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The Self-Aware Network–Leveraging Overlapping Network Layer Capabilities for Higher Performance and Lower Costs

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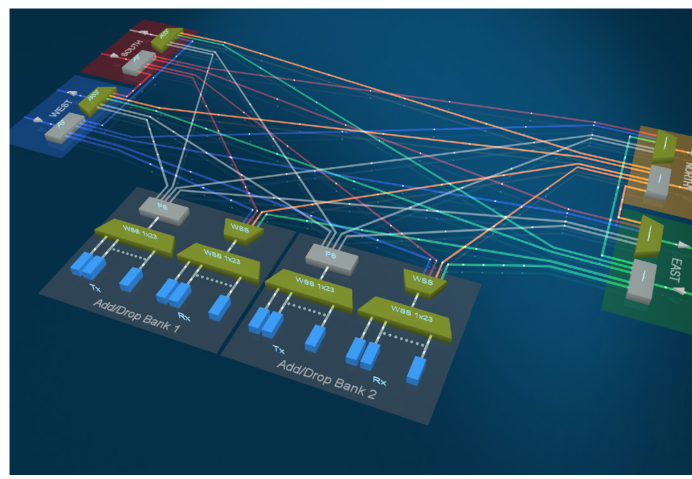
As demand for bandwidth and pressures on per-bit revenue grow, network operators need to grow and optimize their infrastructures while improving cost efficiencies. To do this effectively, they must take a holistic approach and consider the architecture and operations of the full network—fiber infrastructure through OTN switching and packet routing—rather than optimizing network layers independently. Operators need to reconsider how and where many functions reside within the network, and fully harness and leverage all the overlapping capabilities of the different layers.

The latest trends in photonic network and OTN switching technologies enable this holistic approach. Enhanced flexibility and greater capabilities at multiple layers is lowering costs significantly, particularly by letting the lower photonic layer do work traditionally handled by the upper, higher-cost layers.



The convergence of these trends is the Self-Aware Network. With a capable and competent control plane, a network can make automated and informed decisions about operations. It can rapidly, accurately, and automatically adjust the network so that it is always operating cost-effectively. It is constantly aware of the current network status and situation as well as the current capacity and service demands, it evaluates that information against operator-specified criteria, and it harnesses the multitude of photonic-through-packet flexibilities to dynamically maintain the network in its most optimal configuration.

This paper discusses the following aspects of the Self-Aware Network:

- Basic Characteristics
- An Optimized Photonic Layer
- Broad Applications
- High Bandwidth Capacity
- Compact Solutions
- Performance Management

Basic Characteristics

Four qualities characterize the Self-Aware Network: agility, reach, efficiency, and assurance.

Agility – A network with an agile photonic layer—a mesh architecture with colorless, directionless, and contentionless multiplexing and demultiplexing and an integrated aggregation and OTN switch—can flexibly adapt to changing traffic patterns driven by emerging consumer applications, faults and maintenance activities, and the evolution and growth of the network itself. This agility enables fast photonic layer restoration, easier load balancing, proactive maintenance switching, and transponder pre-deployment. Such an operationally efficient system, one that requires less complex planning and minimal manual intervention, ensures optimal performance for the least cost: reducing both CapEx and OpEx.

Reach – To complement photonic layer flexibility, optical signals carried by the network must be capable of spanning sufficient distances and network nodes to fully capitalize on the flexibility concept as well as minimize the need for very costly signal regeneration. This requires high-performance transmission technologies, such as coherent reception, that eliminate the need for expensive and lossy optical dispersion compensation. In addition, network designers will implement Raman and other advanced amplification technologies, along with more loss-efficient network node architectures, to provide lower noise transport networks and maintain the necessary reach at significantly higher traffic capacities.

Efficiency – Reducing costly, redundant hardware, maximizing fiber capacity, and lowering OpEx are just some of the benefits of the Self-Aware Network. For example, enabling a self-healing photonic layer that re-routes immediately and automatically means fewer packet and OTN switches. This lowers overall power requirements to more easily meet green environmental mandates while also reducing the need to repair infrastructure faults with an expensive "at all costs" urgency. A control plane with full visibility and control of the photonic network enables constant, automatic balancing of traffic loads in maintaining maximal network efficiency without requiring significant manual intervention, OpEx, and time.

Assurance – From design through deployment, modular, cost-efficient communications test and measurement tools are critical components in the lab, the production floor, and the field—encompassing protocol layers such as the optical transport network (OTN) and MPLS/Ethernet. Fiber, DWDM, and ROADM infrastructure require characterization, and emerging applications require testing at 40 GE/OTU3 and 100 GE/OTU4. Another vital component is tested and trusted expertise that can properly evaluate data and make quality judgment calls on proposed and existing network configurations.

An Optimized Photonic Layer

The key functional attributes of a modern photonic network are flexibility and scalability. The previous generation of "agile" optical networks gave operators the flexibility to select the wavelengths and routes of new services. However, once deployed, little flexibility existed to modify those wavelengths. However, in the Self-Aware Network, wavelength-management flexibility is dramatically enhanced. Without manual intervention, the network control system can flexibly select and remotely provision the physical route and wavelength through the network between two complementary transponders. This provisioning flexibility exists for both new wavelengths as well as for existing wavelengths that may require re-routing along a different route, via a different wavelength, or both.

Typically, the Self-Aware Network uses a wavelength selective switch (WSS) enabled mesh-network node architecture with several new enhancements. First, multiplexing and demultiplexing wavelengths into and out of the photonic network is fully flexible: any tunable transponder connected to any physical add/drop port can use any wavelength and be routed to or from any transmission fiber pair of the node. This is what is meant by colorless, directionless, and contentionless (CDC) multiplexing/demultiplexing. Second, the functionality of the WSS elements of the degrees is augmented to accommodate both a larger number of interconnected node degrees as well as a modular and cost efficient scalable number of CDC add/drop ports. By decreasing the time required to optically switch wavelengths, the time required to provision and re-provision traffic decreases, allowing quicker and more efficient network activities and use of the photonic layer flexibility.

Another key component of the Self-Aware Network is a rich and integrated control plane that has visibility into and awareness of the multiple layers within a network. It is empowered to leverage that awareness along with the underlying photonic and electronic layer flexibility to enable optimized and selectively autonomous decisions on traffic management. With unified control and management, provisioning new services (and managing existing ones) is greatly simplified. The network management system can make aggregation, grooming, and wavelength and route assignments as part of the provisioning process based upon the current state of the network, perhaps even modifying the current state of the network, to provide an optimal situation. Furthermore, as a network and its traffic grows and evolves, the control system can continue to analyze, suggest, and automatically implement traffic routing and grooming modifications to maintain as near an optimally efficient operating condition and topology as possible.

Broad Applications

The Self-Aware Network offers a number of performance-enhancing, cost-lowering applications.

Restoring the Photonic Layer

Maintaining customer service is a key revenue issue for telecommunications networks, and operators use protection schemes and various amounts of redundancies at different network levels to ensure high service availability during inevitable infrastructure failures and outages.

Redundancy is necessary, but deploying, operating, and maintaining additional equipment increases costs. However, with automated colorless and directionless add/drop capabilities, operators can quickly and automatically re-route photonic layer traffic around network failures. Relative to today's networks, where either the fault must be physically repaired (a potentially very lengthy process) or the traffic manually re-routed, photonic layer restoration significantly increases the photonic layer availability and relaxes redundancy requirements at the upper, higher-cost network layers.

Restoration at the photonic layer in a colorless and directionless environment also means:

- high-cost electrical switching and transponder equipment is always in use
- the probability of unprotected simplex operation is greatly reduced
- the need for complex manual network modifications to restore connectivity is minimized
- completing physical repairs is less urgent.

Also, with an agile network, wavelength traffic can be proactively routed away from planned, potentially invasive maintenance activities, minimizing service disruptions. When maintenance is finished or repairs completed, operators can quickly restore traffic to its original, more optimal routes.

Deploying and Reconfiguring Bandwidth

Colorless and directionless architectures enable operators to simultaneously deploy multiple transponders at nodes where growth is anticipated without the need to accurately predict the nature of that growth. Given the transponders can use any wavelength and any physical route within the network, a small number of transponders can service the collective growth of the node, however it develops. Being already deployed, the transponders allow immediate and remote provisioning of new wavelengths for rapid service turn-ups or regeneration requirements.

Maintaining Network Efficiency

With full transponder-to-transponder wavelength and route agility within the network, load balancing existing traffic and network de-fragmentation becomes a remotely controlled, highly automated, and reliable process with minimal manual intervention. In current networks, this process is generally highly manual and complex and therefore, not typically implemented.

Furthermore, as the network and traffic requirement evolve, operators can deploy additional network connectivity through the in-service deployment of additional node degrees. Existing traffic can then be remotely migrated to new, more efficient routes, relieving congestion and improving overall network efficiency.

High Bandwidth Capacity

Meeting the relentless challenge of increasing the amount of data carried per wavelength while still providing the performance and reach needed over installed infrastructure has triggered several new transmission technologies. First, the preferred technique for encoding data onto the wavelength has shifted from using amplitude modulation of the optical signal to modulation of the phase. Second, the use of coherent detection, effectively digitizing the complete optical signal field, followed by electronic digital processing has provided a powerful technique to mitigate distortions and impairments at high data rates. Importantly, this technique does not significantly reduce performance or require costly modifications to the installed transport infrastructure. For new networks, coherent reception technology allows for the removal of optical impairment compensating devices, such as dispersion compensating fiber, which means lower costs and better transmission performance over a variety of fiber infrastructure types.

As wavelength data rates increase, enhanced amplification techniques such as Raman amplification within the transmission fiber become attractive. This technique enhances transport performance and supports higher data rates over longer distances. Most importantly, Raman amplification technology does not require modification of the existing fiber infrastructure and therefore is cost effective to deploy. And, it maintains the network's transparency and agnostic nature to modulation format. This ensures compatibility with other modulation and transmission technologies as they mature and become cost effective.

The flexible photonic layer within the Self-Aware Network provides another key avenue for capacity growth. Operators can add fiber pairs alongside existing pairs and then seamlessly integrate them into the greater mesh network simply by deploying an additional degree at the endpoints of that span, a process that does not disrupt the remainder of the in-service network. Once deployed, the additional fiber pair effectively doubles the capacity along that route, alleviating local bottlenecks and providing new connectivity so that new or existing traffic can be migrated to this new bit of infrastructure as desired. This allows continued network traffic growth and efficient capacity increases as traffic requirements evolve.

When applications require wavelength data rates beyond 100 G, such wavelengths are unlikely to fit within the conventional ITU-defined 50 GHz channel spacing and will require higher performance amplification to achieve the reaches necessary. In the Self-Aware Network, the wavelength routing hardware, optical monitors, and control plane will have the added capability and responsibility of defining a channel's optical bandwidth as the wavelength is provisioned. Additionally, the use of Raman amplification will improve the noise performance of the network, thus providing these wavelengths the reach needed to be cost effective. This will let operators continue to expand the capacities of their networks by leveraging the most efficient high data-rate transmission technologies.

Compact Solutions

The cost of equipment space and power is a critical factor in achieving a cost-effective network. Historically, transmission components have made up the biggest percentage of optical transport networks. However, as the flexibility and capability of the photonic network increases over previous network generations, it has the potential to occupy a bigger percentage of the overall optical transport infrastructure.

Alongside this trend is the emergence of considerably more dense and functionally integrated optical solutions. Combining multiple optical transport functions such as WSS, optical amplification, optical monitoring, and optical service channels onto a single, highly integrated linecard lets operators reclaim valuable equipment shelf space and power for revenue-generating wavelength services and results in a significantly more cost-effective network.

Performance Management

As complexity increases at the transport and IP layers, it is important to maintain a multilayered approach within the network management system to ensure quality of the network and services.

For IP services, there are three fundamental key performance indicator measurements for quality of service: frame delay, frame delay variation, and frame loss. With the increased flexibility of the Self-Aware Network, it will be important to ensure that the IP services still meet these performance thresholds after automatic adjustments such as traffic re-routing.

For example, frame delay depends on distance, and after a re-routing, the IP service must be assured. This is particularly important with applications such as financial transactions. It is also important that a re-routing does not cause frame loss or a traffic strain on IP devices performing QoS, rate shaping, or policing. An increased load on routers and switches can increase the steady-state frame loss rate.

Given the complexity and dynamic nature of the Self-Aware Network, a disciplined regimen of assuring service quality and monitoring lets operators confidently leverage the network's vastly increased capabilities.

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