: Software architecture for the management platform.



(a) Distribution of packet loss over 40 repetitive B&R tests in each direction.

Bridge-and-Roll	$\lambda_1 \rightarrow \lambda_2$	$\lambda_2 \rightarrow \lambda_1$	max. (all)
packet loss	9628	10204	10511
outage (ms)	8.04	8.52	8.78

(b) Average packet loss and outage for B&R in each direction.

Fig. 4: Measurement of service interruption at Ethernet layer using photonic B&R to switch a client-client wavelength path from $\lambda_1 \longrightarrow \lambda_2$ and $\lambda_2 \longrightarrow \lambda_1$.

5 Performance Measurement

We have measured the statistics of data service interruption with a sequence of 80 B&R events on the GRIPhoN testbed, using the B&R procedure described in Fig. 2. In the experiment, a 10Gb Ethernet packet tester served as the client at each node. The number of packets lost during the B&R events was then measured and recorded. The packet tester transmitted a continuous stream of 1024-byte packets at a constant data rate of 1.2 million packets per second, and packet loss was measured in one of the two directions. 40 rolls from λ_1 to λ_2 were interspersed with another 40 rolls from λ_2 back to λ_1. Fig. 4(a) shows a packet loss histogram of the 80 events. Both the average packet loss per event and the inferred average outage time are shown in Fig. 4(b). Note that the system switches slightly faster in one direction than in the other. This characteristic is probably due to variations among individual port-pairs within the FXC. It is encouraging that the observed blackout times are well below the familiar SONET restoration requirements (50 ms). With such rapid reconfiguration, links of a higher layer network that routes over GRIPhoN connections (such as the IP-Layer) are expected to stay "up" because they will not detect a link outage when the hold-down timers in the higher-layer network are configured properly.

6 Conclusion

We demonstrated Ethernet packet loss period much less than 50 ms in a photonic layer bridge-and-roll experiment. Future study is needed with a variety of FXC technologies and on dimensioning spare resources for network-wide full reconfigurability.

We wish to thank Fujitsu Network Communications, Inc. for its equipment and technical support.

References

1. M. D. Feuer, D. C. Kilper, and S. L. Woodward. *Optical Fiber Telecommunications*, volume B: Systems and Networks, chapter RODAMs and their system applications. Elsevier Inc., London, UK, 2008.
2. S. Fortune and L. Zhang. The effect of bridge-and-roll on minimizing wavelength conversion for dynamic traffic. in *Proceedings of ECOC*, 2008.