This paper describes how the deployment today of an Optical Transport Network based on Dense Wavelength Division Multiplexing technology will enable the evolution to a data-optimized, multi-service network infrastructure, while relieving the stresses currently being experienced due to the growth of existing services, and the exploding demand for new high bandwidth data services. This transition is critical to the success of the metropolitan service provider; the new infrastructure will increase revenues by supporting a broad array of new high capacity data services, and reduce capital costs and operating costs through the elimination of service-specific network elements and the more efficient utilization of bandwidth.

INTRODUCTION
The telecommunications network consists of two layers: the service layer that delivers the network services, and the transport layer that provides connectivity between the service layer network elements. Explosive growth in the service layer has put inordinate demands on the transport layer resulting in a complex, multi-sublayer structure, with each sublayer managing bandwidth at a different, fixed granularity.

This paper describes how the introduction of Dense Wavelength Division Multiplexing (DWDM) technology will address the rapid growth currently being experienced, while simultaneously enabling the transition of the service layer to data-optimized technologies, such as ATM and IP. This paper also describes how the migration of all services to this new service layer, coupled with the expansion of the DWDM-based transport infrastructure, will lead to a simplified network by reducing the number of layers. The result will be a simpler, more cost-effective, higher-capacity, data-optimized network consisting of a multi-service infrastructure interconnected over a DWDM-based Optical Transport Network (OTN).
THE NETWORK OF TODAY
The network of today can be modeled with two layers as illustrated in Figure 1.

Figure 1. Network Layers – Current

The service infrastructure layer provides the functions necessary to provide end-user telecommunications services such as on-demand (dial-up or routed) connectivity with various qualities of service. Therefore, the technology used in service layer network elements evolves as service types change. For example, the rapid growth in data services is causing explosive growth in the deployment of ATM and IP switches and routers, whereas voice services continue, for now, to be provided by narrowband TDM (64Kb/s) switches. Some services, such as leased lines, are fixed-bandwidth pipes provided directly by the transport layer, essentially bypassing the service infrastructure.

The transport infrastructure provides connectivity between the service elements over the physical media: fiber, radio and copper. Fiber is a very high capacity resource -- much higher than is required for the typical connection between any two elements in the service layer. To fully exploit the capacity of fiber, transport layer network elements provide terminal multiplexing, add/drop multiplexing and cross-connection such that many connections can share the same fiber. These functions are collectively referred to as bandwidth management.

TRANSPORT INFRASTRUCTURE EVOLUTION
The transport infrastructure currently consists of sublayers as illustrated in Figure 2. These sublayers are characterized by the granularity at which bandwidth is managed, and chart a history of the growth and evolution of the transport infrastructure. The bandwidth
management granularities shown in Figure 2 reflect the North American transport infrastructure. The transport infrastructure of other parts of the world can be similarly modeled; however, the sublayer granularities would be different.

**Figure 2. Transport Infrastructure Layers – Current**

There are 3 distinct sublayers in the transport infrastructure (not including the fiber) that have evolved over time as the demand for bandwidth increased in response to greater service demand, and new services that consume more bandwidth were introduced.

- The 1.5Mb/s sublayer was introduced because network growth made it impractical to manage all bandwidth at 64Kb/s, new services were being introduced at the higher rates, and an enabling technology made it possible for this rate to be carried over existing copper lines.

- Similarly, the 50Mb/s sublayer was introduced because network growth made it impractical to manage all bandwidth at 1.5Mb/s, new services were being introduced at the higher rates, and an enabling technology (fiber optic cables and fiber multiplexers) made it possible for this rate to be carried between service network elements.

Today, **50 Mb/s is no longer a big enough pipe** for connecting many service network elements to each other. ATM and IP switch vendors are already introducing trunk interfaces at gigabits/second. Furthermore, growth in general is making it impractical to manage all bandwidth at 50Mb/s.
**DWDM is the enabling technology** that will provide connections between the service layer elements at high speeds on the existing fiber plant, and thus provide the next step in the evolution of the transport infrastructure. A DWDM-based OTN provides extremely high capacity per fiber, as well as high capacity per connection. Each DWDM wavelength provides a connection that can carry any protocol with a bit-rate ranging from 50Mb/s to 2.5Gb/s and beyond. These wavelengths can be multiplexed with other wavelengths and added, dropped and cross-connected at the optical level, eliminating the need to manage the bandwidth at a lower granularity when it is not necessary.

**Figure 3. Transport Infrastructure Layers – The Next Step**

With the addition of a new DWDM-based sublayer, the transport network-layering diagram looks like Figure 3.

The new DWDM layer complements the finer granularity layers, by providing coarse granularity bandwidth management. The finer granularity sublayers, primarily based on SONET technology, provide bandwidth management including multiplexing up to the rate of 150Mb/s and beyond. These rates are allocated to wavelengths in the DWDM layer.

The DWDM layer gives the transport infrastructure new capabilities not possible with TDM technology. A wavelength is not constrained by a fixed-rate timeslot in a pre-
defined multiplex protocol; it can carry any protocol, such as SONET, ESCON, FDDI, and Ethernet, and any bit-rate, such as 150Mbs, 1.25Gb/s and 2.5Gb/s. The decision about what protocol and bit-rate to use for a connection between service layer network elements can now be based on the best interests of the service, rather than the convenience of the transport layer. Furthermore, the protocol and bit-rate carried on a given wavelength can be changed ‘on the fly’ without altering anything in the transport infrastructure, giving the network provider the ability to rapidly respond to service changes and growth.

**DWDM is more cost-effective** than TDM-based multiplexing when bandwidth between 155-622Mb/s is required between the service layer network elements. This is illustrated in Figure 4 and is based on the pricing of technology today. Note that Figure 4 makes no statement about the total aggregate bandwidth carried on the fiber, which happens to be much greater in the case of DWDM; what is depicted is the granularity of bandwidth management at which DWDM technology becomes more cost-effective than TDM technology. If the value of fiber is also factored in, DWDM becomes even more economically compelling.

**Figure 4. TDM Vs DWDM Bandwidth Management**

Network providers are introducing high capacity, data-optimized technologies in the service layer to address the rapid growth of data services. The two technologies in the forefront are ATM and IP. As the network capacity consumed by data surpasses that of voice, it is anticipated that all services will eventually migrate onto the new multi-service infrastructures created by these technologies. ATM and IP network elements are
interconnected with high capacity trunks in the range of 150Mb/s to 2.5Gb/s and higher. These rates are most cost-effectively managed by the DWDM layer, such that the finer granularity sublayers in the transport infrastructure will be phased out. A much simpler network will emerge, as represented in Figure 5.

Figure 5. The Network Vision

![Network Diagram]

**THE NETWORK VISION**

Figure 5 illustrates the target network consisting of a single, data-optimized, multi-service infrastructure interconnected over a DWDM-based OTN. The evolution to this network vision will not happen overnight; however, a DWDM-based OTN provides the common, enabling link between the architecture of today and the network vision for tomorrow.

The DWDM-based OTN provides a cost-effective, high-capacity, survivable and flexible transport infrastructure in this network vision.

The elimination of multiple service network overlays and fine granularity transport network sublayers means a reduction in the number and types of network elements and therefore a reduction in capital and operating costs for the network provider. Transport interfaces that are specific to protocol and bit rates are no longer required, reducing the network provider’s inventory costs while increasing network flexibility. At the same time, the data-optimized service infrastructure enables increased revenues by supporting new high value services and rapid growth.
High capacity is inherent in a DWDM-based solution. Each wavelength can support up to 2.5Gb/s and beyond, while 32 or more such wavelengths can be multiplexed onto a single fiber. The resulting aggregate capacities of 80Gb/s and more solve the network provider’s fiber issues, while supporting high capacity trunks between the service layer network elements.

A DWDM-based OTN provides the ability to route wavelengths, and therefore has the same survivability capabilities as current TDM rings when deployed in a ring topology. In fact, the OTN can significantly enhance survivability by reducing the number of electro-optic devices in the network—a major source of equipment failures.

The flexibility of the DWDM-based OTN derives from the protocol and bit-rate independence of the traffic-carrying wavelengths. Protocol and bit-rate independence is a key advantage of DWDM that enables optical transport networks to carry many different types of traffic over an optical channel regardless of the protocol (Gigabit Ethernet, ATM, SONET, asynchronous FOTS, etc.) or bit-rate (150Mb/s, 1.25Gb/s, 2.5Gb/s, etc.).

Protocol and bit-rate independence allows the network provider to make the best choice of service network element interface, and to rapidly respond to new service requests and the need for more bandwidth. For example, native data interfaces, such as Gigabit Ethernet or Native ATM, can be connected directly to the transport layer without costly adaptation. User requests for increased bandwidth or different protocols can be filled quickly, without the need to augment the supporting infrastructure, enabling the network provider to realize increased revenue sooner and turn speed of service deployment into a competitive advantage. New services such as optical leased lines that provide end-to-end protocol and bit-rate independent connections can be offered, attracting new revenue for network provider.

**CONCLUSION**

Optical Transport Networks based on Dense Wavelength Division Multiplexing technology maximize the utilization of the existing fiber plant while accommodating the exploding growth of new and existing services and enabling the transition from multiple overlay service networks to a single, data-optimized, multi-service infrastructure. This new infrastructure will support a broad array of new high capacity data services, generating new revenue for the network provider while reducing capital and operating costs through the elimination of service-specific network elements and the more efficient utilization of bandwidth.

A Dense Wavelength Division Multiplexed Optical Transport Network is the common, enabling link during this transition, and is therefore key to making the transition an evolution, not a revolution.