ROADM Evolves:
Should You Be Paying Attention?

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INFONETICS RESEARCH

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I. The ROADM

Nothing is surer than the increasing use of bandwidth. Over the past 10–15 years, carriers have met increasing bandwidth needs in their transport networks with wave division multiplexing (WDM) to introduce more bandwidth on a single fiber, initially for point-to-point fiber exhaust situations, then for ring transport. The need for more bandwidth flexibility, operational efficiencies, and technology advances brought the optical add / drop multiplexer, or OADM, to add or drop off wavelengths at a node point. This innovation used fixed lasers / filters for fixed wavelengths, and is thus called a fixed OADM, or F-OADM.

But carriers can never know when or where the next rush of bandwidth will come from, thus driving urgency for quick provisioning and re-provisioning of the large amounts of bandwidth coursing over the wavelengths of a WDM network. So, in the past three years, we have seen the next logical step, which is the *remotely reconfigurable* optical add / drop multiplexer, or ROADM. An improvement on F-OADMs, ROADMs allow wavelength add / drops at a node point to be remotely reconfigured, rather than requiring a technician to install add / drop lasers / filters with specific wavelengths into the WDM system node, and equalize the power levels of wavelengths so they can co-operate on the same fiber.

ROADMs are used to give add / drop flexibility to nodes in a ring and to efficiently interconnect rings or construct a mesh. ROADMs solve three main problems: (1) reduce time and labor associated with the manual provisioning needed for F-OADM sites, (2) reduce the amount of equipment needed at ring and mesh interconnect sites, and 3) reduce the WDM circuit planning cycle to one that is more flexible and adaptable to changes in network requirements.

The primary benefit of ROADM technology is to improve the efficiency of a WDM system, at the granularity of a single wavelength. While the terms *fixed* vs. *reconfigurable* are akin to *manually intensive* vs. *automated*, larger WDM spans (both number of nodes and distance) can be built with ROADM-enabled WDM gear.

An industry standard—complementary to ROADM technology—is the Optical Transport Network (OTN), otherwise known as the digital wrapper or the ITU G.709 standard. While the standard was written to address the growing migration of services onto optical transport, with defined operations, administration, and maintenance (OA&M) procedures similar to SONET/SDH, OTN also offers a way to groom multiple services onto optical wavelengths, including sub-wavelength (sub-wave) grooming. This grooming creates additional efficiencies in optical networks and allows routing of multiple lower speed optical services over multiple wavelengths, thus creating a sort of *wavelength router.* While this paper does not cover OTN in depth, references will be made to the technology and how it can help ROADM networks.

ROADMs are evolving from their original functions with new generations of innovation and technology choice. As we propose later in this paper, the combination of electrical switching (or sub-wave grooming) capabilities and optical switching capabilities at a ROADM node site allows even more efficiencies for carrier network designs.

II. ROADM Definition and Applications

A. ROADM Defined

We noted a basic ROADM definition in the first section; below is a full list of ROADM node functions.

- Remotely reconfigurable OADM: with the appropriate cards installed in a ROADM system, an operator in a NOC (network operation center) can provision services by reconfiguring which wavelength or wavelengths are added and which are dropped, and similarly, which wavelengths are passed through, without a technician visit to the ROADM node site
- The granularity of add or drop on a single wavelength; the ROADM capability is superior to previous technology that typically added or dropped a band of 4 or more wavelengths
- The power level of all wavelengths on a fiber are automatically equalized when an add / drop / pass-through configuration is changed
- Most ROADM systems constantly monitor power to ensure signal quality
- 2-degree ROADMs are used in nodes in a ring (or nodes on a mesh "line") where there are only East-West connections, that is, where there is no interconnection of a ring, mesh, or spur
- N-degree ROADMs (N= 3, 4, or more) are used at ring and mesh interconnect points, and at spur points

So, not only are ROADMs remotely configurable (unlike their earlier F-OADM cousins), but many of the human labor intensive functions are automated. ROADM-enabled equipment is used by service providers to build a versatile, agile, quickly provisioned optical transport layer. This transport network can scale in both distance and number of nodes. ROADM systems are designed to help service providers respond to new bandwidth demands, being forgiving to forecasting inaccuracies and network churn; F-OADMs solve capacity problems and are more cost-effective if relative wavelength capacity needs at each node on a ring are predictable, but they are inflexible for spontaneous bandwidth needs.

B. ROADM Applications

The main applications for ROADM equipment are:

- Interconnecting WDM rings with optical pass-through
- Quick capacity activation with ROADM (few minutes/hours compared to few days/weeks with traditional equipment), so service providers can react faster to changing end-user demand
- Replacing SONET/SDH with WDM for core infrastructure, driving down the cost for transporting high-bandwidth circuits (e.g., Gigabit Ethernet)
- Creating *ADM on a wavelength* by assigning a wavelength for SONET/SDH or OTN ADM traffic
- Transport convenience for MSOs: they are adding Ethernet and VoIP to their existing WDM for video on demand (VoD) services, and don't want to manage separate networks; with the demands of video, MSOs also appreciate the ability to add and drop services at 10G at any location whenever their traffic/network demands call for it
- Video on demand (VoD) services today will bring on wavelength services tomorrow

Carriers are now designing, operating, and relying on their ROADM transport networks in the same versatile and operationally efficient manner as they do with their familiar SONET/SDH networks.

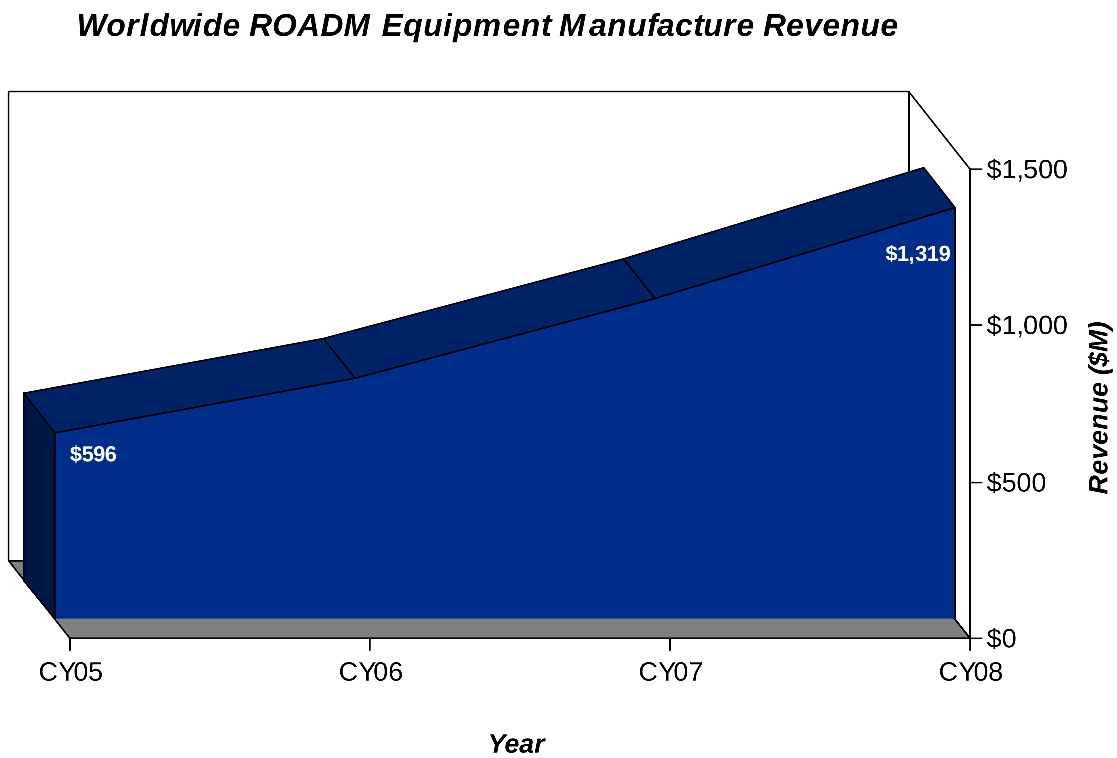
III. The ROADM Market

The ROADM market is alive and well, and growing. ROADM-enabled WDM systems started shipping around 2000 for the long haul segment, and in 2003 for the metro segment.

In our view, SuperComm 2004 marked the beginning of the ROADM era, as most of the major WDM manufacturers announced products or partnerships. ROADM functions and common attendant automation features, such as automatic performance monitoring and equalization, allow carriers to consider WDM systems and metro WDM ring/mesh networks in a new way, as a much more useful, quickly provisioned transport layer, which is positively affecting the planning, use, sale, and deployment of metro WDM.

Worldwide WDM ROADM equipment revenue for metro and long haul hit $596M in 2005, and we project it to reach $1.3B in 2008, a growth of 121% between 2005 and 2008, as shown in Exhibit 1. By 2008, ROADMs will be a standard part of nearly all service provider WDM networks.

Exhibit 1 Worldwide ROADM Equipment Manufacturer Revenue Forecast



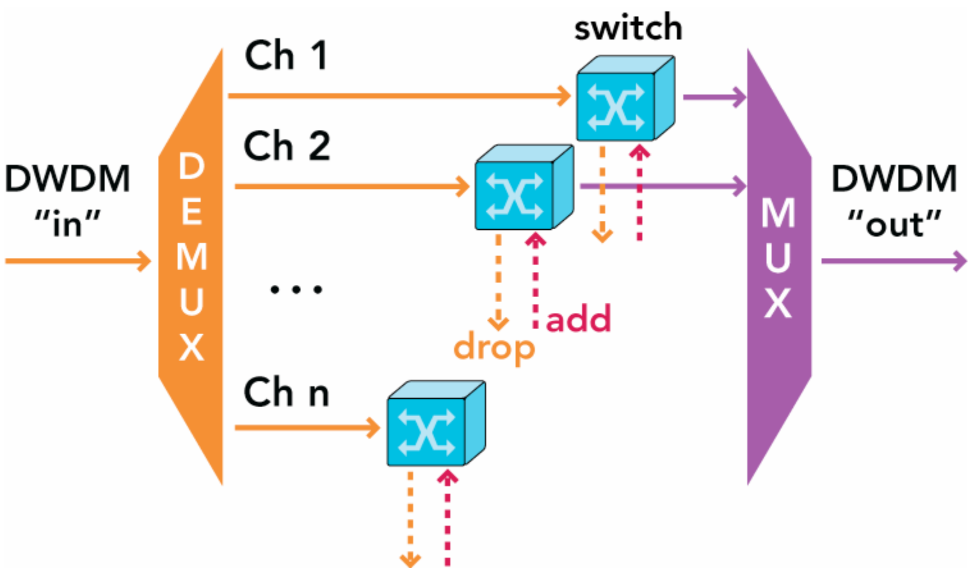
Source: Optical Network Hardware Quarterly Worldwide Market Share and Forecasts, 3Q 2005 *by Infonetics Research, Inc.*

IV. Evolution of the Technology

A. 1st Generation

The original ROADMs employed a demux-switch-mux approach to add / drop / pass-through, a brute force approach compared to today's ROADMs—the original ROADMs were complex, large, and expensive. See Exhibit 2. The main application was to solve fiber exhaust problems, which were caused by inflexibility issues, for point-to-point links first in long haul networks, then in the metro. All wavelengths are demuxed from the incoming fiber, then each is switched to pass-through or drop destinations, while added clients are switched onto outgoing destination wavelengths. All wavelengths require amplification with this scheme, and every add / drop wavelength must be hard-wired to specific client ports. Demux-switch-mux ROADMs have high loss and PDL (polarization dependent loss). This causes spectral narrowing which limits the size of the ring and also requires higher quality DWDM transceivers, thus creating a problem with the accommodation of alien wavelengths and built-in DWDM transceivers on client equipment (e.g., DWDM ports directly on routers).

Exhibit 2 **1st Generation Demux-Switch-Mux ROADM**

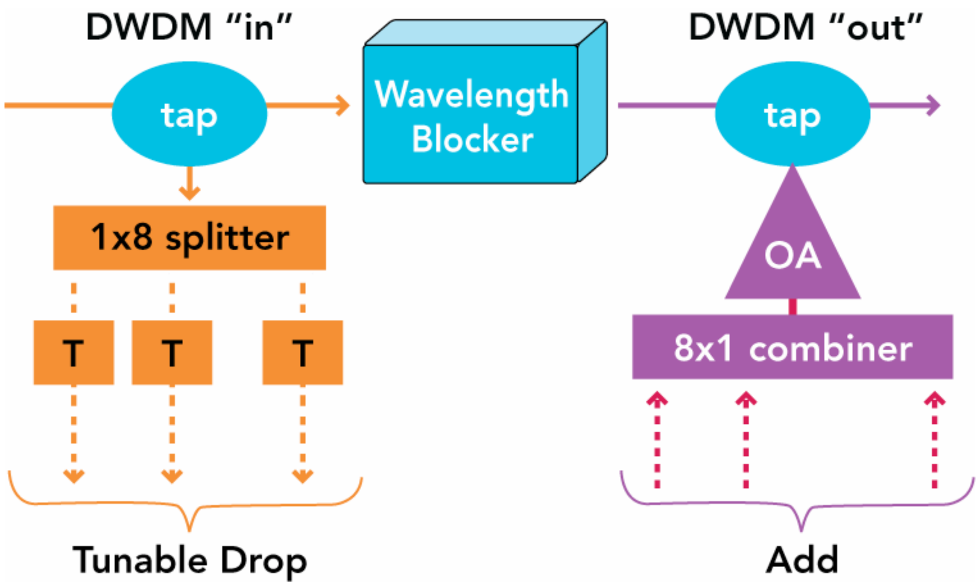


B. 2nd Generation

2nd generation ROADMs are typified by wavelength blocker technology. Some clever technology design finesse is evident in the blocker approach as compared with 1st generation ROADMs. The rather simple structural design of 2nd generation ROADMS is seen in Exhibit 3, where a *tap* (a splitter and filter array) is used to drop any number of selected wavelengths. While all wavelengths enter the blocker, the pass-through wavelengths are not blocked. The final stage in the eastbound traffic is a combiner used to add wavelengths into its tap to enter the outbound fiber.

A wavelength blocker ROADM can equalize, attenuate, and / or block any or all wavelengths. It has low dispersion and low power dissipation, so is more efficient than 1st generation ROADMs. Pass-through wavelengths do not need regeneration, although they may need amplification, which can be efficiently applied to all pass-through wavelengths simultaneously with the same amplifier. Wavelength blockers are primarily used in long haul, regional, and metro core WDM networks.

Exhibit 3 **2nd Generation Wavelength Blocker ROADM**



C. Problems Solved with 2nd Generation ROADMs

Wavelength blockers solve several problems over 1st generation ROADMs to advance the attractiveness and usefulness of ROADMs:

- Use less power, less complicated, smaller size, and lower price than previous approaches
- Can support alien wavelengths at different speeds coming from such various devices as transponders, Ethernet switches, routers, or storage switches
- Improve network engineering on a per wavelength basis by avoiding the problem of stranded bandwidth with single wavelength add / drop granularity, rather than a band of 4 or more (sequential spectrum)
- Jumperless provisioning of wavelengths; need far fewer jumper cables than 1st generation

2nd generation ROADMs are an improvement over first generation to be sure, yet some problems remain:

- Still considered complicated and expensive, with inconsistency of management schemes
- Not a good solution for ring or mesh interconnect points
- Despite good wavelength granularity, doesn't allow sub-wave level provisioning and traffic flow management that providers want

V. What About Sub-Wave Services?

A. Sub-Wave Services

There is no doubt that ROADMs bring enormous efficiencies at the tactical operations level, while also allowing service providers to enter a stage of the strategic next network design: to consider reaching for the holy grail of the *IP over glass* network. While we are not yet there, modern ROADM equipment can be used to deploy the *over glass* part of this vision. Many providers around the world do subscribe to this vision, but whether that's the end game they have in mind or not, a majority of providers have begun deploying or are planning to deploy a ROADM-based WDM optical transport layer in their networks.

Once such a ROADM network is in place, and can be smoothly managed, providers will naturally want to look at new ways to leverage that asset to improve the overall function of their network. It is a natural progression from provisioning end-to-end wavelengths to wanting to provision and manage the various traffic types—the services— inside the wavelengths. So, although the optical layer is transport for the service layers above it, new efficiencies can be gained by the integration of service level intelligence in the transport equipment. This integration can allow wavelengths to be packed with multiple traffic types (sub-wave grooming).

An intelligent integration of optical and electrical could allow service providers to provision higher layer services, such as SONET / SDH, IP / MPLS, Ethernet, storage, etc., across the transport network. In fact, by packing services into wavelengths, a new level of efficiency is gained, materially reducing the number of wavelengths needed in a network to support a given amount of traffic. The obvious practical effect is that a network can be built with fewer wavelengths, which saves capex and makes for a simpler network, reducing opex.

B. Sub-Wave Grooming in the Electrical Domain

Sub-wave grooming is achieved in the electrical domain, and service add / drop / pass-through can be remotely reconfigured. Some providers and others in the industry are referring to this function as an electrical ROADM or eROADM. It is a low cost complement to using an optical ROADM. The eROADM leverages the integrated technology to groom wavelengths electrically at any point in the network, so, like with an optical ROADM, services can be added or dropped at any point on the network and the network or the wavelength can be reconfigured on-demand. eROADM functionality maps well to existing OTN technology, which allows any of the lower speed services to be managed like a traditional SONET / SDH service.

C. Problems Solved by Sub-Wave Grooming + ROADM

Sub-wave grooming via an eROADM solves several problems that ROADMs were designed to resolve by:

- Being less complicated, smaller, and less expensive
- Solving the WDM planning problem by allowing configuration of any wavelength and sub-wave service to anywhere on the network
- Improving network engineering down to a sub-wave level, eliminating stranded bandwidth by offering full- & sub-wave add / drop granularity

However, sub-wave grooming via eROADMs has limitations:

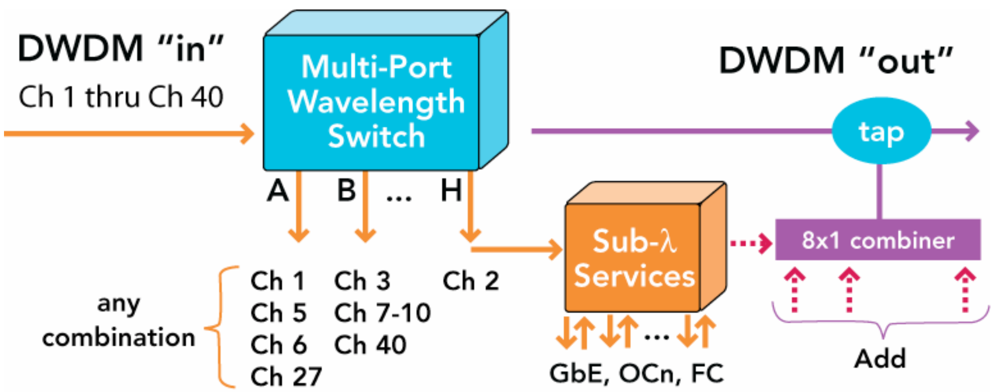
- Loss of efficiency for services above 2.5G
- Variation among vendors in granularity of OTN to levels below 2.5G

VI. WSS: The 3rd Generation of ROADM

A. WSS Defined

The wavelength selective switch, or WSS, is the next advance in ROADM technology. WSSs are more versatile, smaller, consume less power, and are less expensive than 2nd generation ROADMs. WSSs are typically designed to handle 40 incoming wavelengths on a fiber, and drop any combination of wavelengths out any of 8 ports (some systems can drop more), as shown below in Exhibit 4. The WSS is an N-degree ROADM, which allows reconfiguration beyond typical 2 -degree (usually east-west) configurations (a WSS system can be used to interconnect rings or mesh points). This means that wavelengths can be routed from any node to any other node across multiple rings and networks. A WSS system includes a combiner to add wavelengths to the outgoing fiber.

Exhibit 4 **3rd Generation WSS ROADM**



B. Problems Solved with WSS

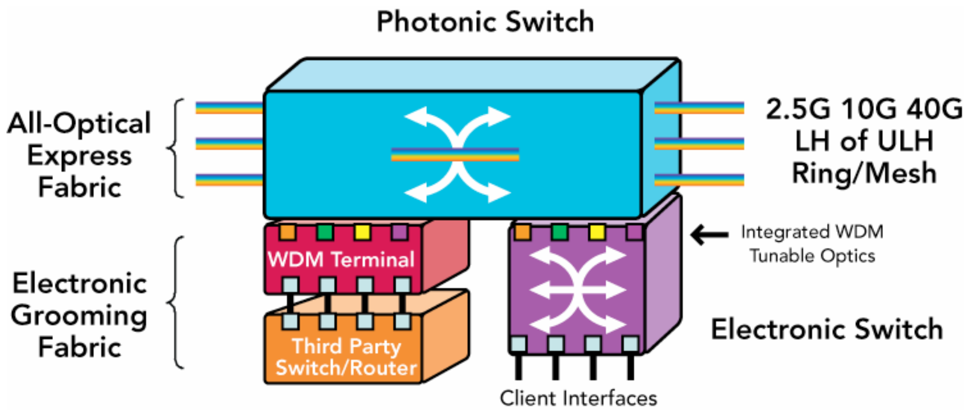
The WSS solves a number of problems inherent in 2nd generation ROADM systems by:

- Being simpler, smaller, and less expensive
- Offering a good solution for ring, mesh, and spur interconnect points
- Future-proofing sites that may start as 2-degree nodes (though additional spurs or subtending rings may be required in the future)

C. Combining WSS with Sub-Wave Grooming

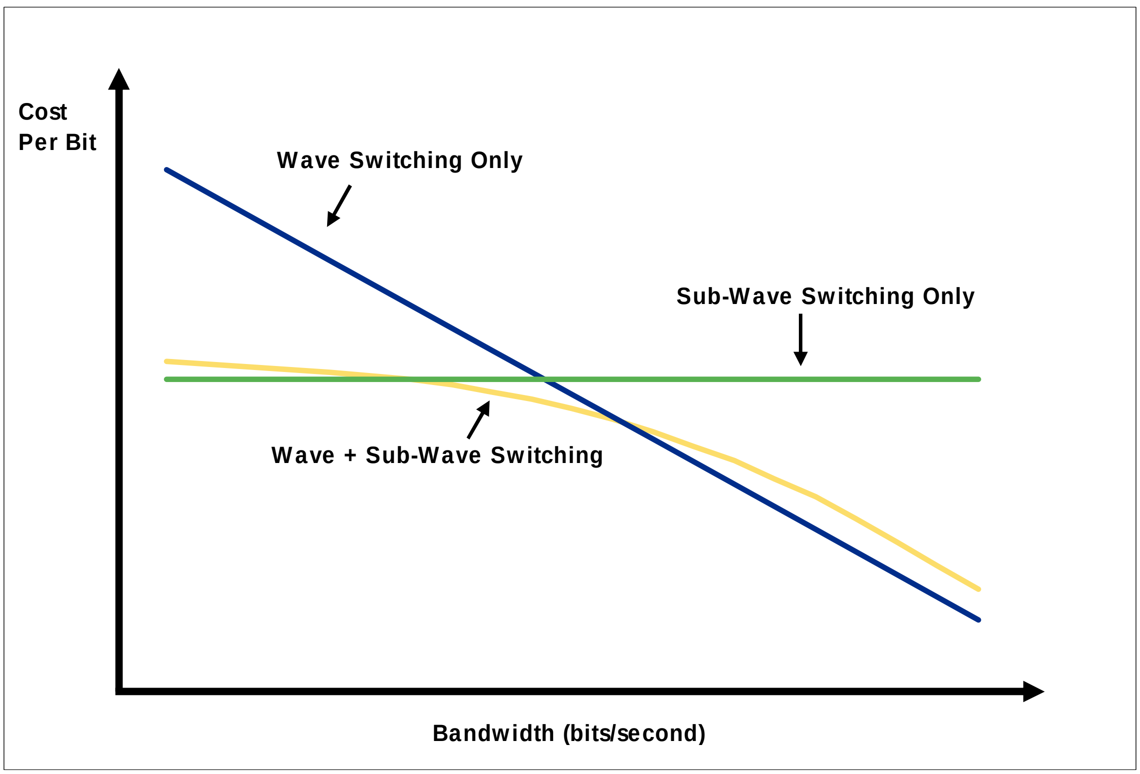
We now arrive at what can certainly be called a state of the art, 3rd generation ROADM system: a WSS combined with sub-wave grooming. In 3rd generation ROADM-enabled networks, the service provider can more efficiently provision services of any bandwidth end-to-end across the optical transport system, across interconnected rings, meshes, and spurs, without requiring back-to-back transponders. This enables end-to-end service-level performance management and service level agreements (SLAs). To achieve this otherwise would require dedicating a full wavelength end-to-end, even, for example, for a 300M Ethernet private line. An example is shown in Exhibit 5.

Exhibit 5 **Example 3rd Generation ROADM System**



The hybrid combination of sub-wave switching (electrical ROADM or eROADM) and WSS-based optical ROADM in a single node offers (1) a larger variety of optical services, (2) the economics of each technology, and (3) new economics of the hybrid. Low speed services can be bundled with high speed services and carried from any point in the network to any other point in the network. This allows wavelengths to be routed from a single point, across multiple ring or mesh topologies to its end destination, thus creating a sort of wavelength router. The economics of each technology and the new economics of the hybrid combination of wave switching (ROADM) and sub-wave switching are shown in Exhibit 6.

Exhibit 6 Economics of System with ROADM + Sub-Wave Switching



VII. Conclusions

ROADM technology has seen technological advancements driven by the end service provider applications. Driven largely by cost savings and flexibility, the first ROADM applications were in the core (long haul) with commercial approaches that were feasible at the time. Newer technologies and better cost points are now bringing the same flexibility to the metro. Reducing cost while adding network flexibility still seem to be service providers' primary motivators. Integrated sub-wave grooming and multi-degree flexibility of newer generation ROADM solutions are classic examples of vendors taking innovative and cost-effective approaches to a classic problem.

Whatever the case, ROADMs are here to stay as an integral part of WDM networks, since they provide many benefits, reduce the costs of networks, and open the opportunity for carriers to build a versatile, agile, easily manageable optical transport layer; ROADMs:

- Extend wavelength transport: more scalable networks and network elements
- Simplify transport network design
- Simplify DWDM operation with optical management
- Remotely provision services in real time, reducing time to service and time to revenue
- Reduce human involvement, reducing opex
- Easily place ADM ring traffic on a wavelength
- Better in-service network upgradability
- Quickly respond to new bandwidth demands; fixed OADMs solve capacity, but are inflexible for spontaneous bandwidth needs
- Cost-effectively interconnect rings and provide multi-degree switching for mesh networks

The technology march does not end here. More flexibility, operational efficiencies, and competitive advantage have arrived in the remotely reconfigurable 3rd generation WSS ROADM technology combined with sub-wave grooming. This combination gives providers the granularity of provisioning Layer 2 and Layer 3 services at the sub-wave level for end-to-end service provisioning across a metro, regional, or wide area optical transport network. This electrical-optical system has advantages over a purely 3rd generation ROADM system:

- Fewer components, fewer devices in network
- Lower capex costs, and higher operational efficiencies
- Fewer wavelengths to carry a given amount of traffic
- Managed services can be provisioned across the optical transport network

ROADM technologies and ROADM-enabled WDM systems have come a long way, and are on the verge of becoming commonplace in the WDM networks of service providers around the world.

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