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Position Paper

Nortel Optical Photonic Solutions

The adaptive, all-optical intelligent network

A new digital era — demanding new, smarter adaptive networks

The amount of digital content around us each and every day is constantly accelerating.

The expectations of both consumers and businesses are simple — access to all this information and content on demand, at any time and from anywhere. Consumers are subscribing to broadband access for this reason — quicker access to information at their fingertips. According to a report by Technology Futures Inc. (TFI)[1], by 2006, 50 percent of United States households will subscribe to broadband access (75 percent by 2010) and a shift to much higher data rates in the range of 24 Mbps to 100 Mbps will have begun.

In the process, core networks will need a significant overhauling to reliably transport this amount of information on demand. In addition, with the availability of increased computing power, personal video recorders, home theater

The amount of information being stored by businesses is growing in excess of 30 percent annually with the average enterprise data center expected to be 72.5 TB by 2007. (Gartner Data Center conference, Dec. 2003)

RHK (April 2005) expects traditional Internet backbone traffic volume to grow from 1,067 petabytes per month (PBpm) at the end of 2004 to over 5,400 PBpm by the end of 2009, a compound annual growth rate (CAGR) greater than 38 percent.

1 http://www.tfi.com/pressroom/pr/2004_broadband.html (December 2004)

and entertainment systems, and home area networks, the demand for higher bandwidths keeps accelerating.

For many of the applications that will be carried over tomorrow's network, such as video on demand, content sharing – peer to peer networking, distance learning and voice over IP, it will be difficult to forecast bandwidth demand as well as routing patterns and requirements.

To be successful in this unpredictable business environment, an operator will need to be able to deliver reliably all the services being requested, as quickly as possible for the lowest cost while maintaining a healthy profitable margin.

Today's networks traditionally have been designed and optimized for specific applications over pre-engineered, well-defined network paths. Unfortunately, in this new digital era environment of anything and everything being available on demand, the traditional approach becomes cost prohibitive. The result is that today's optical networks must evolve to meet the new challenge.

This optical network must have the following four characteristics:

Adaptive — Operate cost-effectively over mixed fiber plants, a network that is readily changed and reconfigured to meet all end-to-end demands

Intelligent — Continuously optimize the optical layer as network paths change and services are provisioned on demand

All optical — Maximize simplicity and reliability for aggregate demands and minimize OEO (Optical to Electrical to Optical) costs through extended reach

Scalable — Carry increasing amounts of data and services flexibly while minimizing the operations complexity

Migrating to the adaptive, intelligent all-optical network

This paper discusses how Nortel continues to evolve its solutions to the next generation of adaptive, intelligent all-optical networks.

Figure 1. Objectives of the adaptive, all-optical network

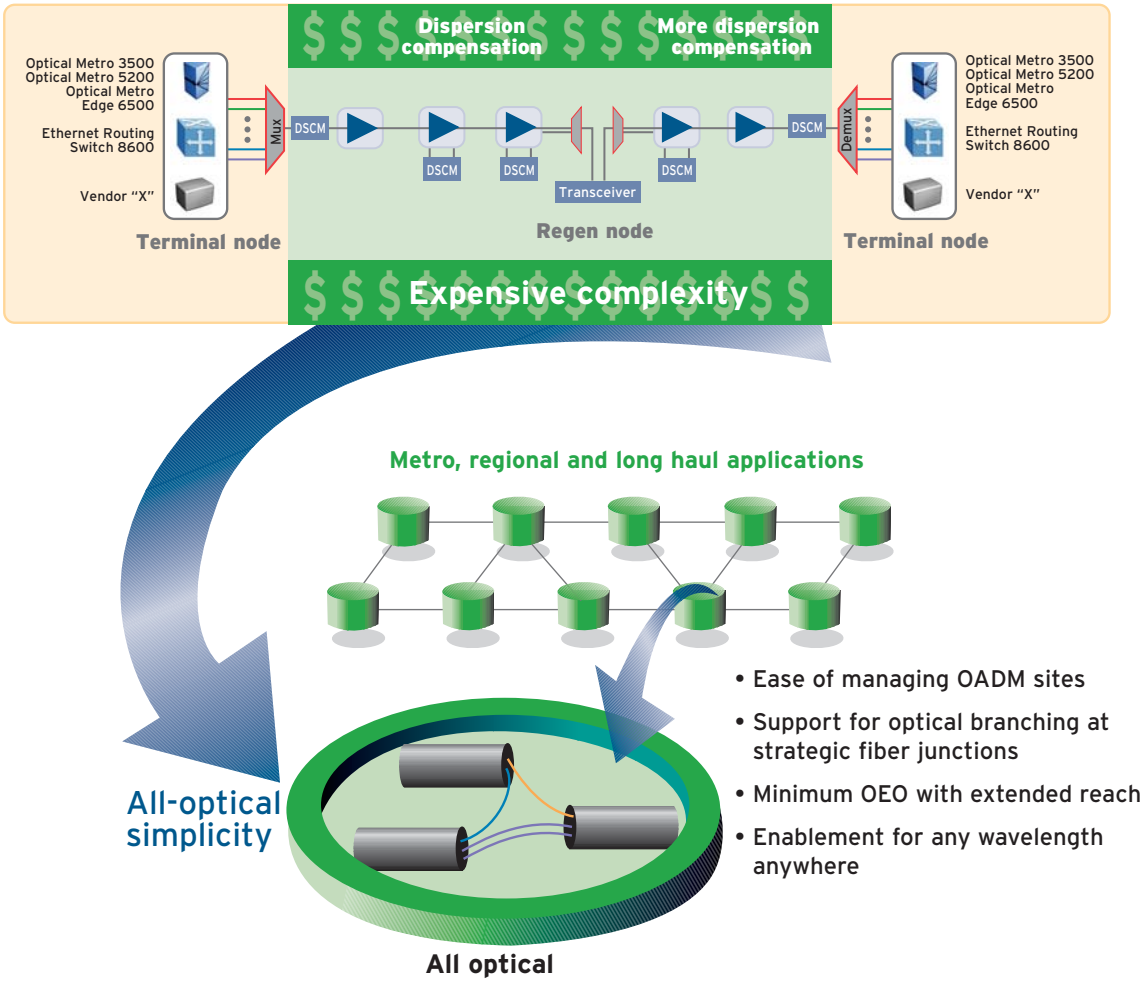
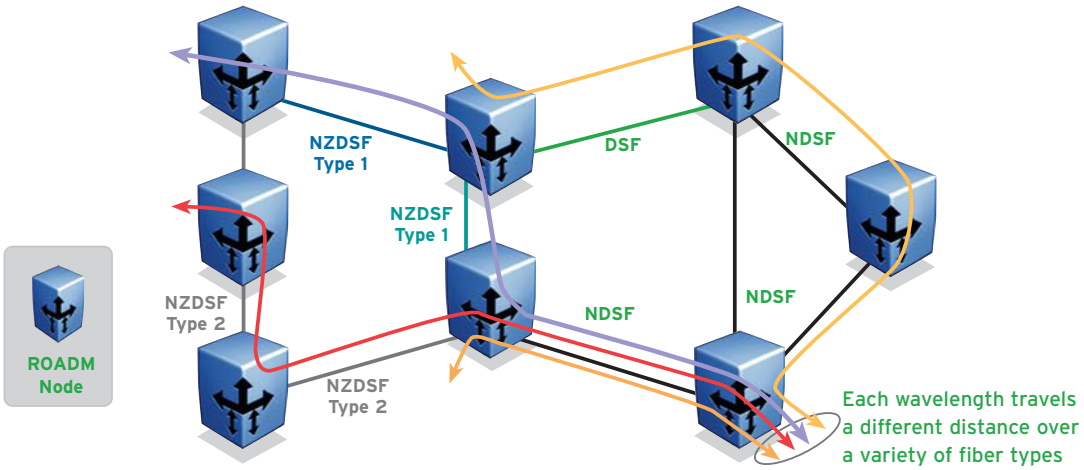


Figure 2. A meshed optical network design



Reconfigurable Optical Add Drop Multiplexer (ROADM)

At the heart of the next-generation optical network is the ROADM capability which provides a flexible approach to rapid provisioning of changing service and traffic patterns. ROADMs allow dynamic per wavelength management at the optical level for add/drop and optical pass-through at any node in the network. Since wavelengths are managed optically, lower OEO conversions and fiber interconnections are required, providing cost-effective flexible transport while reducing the chance of outages caused by incorrect manipulation of equipment.

In addition, to enable the delivery of any wavelength to any location, ROADMs must have "colorless" ports; that is, any wavelength can be dropped or added on any port at any time. Many first-generation ROADMs are "colored", which means only specific wavelengths can be dropped or added on that specific port, significantly restricting the overall network flexibility.

Problem: The missing element

ROADMs alone fall short of the realization of a truly adaptive, all-optical network, due to the fact that they are employed in a combination with legacy transmit and receive optical technology. These optical interfaces are subject to a variety of physical impairments in the photonic line. It is this need to compensate for impairments which limits the agility and service forecast-tolerant nature of an adaptive, all-optical network. In order to fully leverage ROADM capability and truly deliver end-to-end network agility, ROADMs must be deployed in conjunction with an equally crucial technology component, one that eliminates path-dependent penalties and makes the design of all optical switched networks practical.

To illustrate this point, consider the example shown in Figure 2. In this meshed configuration, how do we deliver any wavelength on any path and engineer a network that manages optical dispersion in a wavelength-branching, mixed-fiber network? In this meshed network, there are an infinite number of combinations and permutations of end-to-end paths that makes the engineering and planning of link budgets for every possible path totally impractical.

Dispersion, like attenuation, is an impairment that degrades the optical signal as it travels over distance. It is a physical phenomenon caused by the fact that the various frequencies or colors which make up a composite or multiplexed Dense Wavelength Division Multiplexing (DWDM) signal have different propagation velocities. In order to compensate for this degradation, legacy DWDM solutions require one of two options:

Option 1: Signal regeneration (e.g., OEO conversion) of each individual wavelength every few 100 kms, which is an expensive proposition and goes against the target of all optical networking, where each wavelength travels end-to-end as a light path.

Option 2: Engineered deployment of in-line bulk Dispersion Compensation Modules (DSCMs) at specific locations in the optical line, which forces the photonic layer design to be constrained to pre-defined, pre-engineered, fully characterized working and protection paths where dispersion is already calculated and known. Bulk dispersion compensation is complex, and in-line DSCMs introduce additional attenuation, further limiting the optical signal reach.

Therefore, in order to deliver any wavelength on any path in the example illustrated in Figure 2, a new innovative optical technology is required.

Introducing electronic Dynamically Compensating Optics (eDCOs)

eDCOs address the complex problem described above by providing dispersion compensation and support for real-time performance optimization on a per-wavelength basis directly at the signal source; that is, on the transmitting optical interface. This capability results in a dramatically simplified design and easier operations because the need for pre-placement of optical dispersion compensation modules or OEO conversions in the optical DWDM line has been completely eliminated. eDCOs, in combination with ROADMs, allow for the realization of a truly agile, all-optical network with full optical branching. The eDCO offers significant advantages:

- Supports the rerouting of any wavelength along any route of varying end-to-end distances in the network, up to 2000 km, by dynamically adjusting the modulation of each individual wavelength right at the transmit source
- Accelerates service velocity by eliminating costly optical re-planning and re-engineering of the DWDM optical layer
- Allows wavelengths to be carried over different types of fibers indiscriminately
- Allows the addition to a new node in a network without impact to the link engineering
- Enables fault-tolerant mesh network architectures (Figure 2) that were previously cost prohibitive or impractical to implement

In summary, eDCOs allow each individual wavelength to be routed through the network independent of distance, fiber type or number of intermediate ROADM nodes by providing automatic dispersion compensation adjustment right at the source of the signal.

The final aspect required to provide operators with the ability to fully exploit the service capabilities that ROADM and eDCO technology enables, while simultaneously simplifying all operational aspects, is a new level of optical intelligence.

Intelligent software control — The DOC

Embedded photonic line intelligence provides the missing link that brings all the elements and aspects of photonic networking together. This DWDM optical line control is delivered by way of an intelligent software engine that automatically diagnoses and dynamically adjusts all the components that reside on the various optical interfaces (eDCOs), filters, amplifiers and ROADM modules to guarantee the integrity and health of the end-to-end signals at all times, including upon network reconfigurations (initiated by the maintenance personnel or automatically by the system to protect a fault). The Domain Optical Controller (DOC) is the automated intelligence responsible for continuously monitoring and optimizing the entire optical network.

This intelligent software engine:

- Accelerates initial system installation of the end-to-end network
- Accelerates the provisioning and incremental wavelength additions through automation
- Ensures continuous photonic line optimization through autonomous adaptive power equalization, self fault isolation and health checks that all run as background processes
- Enables true all-optical networking when deployed along with ROADMs and eDCOs, while delivering significant reductions in operational expenses

Nortel is the recognized market leader in DWDM solutions globally for the last five consecutive years (2000-2004 incl.). As of the end of 2004, more than 50% of all 10-Gbps long haul and metro wavelengths carrying circuit and packet transport are delivered using Nortel's optical products.

(Source: Dell'Oro Group, May 2005)

Nortel delivers the adaptive all-optical network

In June 2004, Nortel introduced its fourth-generation DWDM Optical Layer solution – the Common Photonic Layer (CPL). CPL leverages years of proven expertise in developing and deploying metro, regional and long haul optical networks. Building upon the CPL foundation, Nortel is delivering the adaptive, all-optical intelligent network through the addition of the enhanced-ROADM (eROADM) and eDCO components powered by the CPL Domain Optical Control (DOC) software.

The eROADM is a new functional module that is part of the CPL platform. The eDCO interface will be offered on a number of Nortel service terminals, starting with the Optical Multiservice Edge 6500. In addition, it supports full C-band tunability, which reduces the sparing requirements and offers true all-optical networking with the elimination of fixed wavelength constraints.

Here are some of the key characteristics of Nortel eROADM, eDCO and DOC software technology:

Nortel enhanced-ROADM

- Wavelength Selective Switch (WSS) technology with colorless ports
- Up to five connected nodes for all-optical multi-directional branching
- Single wavelength add/drop granularity
- Automatic power optimization upon reconfigurations and wavelength add/delete
- Scalable up to 72 wavelengths

Nortel eDCO

- Full C-band wavelength tunability for simple sparing and all-optical networking
- Advanced Forward Error Correction (FEC)
- Cost optimized solutions for up to 2000 km reach applications
- Complete elimination of in-line dispersion compensation modules (DSCMs)
- 50-GHz compliant interfaces

Nortel Network Intelligence (DOC)

- Automates provisioning and incremental wavelength additions
- Continuously optimizes the photonic line
- Enables any wavelength, anywhere with eROADMs and eDCOs

The real advantage of eROADMs and eDCOs is further supported by Nortel planning studies based on actual customer data that demonstrate up to 56 percent savings in operational expenses.

Nortel's optical industry leadership was founded on the introduction of DWDM and 10-Gbps optical networking. This leadership has continued to evolve through technology introductions that have delivered increasing reach, scale, capacity and simplicity. Nortel continues to be at the forefront of research and development for next-generation networks with the introduction of its eROADM and eDCO technology powered by the DOC intelligent software for the implementation of per-wavelength management and total network agility.

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