The Agile Optical Network Continuum

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I. The Agile Optical Network Continuum

Optical networks and the underlying optics they rely on have been evolving for 25 years. As with any technology, industry, or product type, simple beginnings give way to increasing diversity to meet the requirements of various market segments, with many of these segments emerging due directly to the advances of technology. This is certainly the case with optics, optical network systems, and service providers' optical networks.

In our view, innovation comes in two main strains—(1) pure innovation or invention of something completely new, and (2) the combination of multiple existing technology elements or functions into a new form. These strains play out whether at the optical components / subsystems level, at the optical equipment level, or at the service provider network level. The focus of this paper is to trace the innovation continuum of the AON, or Agile Optical Network.

The essential ingredient in the AON is dynamic reconfigurability, a capability that brings (1) significant cost savings in operational efficiency, (2) quickened time to service revenue, and (3) reduced time for planning / provisioning of wavelengths, for the service providers that employ an AON. To be sure, the AON is a requirement for competitive delivery of triple play services, principally video services, especially VoD (video on demand), and is the enabler for future wavelength services.

The operational agility of an optical network depends on the optical equipment forming the network; in turn, optical equipment embodies many *points of agility* that support network agility; these points of agility are embedded in optical components and subsystems designed into the equipment.

The optical network began with the introduction of DWDM in the 1990s, which allowed for an explosion of capacity in optical networks. The capacities available with DWDM far exceeded the market requirements of the time, especially without the intelligence and agility available today. DWDM gave us very fat pipes, which were useful, but there were no tools to make the fat pipes into new services. On the other hand, there were no applications to drive the need for bandwidth and agility, such as IPTV. Nonetheless, the optical networking potential had already become apparent, and gradually the optical layer is becoming the nerve center of the telecom network.

We believe that a major advance took place with the invention and introduction of ROADM equipment in long haul optical networks—this is the beginning of the *Agile* Optical Network, the 1st inflection point of the AON, and the start of the AON continuum. Advances in optics, clever components continuously designed at lower cost, and their arrangements in subsystems, created new types and new generations of ROADMs suitable for metro networks, and brought us the 2nd inflection point on the AON continuum. We can see down the road that there is an obvious 3rd inflection point within reach.

II. What is AON?

The AON is a *dynamically reconfigurable* DWDM network, has a growing number of automated functions, and has these properties and characteristics:

- Allows wavelengths to be remotely reconfigured dynamically in ROADM nodes
- Reduces the time for wavelength provisioning, typically from weeks or months to a few hours or days, through dynamic reconfigurability
- Reduces opex, as human labor is reduced and truck rolls are minimized
- Enables efficiencies required for triple play, especially IPTV services
- Provides capabilities required for dynamic wavelength services
- Shortens time to service revenue
- Supplies automation and/or automatic functions (or not) through points of agility
- Provides resiliency to respond to spontaneous bandwidth demands; compensates for errors in the planning process

The basic building blocks for the AON—the points of agility (as we described in Chapter I)—reside in optical components and subsystems. We describe some of the more prominent points of agility in Exhibit 1.

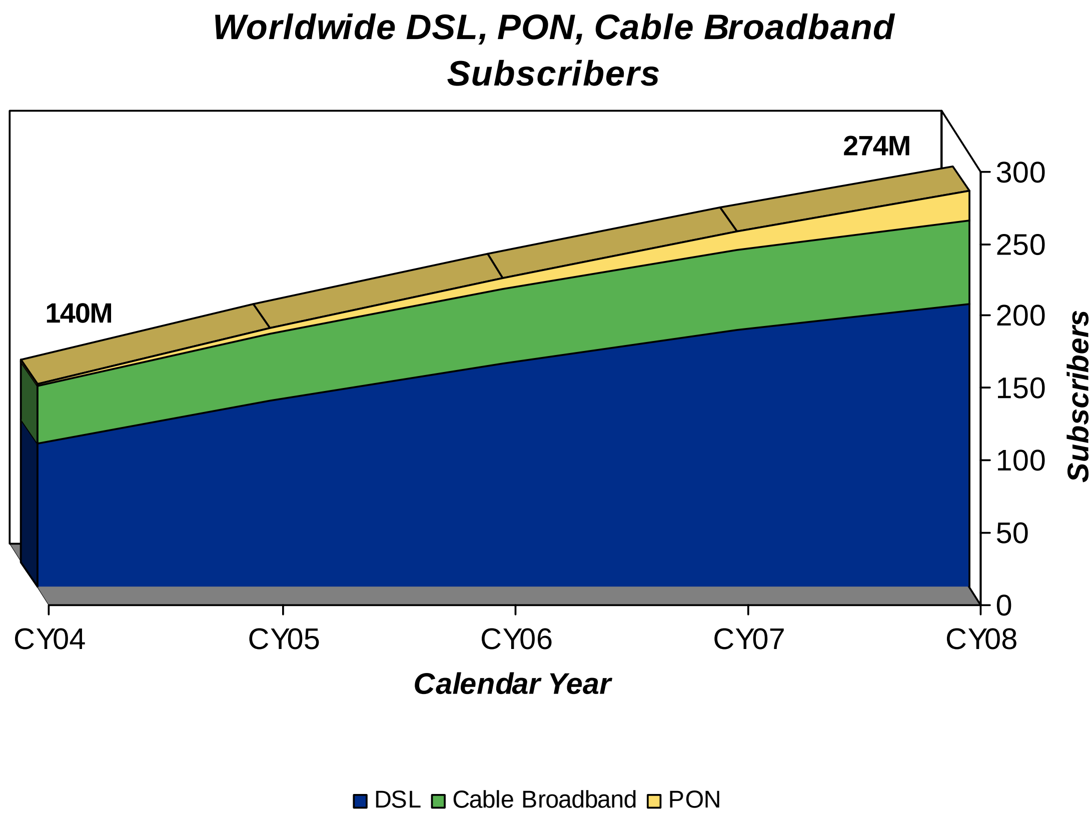
Exhibit 1 **Points of Agility for the AON**

Point of Agility	Description	AON agility function
ROADM	Reconfigurable optical add drop multiplexer	Dynamically reconfigures wavelengths
EDFA	Erbium-doped fiber amplifier	Automatically responds to changes in input power or number of wavelengths
Tunable transponder or laser	Transponder or laser that can dynamically change its wavelength	Responds to commands to transmit light at a particular wavelength
DGE	Dynamic gain equalizer	Automatically equalizes power over a spectrum of wavelengths regardless of network conditions
Tunable filters	Can dynamically change the wavelength that it filters or drops	Selects and filters (add/drop) any single wavelength
Protection switch	Switch that handles failures in a network	Automatically switches to alternate route to ensure traffic flow
Dispersion management	Module to measure and correct dispersion	Manages dispersion and compensates, enabling longer propagation distances, mixed wavelengths from other sources, and higher capacity
VOA	Variable optical attenuator	Adjusts and manipulates the power level of individual wavelengths
OPM	Optical performance monitor	Automatically monitors power level, channel and optical signal to noise ratio
Optical handheld power meter	Operated by technician	During commissioning and troubleshooting, verifies/debugs power levels
OSA	Optical spectrum analysis	Validates/debugs wavelengths, especially for ROADM add/drop signals
CD/PMD	Chromatic dispersion/polarization-mode dispersion	Validates PMD and CD as metro networks are converted to AON equipment

III. Transport Networks in 2006

There is no end to the march of bandwidth growth, and IPTV will push this growth even more. Broadband subscribers stood at about 140M in 2004, and will reach about 270M by 2008, as shown in Exhibit 2.

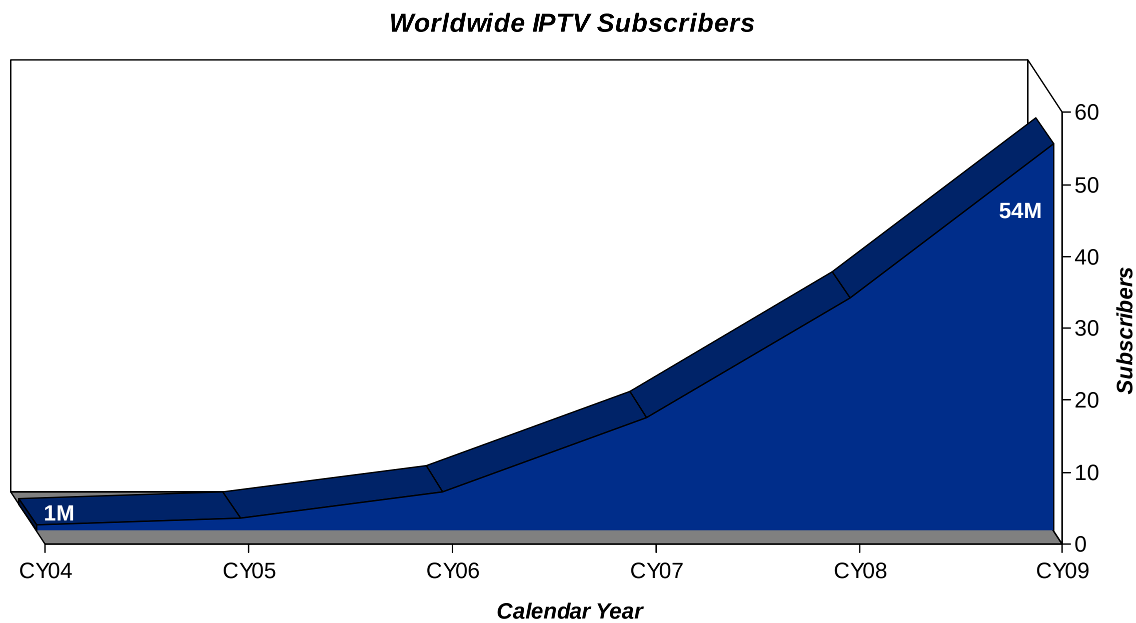
Exhibit 2 **Worldwide Broadband Subscribers**



Source: Infonetics Research, 2005

A fast growing number of broadband subscribers will be using IPTV, growing from under 1 million in 2004 to almost 54 million in 2009, as shown in Exhibit 3. IPTV will cause providers to add massive amounts of capacity to their networks.

Exhibit 3 **IPTV Subscribers 2004–2009**



Source: Infonetics Research, 2005

Cisco CEO John Chambers recently said Cisco sees bandwidth growing at 100% a year in some carrier networks in the present; in the future, 300% to 500% annual traffic increases are not out of the question, if IPTV becomes the primary way that consumers get television service.

And, the *type* of bandwidth fundamentally changes, as IPTV brings with it not only the massive amounts of new bandwidth, but the exacting requirements of delivering a satisfying user experience to an unforgiving customer audience. Telco delivered IPTV cannot perform at the level of mobile phone quality (or lack of quality), it must deliver the same high quality as broadcast or cable TV, particularly at a time when analog TV is being replaced with high definition digital TV. This QoS and the unpredictable spontaneity of demand means that service providers' networks must be engineered differently. The notion of oversubscription as a rule for network design goes away; with IPTV, oversubscription is out of the question.

In 2004, many North American MSOs deployed new DWDM metro networks to support VoD services. Only DWDM could meet the growing bandwidth demands, and only ROADM equipment could meet the agility needed for VoD services.

Providers spent US$3.3 billion on DWDM network equipment in 2005, and will spend US$4.5 billion in 2008. Although bandwidth is increasing exponentially, this investment in DWDM equipment is growing in a reasonable, straight line. This means that the capex/opex spent per wavelength is decreasing. To meet these dynamic requirements, innovation is driving up the AON utility and value of the equipment.

We are on the AON continuum, riding the invention, innovation, and integration, of optics, components, and subsystems used to create equipment with more and more points of agility—this allows carriers to deploy an ever increasingly agile optical network. Today, providers have a predominantly copper-based access network. In order to capitalize on their copper plant, the major incumbent telcos are upgrading their access networks with various xDSL flavors. Others such as KT and NTT, and Verizon, are already migrating to FTTx. Consequently, bringing fiber to every home will mark the next phase of deployment of end-to-end AONs.

IV. Benefits of AON to Service Providers

Now that we have defined the AON, described its continuum, and presented the economics of the AON, we turn to how service providers are using and can use the AON. In wireline telecom networking, we see two main drivers today:

- Broadband growth and diversification around the world: DSL, cable, FTTP (PON and Ethernet), driven by high capacity triple play; providers must deliver a minimum of 20–25M of bandwidth/customer, with many, such as Deutsche Telekom, planning a network that can deliver 100M to every subscriber
- Carriers converging to a single data network centered on IP/Ethernet over DWDM

The AON is part of the basic solution underpinning both of these drivers. As telcos accelerate triple play growth, they need to reduce the cost of operations, yet more quickly provision services. They have to scale capacity quickly without incurring high capex and opex, and this is exactly what the AON supplies today.

We have focused on IPTV, which is primarily a consumer play, but businesses also put growing bandwidth and service diversity demands on carrier networks. The same AON provides a supple supply of agile capacity for providers to react to the changing market, and lays the foundation for coming wavelength services.

V. AON Continuum Today and the Next Steps

During the 1990s, network improvements came in terms of incredible bandwidth increases—4X, 10X, 40X per fiber, with the introduction of DWDM. The driver was simply more bandwidth, and this technology jump outstripped any market requirements. In a real sense, the market did not dictate massive amounts of new bandwidth, but rather the amount of fiber in the ground—or lack thereof—was the driver. In many ways, the DWDM network was viewed as a tactical necessity to transport growing amounts of traffic.

Today, we are in a much different situation, as there is a pronounced demand by providers for agility and intelligence in their DWDM networks to support VoD, IPTV, and other emerging applications. Today’s DWDM networks are strategic to providers’ ability to offer these services and keep their business models from getting out of whack. Without agility at the optical layer, the new video services would require:

- More operations staff
- More planning staff
- More wavelengths in the networks
- Slower time to deploy new services
- More capex and opex

In the 1990s, DWDM networks were not agile, but fairly static, used mostly for point-to-point connections, and were primarily deployed for long haul routes. The AON was birthed by the invention of the first ROADMs, used in long haul gear, which we describe as the 1st inflection point of the AON, the start of the AON continuum. Over the next few years, inventions in optics, components, and their use in subsystems, spawned new types and new generations of ROADMs designed for metro networks (and they benefit long haul applications), and brought us the 2nd inflection point on the AON continuum.

ROADMs are the principal point of agility that give carriers the dynamic reconfigurability at the heart of the AON. There are many other points of agility, that is, components or subsystems that bring more automation, flexibility, or utility to AON equipment, and thus to the AON itself. Some notables include the EDFA (erbium-doped fiber amplifier), automatic DGE (dynamic gain equalizer), OPM (optical performance monitoring), tunable transponders/lasers, tunable filters, VOA (variable optical attenuators), protection switch, dispersion management. These are all undergoing innovation, evolution, size reduction, cost reduction, and feature/function integration, leading to an even more agile AON. In deploying and operating an AON, some tools provide irreplaceable value, such as handheld optical power monitors, optical spectrum analyzers, and CD/PMDs.

Finally, just down the road, we can see that the next inflection point is within reach, covering the metro access and into the enterprise, including campuses, large buildings, and data centers. This 3rd inflection point will be characterized by lower cost components, inventive ROADM subsystems, and tunable filters designed for equipment that handles fewer wavelengths than in metro equipment.

As we ride the AON continuum, the focus of the 1st and 2nd inflection points—the long haul and metro—will not be neglected. Invention and innovation at the optics level in components and subsystems will continue to create more points of agility that have more automation and automatic functions; and these will be built into equipment that carriers will use in AON applications in the long haul, the metro, and the access/enterprise.

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