3D-MEMS PHOTONIC CROSS-CONNECT IN SUBMARINE CABLE LANDING SITES

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Abstract

Undersea fiber-optic cables provide the vast majority of intercontinental Internet bandwidth. With the tremendous traffic growth on these cables, outages caused by cable breaks and equipment failures are unacceptable. Furthermore, traditional protection schemes do not protect against simultaneous catastrophic failures. Through the use of photonic cross-connects, a submarine cable operator has successfully deployed a solution capable of remotely creating, monitoring and restoring the light paths as needed. This paper will discuss the deployment of 3D-MEMS photonic cross-connects at submarine cable landing sites. With this approach, the operator has improved network availability and manageability, reduced OPEX, and enhanced network upgradability.

1. INTRODUCTION

Over the past several years, global undersea cable operators have faced severe pressure on cost due to protracted price erosion and network overbuild while confronting increasing commitments on service quality. At the same time, these networks have been forced to keep pace with the bandwidth growth on terrestrial networks. Most undersea cables installed today support hundreds of thousands, or even millions, of simultaneous voice calls and internet traffic due to the adoption of DWDM technology on these networks. This technology allows multiple high-speed channels, i.e., 10 Gbits/sec, using different wavelengths, i.e., 40 colors of light, to be transmitted over a single fiber. With this high volume of traffic running over a single fiber, and the increasing amount of information terminated on each of the many transponders, any fiber break or equipment failure can result in significant down time for the customer(s). Therefore, it is critical to ensure service continuity to avoid costly Service Level Agreement (SLA) penalties and maintain customer satisfaction.

Since the first transoceanic cables were laid, there have been cable breaks and equipment failures. As redundant fiber optic networks have been deployed, the number of cable breaks and equipment failures has lessened, but the time to repair is still unacceptably long and, due to traffic growth, the impact of a service outage is exponentially greater.

In 2006, a submarine cable operator realized that they had a growing problem at their submarine cable landing sites. They were experiencing extended outages at these sites resulting from wavelength transponder failures. Later that same year, an earthquake in Taiwan raised awareness broadly among operators of the affects of any service disruption whether it is natural or terrorist related[1]. Photonic cross-connects have emerged as a viable solution to enhancing the survivability of communications at undersea landing sites.

In the case of wavelength transponder failures, maintenance windows are usually narrow and require advanced scheduling since cable landing sites are generally in remote locations. As a result, once a fault occurs, service restoration could take hours to a day. In this scenario, the operator had to significantly increase maintenance costs to avoid severe SLA penalties. The maintenance costs were primarily due to a dramatic increase in support calls to affected sites. Moreover, these calls had to be performed by highly experienced technicians. The failing equipment was frequently the wet side line cards, whose replacement was expensive, specialized, and problematic. Not only was it difficult to schedule a technician who was qualified to replace them, but in some instances the replacement cards would fail as well. This often required the technician to make a return trip with another line card. Ultimately, the submarine cable operator successfully addressed these problems by using photonic cross-connects to improve network availability and reduce operational costs in the process. The resulting benefit is a network which is easier to manage and better positioned for future upgrades.

This paper will discuss Three Dimensional Micro-Electro-Mechanical Systems (3D-MEMS) based photonic cross-connect deployment for wavelength restoration, central monitoring and management, simplified equipment upgrades, and other photonic switching applications at submarine cable landing sites. The benefits of these applications are increased availability and reduced OPEX at these facilities.

2. PHOTONIC CROSS-CONNECT

Photonic cross-connects began being deployed in 2002. Carriers and undersea operators recognized that the ability of the photonic cross-connect to transparently switch optical signals from one fiber to another without conversion to the electrical domain has major benefits for a wide range of applications in the fiber optic industry. Furthermore, MEMS based photonic cross-connects have the following benefits over electronic cross-connects: lower cost, smaller size, lower heat and power, protocol and line rate transparency, and higher efficiency.

This dramatic reduction in power, size and heat for a system capable of remotely switching optical signals meets requirements at undersea landing sites. This translates into a reduced footprint and lower operational cost by eliminating the need for additional power-generation and distribution equipment such as batteries, rectifiers, diesel generators and monthly maintenance.

In terms of technological enablers, 3D-MEMS architecture has emerged as the economically viable approach for building transparent and scalable systems. 3D-MEMS fabrication is performed by tools and techniques similar to those used to manufacture widely adopted integrated circuits (IC). As a result, the technology has quickly found its way into a variety of commercial, defense, and medical applications. The primary advantage of 3D-MEMS technology is that it allows many small but complex elements to be precisely built on a wafer through lithography, etching, and masking processes. Through batch fabrication and minimization of materials, 3D-MEMS-based products have become mass manufacturable and cost-effective. These micro devices are light-weight and require very low power while providing high performance.

3D-MEMS photonic cross-connect systems based on beam steering mirrors have been explored by many researchers[2-3]. These switches allow many optical channels to be switched in a relatively small amount of space, utilizing micro mirrors to switch or reflect an optical signal from one fiber to another dependent on the relative angle of the micro mirror, as shown in **Figure 1**.

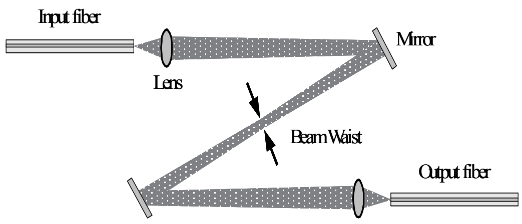


Figure 1 Simple fiber-to-fiber relay system.

Manual fiber connection is not only operationally costly and labor-intensive it also increases opportunities for human errors. Alternatively, photonic cross-connects enable operators to provision, monitor, and reconfigure optical light paths remotely, which reduces provisioning intervals and lowers capital and operational expenditures.

Undersea cable operators have begun taking advantage of photonic cross-connects to offer better service resiliency and flexibility while reducing operational costs. Photonic cross-connects allow operators to expand their legacy ring-based undersea networks into a logical, intelligent, optical mesh network[4]. The ability of photonic cross-connects to rapidly and remotely manage light paths without regard for data format, line rate or wavelength count leads to many benefits.

3. FAULT DETECTION/ISOLATION

One of the major problems facing network operators today is the limited ability they have to monitor the physical layer in order to recognize or predict a failure and/or to diagnose a problem once it has been recognized[5-6]. Some photonic cross-connects inherently detect Loss of Light because they continuously monitor optical power to optimize the strength of the connection[6]. In addition, the availability of extra ports on a full photonic cross-connect offers the ability to perform a wide range of remote diagnostics.

To enable remote diagnostics, test equipment could be attached to a cross-connect. If a particular light path is experiencing a problem, that light path can be switched to a dedicated test port on the photonic cross-connect for additional analysis. For non-intrusive monitoring, a photonic cross-connect can be equipped with dedicated input splitters. As shown in **Figure 2**, using splitters with asymmetrical taps, i.e. 90/10, enables the operator to check the signal when desired without needing to disrupt traffic by breaking the connection in the act of switching. This solution limits the impact on the planning of the optical power budget.

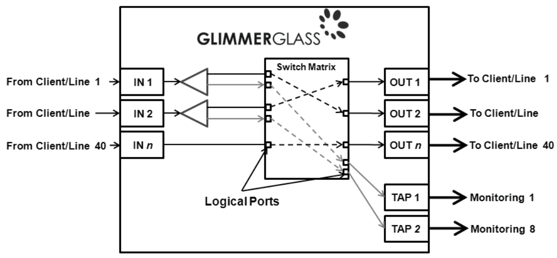


Figure 2 Test equipment attached to a cross-connect enables remote diagnosis.

Whether doing proactive or reactive maintenance once a fault has been detected, the remote operator can instantly loopback suspect lines and/or switch to a port connected to specialized test equipment required for remote diagnostics. This saves hours of time sending technicians with patch cables and test equipment to remote sites. The ability to perform these diagnostics remotely means that an appropriate service team can be sent with a clearer idea of the nature of the problem. Since most problems can now be circumvented remotely, any follow up activity can be scheduled as a routine service call rather than requiring an emergency response.

4. LIGHT PATH RESTORATION

In the event a fault is detected, either Loss of Light detected by the photonic cross-connect or signal degradation detected by other test equipment attached to the cross-connect, a remote operator can remotely switch the affected light path around the failed transponder to a backup transponder. Once this operation has been performed on each side of the submarine link, the traffic is restored.

Shown in Figure 3 is a wavelength Protection and Restoration scheme based around a photonic cross-connect. Once this operation has been performed on each side of the submarine link, the traffic is restored. As DWDM signals arrive at termination points, they become colorless. In effect, the photonic cross-connect allows the operator to perform a wavelength conversion restricted to the problem link.

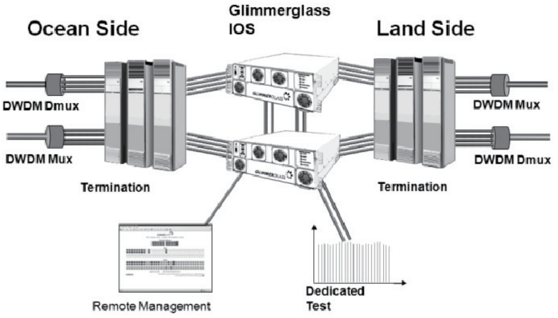


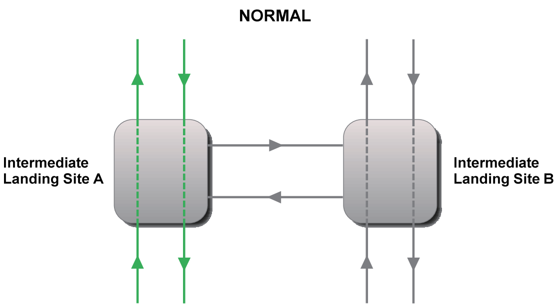
Figure 3 Wavelength Protection and restoration scheme based around a photonic cross-connect.

It is important to note that this restoration could be performed automatically through a system-initiated protection switch or manually through a software command that can be issued remotely. Thus, what would have been an outage lasting hours and requiring an emergency response can be cured in minutes or less.

5. PROTECTION AGAINST MULTIPLE FAILURES

While traditional transport protection schemes adequately protect against a single failure, they do not generally provide a solution for routing around multiple network failures[8]. As a result, undersea cable operators are interested in the potential of 3D-MEMS photonic cross-connect systems to restore services in the event of multiple failures. For example, if a network experiences a fiber cut on the primary light path, traditional transport protection schemes would switch to a protection light path. Using a photonic cross-connect, the operator can switch around one or both failures either to unused fibers, or temporarily to protection fibers reserved for unaffected light paths.

The following example further illustrates this point. In this case, a photonic cross-connect could be placed at the meeting points of five submarine line segments. The network configuration is in the form of an 'H' with two bearers north and south plus a cross link. The logical configuration of the switches would mimic the diagram in **Figure 4**. In the event of a dual segment failure (diagonally opposite segments) the light path could be switched across the interlinking segment and onto the remaining bearers in an 'S' configuration. Under normal circumstances, a dual segment failure would cause a catastrophic service outage; however, with the photonic cross-connect in place, the failures can easily, quickly, and remotely be routed around.



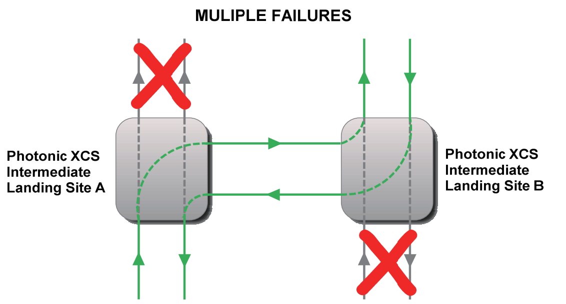


Figure 4 The network configuration in the form of an 'H': normal operation, and restoration with photonic cross-connects after multiple failures.

6. NETWORK SCALABILITY

Terrestrial network operators have seen the benefit of using photonic cross-connects to enhance network upgradeability. This is even more critical for undersea operators due to the operational complexity of performing upgrades. Photonic cross-connects are especially well suited for this environment since most of the core network of the submarine system will only require wavelength granularity as the tributaries are multiplexed to the high-speed interface. The result is a very simple optical layer switching fabric at the node of submarine networks.

Photonic cross-connects have two strong advantages as 'future proof' equipment for growing networks. First, they are transparent to line rate and format, allowing them to accept and manage current and future transmission rates and protocols. Second, they are very good at integrating with the currently installed network equipment while supporting future upgrades. To further illustrate this second point, **Figure 5** shows traditional network protection during a segment upgrade versus using a photonic cross-connect to temporarily switch light paths around the congested segment while the upgrade is performed. As opposed to the traditional model, which uses the protect path while upgrading the working path, using a photonic cross-connect eliminates the creation of a single point of failure. Once the upgrade is complete, the photonic cross-connect can switch the light path back across the original network segment.

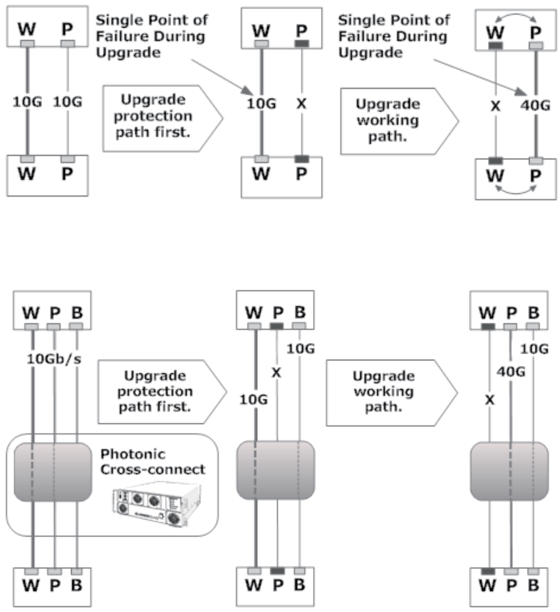


Figure 5 Traditional network protection during a segment upgrade versus protection with a photonic cross-connect.

7. CONCLUSION

Photonic cross-connects enable undersea cable operators to build more resilient and flexible networks while reducing operational expenditures. Specifically, undersea cable operators can deploy photonic cross-connects to achieve the following benefits for cable operators and their customers:

- Reduced length of outages and reduced SLA penalties
- Reduced frequency of emergency service events by converting to scheduled events
- Improved long-term performance monitoring of undersea circuits
- Remote monitoring of network health at the physical layer without disrupting traffic
- Improved availability and scalability

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- Data rate and format transparency, simplifying future network equipment upgrades

In today's high speed networks, customers are in need of near-zero downtime, relying on highly reliable infrastructures to sustain and grow their revenues. As global undersea networks continue to grow with increasing traffic and higher data rates, all-optical switching technology has become a critical element of any survivable optical network. In this paper, we presented how an intelligent photonic cross-connect could improve scalability, lower costs, and most importantly avoid costly network failures. In addition, photonic cross-connects enable remote, centralized monitoring and management, allowing carriers to reduce operational costs and respond more quickly to service requests. In conclusion, photonic cross-connects simplify operation and reduce human errors, which have a direct impact on operator revenues.

8. REFERENCES

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