

## **Architectural Advantages of WDM Technology in Access Networks**

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### **Introduction**

Wavelength Division Multiplexing (WDM) has emerged as the favored technology for backbone networks due to the huge transport bandwidth that it provides. While WDM is likely to soon dominate the backbone, its role in an access environment is just beginning to take shape, with vendors starting to discuss WDM access network solutions, particularly to serve business customers. Huge bandwidth is one advantage of deploying WDM in an access environment; however, the chief benefits lie in the enhanced flexibility and upgradability that WDM provides. One differentiating characteristic of an access network is that it directly interfaces with customer premises and thus must accommodate a range of data formats and data rates. WDM gracefully delivers this diversity of services through its inherent ability to maintain a degree of isolation among customers. This holds for both business and residential access environments. Additionally, WDM technology allows the logical network topology to adapt to changing customer requirements, further enhancing the scalability of the network.

### **WDM Business Access**

First, we consider providing access to high-end customers, such as businesses, campuses, etc. A simple example of a high-end access environment is shown in Figure 1, where the distribution network extends from an Access Node in a tree topology. In a WDM access solution, one or more wavelengths are assigned to each customer. For example, the tree in Figure 1 could represent a fiber pair, with traffic from multiple customers multiplexed onto the fiber; the fork points represent power or wavelength-band splitters. Alternatively, since high-end customers are generally not very densely packed, a one-fiber-per-customer (i.e., non-WDM) solution is also viable. In this solution, the tree in Figure 1 is comprised of multiple fibers extending from the Access Node to the customers.

An access network must be scalable in terms of both number of customers and demands of any given customer. In a WDM solution, additional customers can be accommodated by dropping more wavelengths (up to a limit). In a dedicated-fiber solution, an increase in customer base can result in all the fibers in a sheath being consumed, thereby requiring more fiber to be laid - a very costly upgrade. Or, a customer may request an additional optical connection, due to large traffic volume (e.g., more than an OC-48), or due to the desire to transmit multiple services in their native data format or rate. This latter application, which potentially benefits from the transparent nature of wavelength routing, is growing in importance as customers request that access networks provide virtual-LAN like functionality over a range of protocols. With WDM, the needs of the customer can be met by dropping an additional wavelength. In a dedicated-fiber solution, an additional fiber needs to be run to the customer.

Furthermore, WDM more readily provides shared-over-time bandwidth. Using passive WDM technology, a set of wavelengths can be made accessible to multiple customers. A shared wavelength can be dropped at a particular customer only when needed, allowing it to be used by other customers at other times. This capability will be greatly enhanced once the technology for remotely tunable passive wavelength add/drops is developed. In a dedicated-fiber solution, another fiber needs to be permanently tied up at a customer needing only occasional extra bandwidth.

Another non-WDM alternative is to use Time Division Multiplexing (TDM) on a fiber. For example, four customers, each transmitting an OC-3, can share a single fiber pair deployed in an OC-12 level SONET ring, where each customer premises has an OC-12 Add/Drop Multiplexer (ADM). However, if one of the customers requires that its data rate be increased to OC-12, the rate of the ring must be increased and the ADMs at *all* four customer premises need to be upgraded. WDM provides more graceful upgrades, as assigning a wavelength per customer naturally isolates the customers to a large degree.

### **WDM Residential Access**

In a residential network, the density of customers is typically too large to consider dedicating a single fiber per customer. Also, the range of services that needs to be provided is even greater than in a high-end network, ranging

from simple POTS service to full broadcast video capabilities. It is desirable to deploy a single access network that can accommodate all customers and allow graceful upgrades.

Passive Optical Networks (PONs) have been proposed as a fiber-based solution to residential access.[1] Most proposed PON architectures utilize TDM-based broadcast-and-select to accommodate multiple customers on a fiber. The TDM architecture has similar limitations as described previously; upgrading one customer impacts the service of others. In addition, broadcast-and-select imposes power budget penalties and security concerns. A more flexible and secure solution is provided by WDM-based PONs, for example the Split-Net PON architecture.[2] In this particular architecture, an LED-source is used in combination with a Wavelength Grating Router to deliver LED-based broadcast services, and TDM-based broadcast-and-select digital services. In addition, Split-Net can deliver high-speed point-to-point services to high-end customers, as needed, through the use of laser-based WDM channels.

### WDM Rings With Wavelength Add/Drop

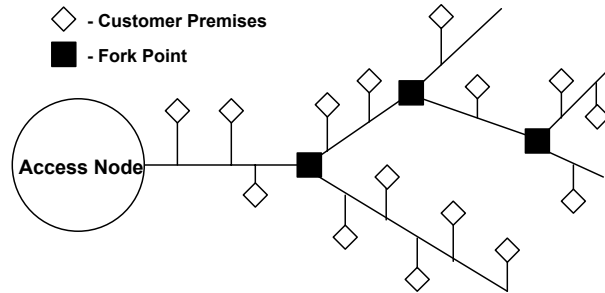
Logical WDM topologies are defined by the nodes at which the various wavelengths are dropped. Wavelength add/drop technology allows a particular wavelength to completely bypass a node, thereby eliminating the need for the associated costly terminating equipment at that node. This allows the network to better scale with customer demand. Furthermore, with configurable add/drop technology, the topology can be reconfigured as customer demands change. The benefit of wavelength add/drop has been investigated in WDM access rings, where the traffic is directed to a number of hubs on the ring.[3] Figure 2 shows the amount of terminal equipment savings possible for a range of ring sizes and a range of nodal demand, for a single-hubbed ring. As shown in the figure, the benefit of wavelength add/drop increases with ring size and with nodal demand.

### Conclusions

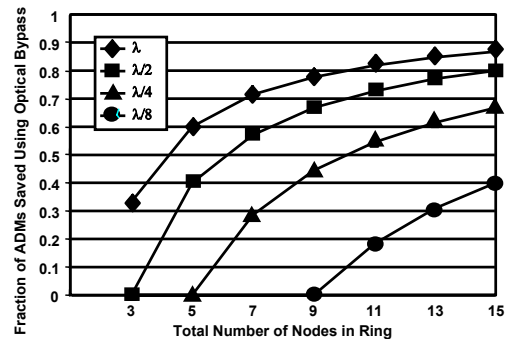
The flexibility and scalability of a WDM access architecture have been discussed. WDM will play an important role in deploying access networks that can meet future customer demand in both the business and residential markets.

### Acknowledgments

I thank Adel Saleh for many interesting and insightful discussions regarding WDM in access networks.



**Figure 1** A simple example of an access network deployed in a tree topology. In a WDM solution, one or more wavelengths are dropped at each customer. In an alternative, non-WDM, solution, a separate fiber runs from the access node to each customer.



**Figure 2** Fraction of terminal equipment that can be saved in a single-hubbed access ring using optical bypass. The parameter represents the amount of traffic, in terms of fraction of a wavelength, sent from each node on the ring to the hub.

### References

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 [2] Frigo, N.J. et. al., "A WDM PON Architecture Delivering Point-to-Point and Multiple Broadcast Services Using Periodic Properties of a WDM Router," *OFC'97*, Dallas, Paper PD24.  
 [3] Simmons, J.M. and Saleh, A.A.M., "On the Value of Wavelength-Add/Drop in WDM Rings," *Topics in Optics and Photonics*, Vol. 20, June, 1998.