

The Evolution of Wavelength Switches

Light at the End of the Fiber

ABSTRACT

DWDM networking is evolving at a phenomenal pace, particularly the area of wavelength switching. This paper examines the evolution of wavelength switches, comparing today's 1st generation architectures with soon to be released 2nd and 3rd generation alternatives.

This information will assist Service Provides in making more informed network decisions, thereby avoiding stranded capital and loss of competitive edge.

A NEW UNIT OF CAPACITY

Since the first deployment of Dense Wave Division Multiplexing (DWDM) technology in the mid-nineties the capacity of optical fiber has increased by a factor of nearly 200 with no signs of a slowdown.

In addition to enabling this astounding bandwidth growth, DWDM also introduced the wavelength (or lambda) as a new unit of network capacity. As shown in Figure 1, situated between the multi-terabit capacity of a single fiber, and the relatively small 50Mb/s building block of the SONET hierarchy, the wavelength is a perfect addition to the grooming hierarchy.

Unfortunately, today's switching equipment is unable to groom at the wavelength level, and so operators are forced to use traditional SONET cross-connect equipment as an expensive stopgap.

As a result, the development of an all-optical switch capable of cost-effectively grooming signals at the Wavelength level has become a major thrust in the telecommunications industry.

This paper examines the evolution of wavelength switching and compares alternative architectures, both in-service and being proposed in the marketplace.

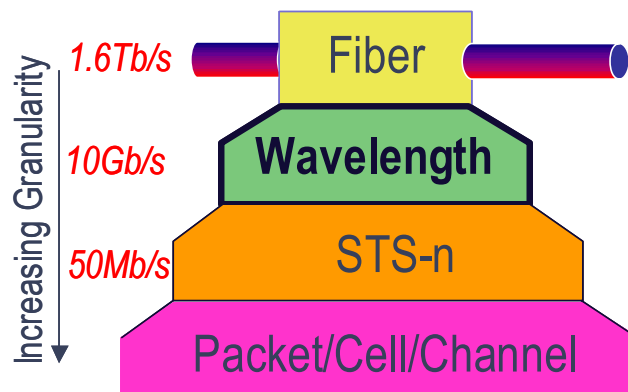


Figure 1.
Signal Grooming Hierarchy

THE IDEAL WAVELENGTH SWITCH

Before comparing alternative switch architectures it is worth defining the functionality of the 'ideal' wavelength switch to use as a basis for evaluation.

In this paper, the term "wavelength switch" refers to a device that terminates multiple optical fibers each carrying multiple wavelengths (see Figure 2).

From a grooming perspective, a wavelength switch can transfer the entire contents of **any** wavelength on **any** incoming fiber, to **any** wavelength on **any** outgoing fiber. Wavelength connections are established in the order of tens of milliseconds under the direction of provisioning staff.

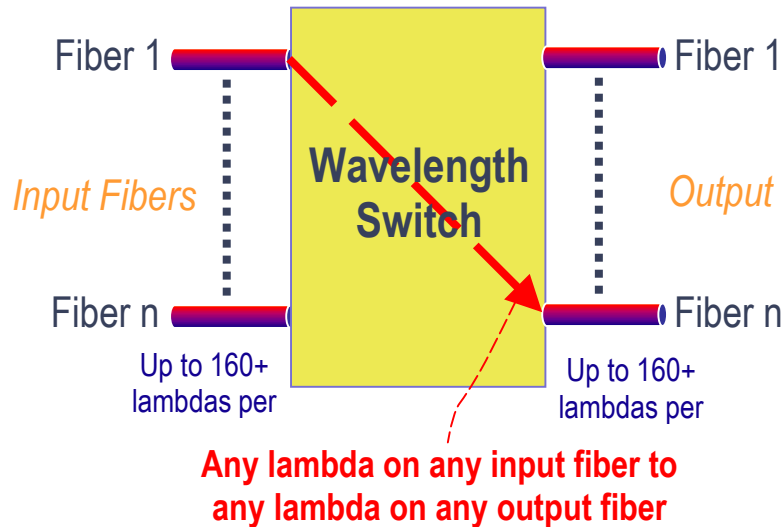


Figure 2. Generic Wavelength Switch

Wavelength switches do not groom traffic at the sub-wavelength level (e.g. STS-1). Instead, STS level traffic would be aggregated onto dedicated fibers and passed to a lower level SONET switch to be groomed

In many respects, the high-level requirements of a wavelength switch are identical to those of an electronic switch: i.e. non-blocking, scalable, automated, cost-effective, etc. In addition however, DWDM has opened-up an exciting new possibility – transparent wavelength switching.

A transparent wavelength switch grooms individual wavelengths carried by a DWDM fiber without imposing restrictions on either the rate, or the format, of signals carried on those wavelengths. The benefits of transparent routing are enormous, for example, signal rates can be upgraded (OC-48 to OC-192 to OC-768), and new protocols deployed (e.g. 10GbE), without any hardware changes to the switch. In contrast, Optical-Electrical-Optical (O-E-O) switches are not rate or protocol independent (referred to as 'Opaque'), and require a forklift upgrade to achieve the same results.

In an era when subscribers expect service changes and upgrades to be instantaneous, and an era when Service Provider competition is at the highest level ever, many of the benefits of instant rate and protocol change are obvious. Maybe not so obvious though, transparent wavelength switching also enables a wide range of new offerings such as:

1. **New Services:**
Wavelengths-on-Demand, Time-of-Day service, Native Rate LANS (10GbE) etc.
2. **Service Level Agreements:**
Type-of-Service (ToS), Class-of-Service (CoS), Quality-of-Service (QoS).
3. **Network Protection:**
Varying degrees of dynamic wavelength protection and restoration.

Another important capability that can be offered by a wavelength switch is the ability to broadcast the contents of one wavelength to multiple other wavelengths. This functionality is key in applications such as video distribution, and further serves to distinguish a transparent wavelength switch from an O-E-O switch.

THE EVOLUTION OF WAVELENGTH SWITCHES

Many of the components required to build a fully functional all-optical wavelength switch are based on state-of-the-art technology that is in the process of moving from the lab to product. For this reason, the first all-optical wavelength switches will not reach the market until the end of 2001.

In the meantime, a number of interim approaches are being proposed. The following sections compare these approaches with the ‘ideal’ switch described in the previous section.

1ST GENERATION WAVELENGTH SWITCHES

In today’s telecommunications networks, the basic functionality of a wavelength switch is achieved by combining multiple discrete products (refer to Figure 3). For simplicity only one direction of signal flow is represented, and passive optical components such as splitters, combiners and filters have been omitted.

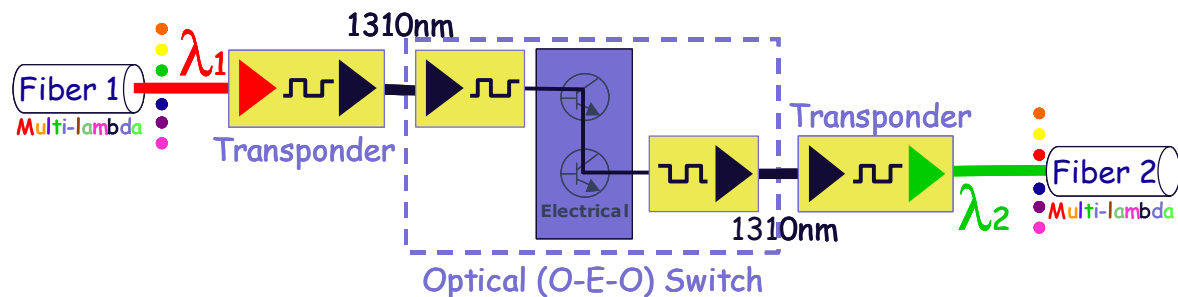


Figure 3. 1st Generation Wavelength Switch Architecture.

Following the signal flow from left to right each DWDM wavelength on the incoming fiber is first terminated, and then typically converted to a generic short-haul 1310nm interface by

an outboard O-E-O transponder. Since each DWDM equipment vendor uses the ITU grid in a different manner the transponders are vendor specific.

The 1310nm optical signal is then passed to the optical switch where it is converted back to electrical, demultiplexed into a stream of sub-rate signals and cross-connected to the appropriate output port using an $n \times$ STS-1 matrix. The signals are then multiplexed back to a higher SONET rate, and converted back to 1310nm optical – again using an O-E-O device. The label “optical” here is clearly a misnomer since the core switch is electrical, and for this reason such switches are often referred to as an O-E-O switches.

Finally, the 1310nm output from the switch is passed to another outboard O-E-O transponder, which terminates the 1310nm signal converts the signal to the appropriate DWDM wavelength.

Today’s O-E-O switches utilize an ‘ $n \times$ STS-1’ based electrical core and the O-E-O transponders are clocked at the SONET rate; hence neither device provides protocol or bit rate independence. This architecture is therefore referred to as “Opaque” to distinguish it from a transparent wavelength switch.

This 1st generation architecture is a very crude attempt at wavelength switch functionality and suffers from numerous drawbacks:

- ✗ Changes in bit-rate (i.e. OC-192 to OC-768) require major hardware change outs.
- ✗ The architecture is restricted to use with SONET traffic.
- ✗ The large number of optical-to-electrical conversions (6 per wavelength) makes 1st generation wavelength switches expensive, low density and power hungry.
- ✗ Electronic switch cores do not scale well and require multiple inter-connected matrices to increase capacity. As a result, the cost and footprint of the core increases almost geometrically as the port requirements increase.
- ✗ There is one patch cord for each O-E-O transponder, and one transponder for each wavelength. This results in an extremely large number of optical patch cords with the associated increase in cost, reduction in reliability, and administrative headaches.
- ✗ The optical interface card associated with each wavelength has a different part number and hence 1 spare transponder card is required per wavelength. Since spares are typically maintained at every office, the result is a huge inventory of transponder cards with the associated cost and administrative headaches, particularly in systems supporting close to 200 wavelengths per fiber.

2ND GENERATION WAVELENGTH SWITCHES

Proposed alternatives to fully transparent wavelength switches replace the electrical core of today's O-E-O architecture with an optical matrix (see Figure 4)¹. Most of these offerings are slated for deployment in the second half of 2001. Based on recent press releases optical MEMS appear to be the technology of choice for the optical matrix however, other options are undergoing evaluation, including liquid crystal and bubble technologies.

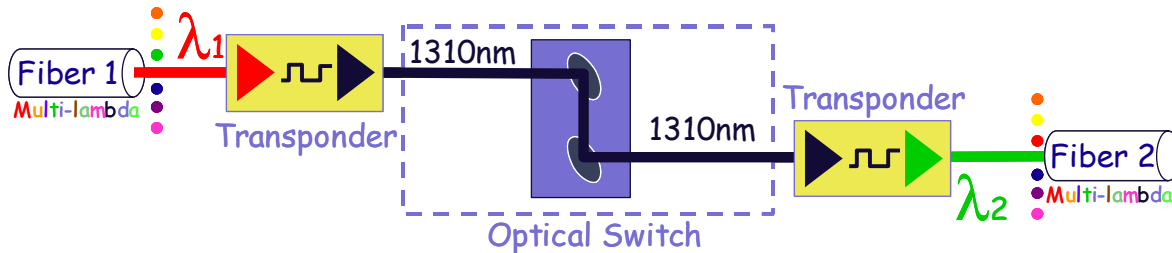


Figure 4. 2nd Generation Wavelength Switch Architecture.

Although the core switches proposed for use in these 2nd generation offerings are transparent, they have no visibility of individual wavelengths carried by the fiber and hence function as an automated fiber patch-panel. In order to switch individual wavelengths transponders are required in conjunction with the optical switch matrix.

The overall 2nd generation wavelength switch architecture has the following advantages and disadvantages:

- ✓ All optical switch cores are in the early stages of development and show promise to scale more cost effectively than their electrical counterparts.
- Comparing Figures 3 and 4, it can be seen that the 2nd generation architecture reduces the number of optical-to-electrical conversions per wavelength from 6 to 4. This simplification is likely to result in improved cost and footprint over the 1st generation approach; however, since the improvement came from the removal of low cost intra-office interfaces and not the more expensive DWDM optics, the overall savings are likely to be modest.
- ✗ Changes in bit-rate (i.e. OC-192 to OC-768) require major hardware change outs.
- ✗ The architecture is restricted to use with SONET traffic.
- ✗ The optical switch matrix cannot support broadcast capability.
- ✗ There is one O-E-O transponder, and one interconnection between the transponders and switch for each wavelength in each direction of traffic. This

¹ A White Paper reviewing different 2nd generation switch architectures is available on LuxCore.com.

results in an extremely large number of optical patch cords with the associated increase in cost, reduction in reliability, and administration headaches.

- ✗ The optical interface card associated with each wavelength has a different part number and hence 1 spare transponder card is required per wavelength. Since spares are typically maintained at each office the result is a huge inventory of transponder cards with the associated cost and administrative headaches, particularly in systems supporting close to 200 wavelengths per fiber.

One variant of the 2nd generation approach integrates the transponders with the optical switch matrix instead of using outboard 3rd party transponders. In addition to the points listed above, this arrangement has the following pros and cons:

- ✓ A higher level of integration should yield reduced costs and footprint, and removes the fiber inter-connection issue.
- ✓ Optical switch fabrics are in the early stages of development and show promise to scale more cost effectively than their electrical counterparts.
- ✗ Direct inter-working with other vendor's ITU grid wavelengths without tunable interfaces is likely to be a major challenge.

A second variant of the 2nd generation approach moves the transponders to the edge of the networks, and then uses a simple MEMS switch at intermediate locations to groom wavelengths in 'bands'. In addition to the points listed above, this arrangement has the following pros and cons:

- ✗ Bundling wavelengths into bands can lead to significant under-utilization of fiber. In some cases over 50% of the fiber capacity could be unused.
- ✗ Wavelength engineering is a nightmare.
- ✗ Switching wavelengths on a band basis is significantly less flexible than switching individual wavelengths.
- ✗ The optical switch matrix cannot support broadcast capability.

3RD GENERATION WAVELENGTH SWITCHES

To meet all the requirements of the ‘ideal’ wavelength switch described earlier in this paper requires a sophisticated combination of tunable optical devices including lasers, wavelength converters, filters and multiplexers.

The basic architecture of a 3rd generation “all-optical” wavelength switch is shown in Figure 6. As a wavelength enters from the left a transparent, tunable wavelength translator converts it to a second, fully selectable outbound wavelength. A transparent optical core then directs this new wavelength to the appropriate output fiber thus completing the connection.

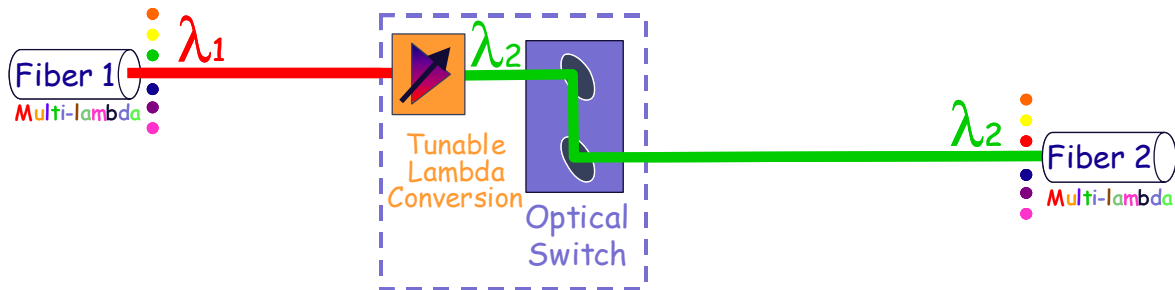


Figure 6. 3rd Generation (All-Optical) Wavelength Switch Architecture.

In contrast to the 1st and 2nd generation architectures described earlier, the 3rd generation architecture is the first to offer a fully integrated, fully functional solution. In particular:

- ✓ The 3rd generation architecture is 100% transparent and hence totally independent of both protocol and data rate.
- ✓ Any wavelength on any incoming fiber can be dynamically converted to any wavelength and exit on any other fiber without conversion to electrical.
- ✓ All fiber interfaces are at the DWDM level avoiding the need for the mass of per wavelength patch cords required to interconnect today’s architecture and some interim architectures.
- ✓ Wavelengths can be switched individually avoiding the stranded wavelengths associated with the ‘bundled’ approach.
- ✓ Tunable optical devices are still early on the technology curve and hence have huge potential for cost reduction and miniaturization.
- ✓ The signal carried by any incoming wavelength can be broadcast to any number of outbound wavelengths.
- ✓ Wavelength engineering is simple, even in very large networks.
- ✓ The signal carried by any incoming wavelength can be broadcast to any number of outbound wavelengths.

IN CONCLUSION

Table 1 summarizes the relative merits of the architectures described in this paper. While the 2nd generation proposals appear to offer some advantages over today's 1st generation approach, given the short time until fully functional 3rd generation wavelength switches are available these advantages will most likely be short lived, and associated investments stranded.

Table 1. A High Level Comparison of Alternative Wavelength Switch Architectures

	1st Generation	2 nd Generation	3 rd Generation
Availability	Now	3Q01	4Q01
Protocol Independence?	✗	-*	✓
Bit Rate Independence?	✗	-*	✓
Per Wavelength Switching	✓	-*	✓
Fiber Utilization	✓	-*	✓
Fiber Count	✓	-*	✓
Scalability?	✗	✓	✓
Cost/Footprint	✗	-	✓
Broadcast?	✗	✗	✓
Spare Interface Cards	✗	✗	✓
Per wavelength Patch Cords?	✗	✗	✓

✗ Bad - Average ✓ Good

* Varies according to switch architecture ².

Perhaps more importantly, in an environment where bandwidth prices are dropping at an astonishing rate (reportedly as high as 50% every 6 months³), Services Provider's can no longer compete on price alone. Instead, the ability to introduce new services quickly and effectively will be the key to survival. As described earlier, transparent routing is both bit-rate and protocol independent providing a sound platform for new service capability and increased service velocity.

The exciting news is that fully transparent 3rd generation wavelength switches and photonic routers are finally viable. For example, Luxcore's family of groundbreaking OXR 3rd Generation wavelength switches, which offer 100% transparent routing at the wavelength level, will be available the 4th quarter of 2001.

If you would like to arrange a live demonstration of tomorrow's technology in operation today, or to get more information on Luxcore's entire range of optical products, please visit our web site at www.luxcore.com.

² A White Paper describing different 2nd generation switch architectures is available on LuxCore.com

³ Phillips Group, Parsippany, New Jersey (Red Herring, Jan 16th 2001)

