Agile Photonic Networking

a report by
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Introduction

The past five years have seen many significant changes in the telecoms sector, especially the inter-exchange carrier (IEC) space. The free-flowing capital markets of the past spawned an over-investment, creating the recent flurry of Chapter 11 filings. Sector survivors have been subjected to hypercompetition, with many companies vying for business to sustain cash flow. This pricing spiral resulted in contracts based on marginal cost rather than total cost, a process that has essentially eliminated profit from the industry. The result is an increased focus on efficiency of not only capital costs, but increasingly a focus on workforce efficiency and operational costs.

Bandwidth growth will continue to be a key enabler for the applications that fuel productivity growth across the macroeconomy. As such, the long-haul marketplace is not dead, but is in the beginning of the recovery process that resulted from a 'carrier glut'. Carriers have begun the evaluation process to select the technology suited for the builds that will support the continued growth. The challenge to equipment vendors is to develop solutions that allow carriers to address on-going bandwidth growth with new levels of efficiency. One leading technology solution for this challenge is 'agile photonic networking' (APN).

APN Overview

APN combines a few key concepts to deliver cost reduction and scalability of the network, while, at the same time, enabling rapid set-up of bandwidth. Transparency leverages all-optical switching to facilitate cost-effective connection set-up across multiple segments of a network without having to undergo optical-electronic-optical (OEO) conversion. Full-range tunability provides the mechanism to deploy generic capacity pools, reducing over-provisioning and risk of stranded capital, and making transparency and agile reach manageable. In addition, these concepts need to be automated and simplified for operational viability.

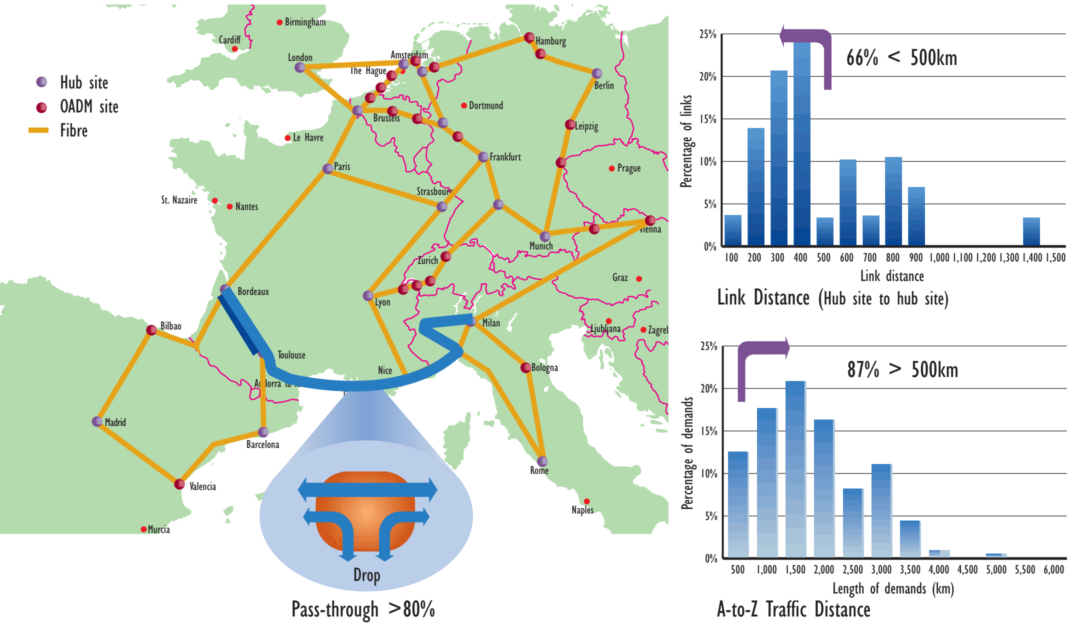
Transparent networking involves the ability to enable photonic pass-through at hub and optical add/drop multiplexer (OADM) sites. Although the benefits of pass-through provided by an OADM on a linear dense wavelength division multiplexing (DWDM) system are well understood, this concept can, more importantly, be extended across the whole network. A quick snapshot of network characteristics is illustrated in *Figure 1* to outline the rationale for transparency beyond simple OADMs to multiway junctions.

Network characterisation based on a distance and population-weighted gravity model for traffic shows that a substantial number of end-to-end paths pass through intermediate sites (upwards of 80%). The management of these pass-through connections can be accomplished on conventional architectures by going through an OEO conversion between point-to-point systems (either regenerator, back-to-back transponder or through a grooming switch). Migrating to a transparent node that keeps pass-through signals in the photonic domain provides savings of more than 50% on capital cost, footprint and power consumption. This capability combines with point-and-click 'A-to-Z' connection set-up to decrease turn-up time of wavelengths dramatically.

Traditional point-to-point DWDM models with fixed uniform demands have, to date, been a standard benchmarking activity in carrier costing exercises but, in fact, can belie achievable cost per bit on a deployed system. Variations in physical characteristics such as loss, length and fibre type impact system design relative to a homogeneous model. However, wavelength demand patterns will also impact network cost overall and can often impact the technology choice, resulting in a mix of conventional and ultra-long reach (ULR) DWDM attributes. The ability to assign regeneration and wavelength conversion on a per-demand basis results in a cost-optimised network.

Full-range tunability provides the final piece of the APN puzzle. The ability for a single module of capacity to map to any wavelength heading in any direction at connection endpoints enables dynamic capacity additions to provide dynamic wavelength conversion and eliminates the need to build and engineer network resources to a set forecast. Since capacity resources can be reconfigured dynamically,

Figure 1: Network Characterisation Illustrates the Rationale for Transparency



complex wavelength engineering and stranded modules or ports can become a thing of the past.

APN Requirements

A number of technologies in the past few years have been introduced in an attempt to realise a subset of the APN values. Past technology introductions have included photonic switches, ULH WDM systems and OADMs. The first systems to offer end-to-end transparency and wavelength turn-up capabilities are just entering the market now. To benefit fully from an APN, a number of key elements are essential, and the exclusion of any one of these reduces the overall effectiveness dramatically. The key components required for an APN are:

- transparent photonic switching;
- networked optimised reach capability;
- fully tunable edge;
- network-aware control system; and
- enhanced photonic operational capabilities.

Transparent Switching Cost Reduces the Node

Transparent photonic switching enables cost savings, space and power reduction and also the ability to rapidly turn up new wavelengths across a network. In addition, in order to ensure this value can be realised at all sites in the network, switching solutions need to be developed that address the varying degrees of nodal connectivity required. Typically, 50% to 75% of network nodes (smaller/intermediate sites) can be addressed by an OADM optimised for small terminating traffic requirements. The remaining network nodes require a higher degree of connectivity to build a mesh interconnect and need to support a larger portion (20% or more) of terminating traffic.

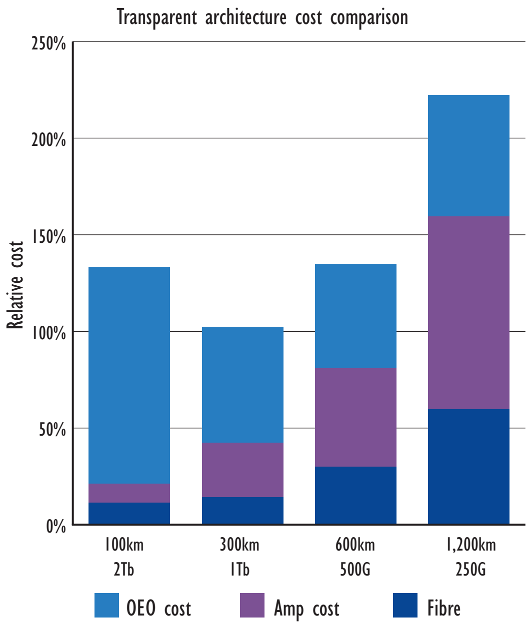
The APN allows the activation of wavelengths from any point to any other across the network. As a result, each switch will have many optical channels of varying path length between multiple line systems. In order to support the management of these various channels, the ability to provide per-channel power management is a prerequisite. This function must be automated to accommodate the addition or reconfiguration of wavelength patterns to manage incremental network growth and changes of connection patterns.

Finally, it is important that there is a minimal amount of signal degradation caused by the switching elements for pass-through channels. This implies that the switch and OADM induce minimal channel filtering as well as low insertion loss. This facilitates pass-through at many consecutive sites before regeneration is required. New component-level technologies have introduced integrated DWDM/demultiplex functions that meet these signal degradation needs.

Cost-optimising Network Reach and Capacity

One of the most important factors in optimising network economics is to have the right combination of reach and capacity. In an APN, system reach capability is ideally defined by the A-to-Z wavelength demand requirements, allowing an optimisation of optical amplifier cost versus intermediate OEO regeneration. All intermediate OEO interfaces could be removed (except for a few per cent utilised for wavelength blocking reasons) if the system minimum reach capability were to exceed the longest A-to-Z demand requirements. On a conventional system

Figure 2: Reach/Capacity Trade-offs versus Network Cost



design, extending the minimum reach is achieved by a combination of limiting capacity or increasing the cost of optical amplifier systems. The problem, however, is that, while this may optimise the system cost point for the longest A-to-Z demand requirement, the entire network traffic will be realised at a much higher cost, due to the cost premium placed on shorter connections. In order to minimise network cost, the answer is generally to focus the reach on more typical link or connection length. While this may leave some OEO regeneration in the network, it generally provides an overall lower network cost. In North American backbone networks, this typically results in a reach requirement of about 2,500–3,000km, with approximately one terabit per second (Tb/s) of line capacity.

Full Edge Tunability Simplifies and Speeds Up Bandwidth Deployment

One of the key differentiators for the APN is the ability to enable rapid deployment of bandwidth. In traditional systems, the deployment of new wavelength channels was complicated by the requirement to complete detailed frequency (wavelength) planning activities before costly OEO interfaces could be ordered and deployed. Combining full tunability (across all system wavelengths) of OEO interfaces and DWDM filters eliminates the frequency planning process by allowing the system to choose and tune wavelength interfaces. The ability to turn up new channels rapidly, without a complex engineering and ordering process, also minimises susceptibility to demand forecast errors since capacity can be redeployed anywhere automatically. This enables deployed capacity to be optimised much closer to actual demand requirements, resulting in a much more cost-effective network that is able to respond to any set of demands rapidly. The ability to have one interface in the network removes the necessity for wavelength planning, freeing network planners to focus on increasing network efficiency.

Network-aware control systems automate engineering and connectivity of variable path lengths. In order to guarantee network performance, it is important that the network control system can detect, measure and react to actual network parameters as they exist in the field. This will ensure that the system can optimise performance around the true physical plant and operating conditions. These operating conditions include actual loss and dispersion of fibre in the ground as well as all components within the system, which can be measured and maintained in a network-wide database. In addition, all elements of network topology, from card-to-card connections to system fibre types, should be audited automatically to allow simplification of network operations as well as allowing the system the latest view of connectivity. Using actual network conditions, the APN can optimise connections automatically on an end-to-end basis.

Enhanced Operational Capabilities

With the introduction of an APN, operational features that the carrier was accustomed to with the electrical (Synchronous Optical Network/synchronous digital hierarchy (SONET/SDH)) layer must be reintroduced at the photonic layer. This means that the photonic system must build on the industry-established ability to provide fault isolation and correlation, performance monitoring and troubleshooting to a level acceptable to support traditional operations. With these capabilities included at the photonic layer, network operations can actually be improved over traditional systems where most of these features were previously left to manual engineering operations. The underlying complexity of the various elements can be hidden from the network operator with a simple interface that translates resource availability and assignment, performance metrics and physical commissioning, and provisions information into easily managed elements. Similarly, applying a degree of automation to commissioning and physical troubleshooting procedures reduces human error.

Automating the Core

APN provides a clear path to improved cost and operational efficiency but involves a number of interdependent technologies to be feasible. Essentially, an analogue engineering problem needs to be adapted for ease of use with digital-like automation of the core elements. The net benefits of core automation provided by APNs combine cost savings, capacity scalability and operational simplicity. ■