Leveraging Complementary Technologies

The Evolution of SONET/SDH Over WDM

Paul Bonenfant

Although the telecom market has suffered serious deflation on the optical spending side, a new crop of promising innovations is moving to market. Chief among them are a fully automated optical layer and fully integrated synchronous optical network/synchronous digital hierarchy (SONET/SDH) over wavelength division multiplexing (WDM). Both of these innovations leverage technologies that have high currency value to carriers.

A Photuris engineer holds a WDM transponder line card incorporating SONET/SDH "ADM-on-a-chip" technology.

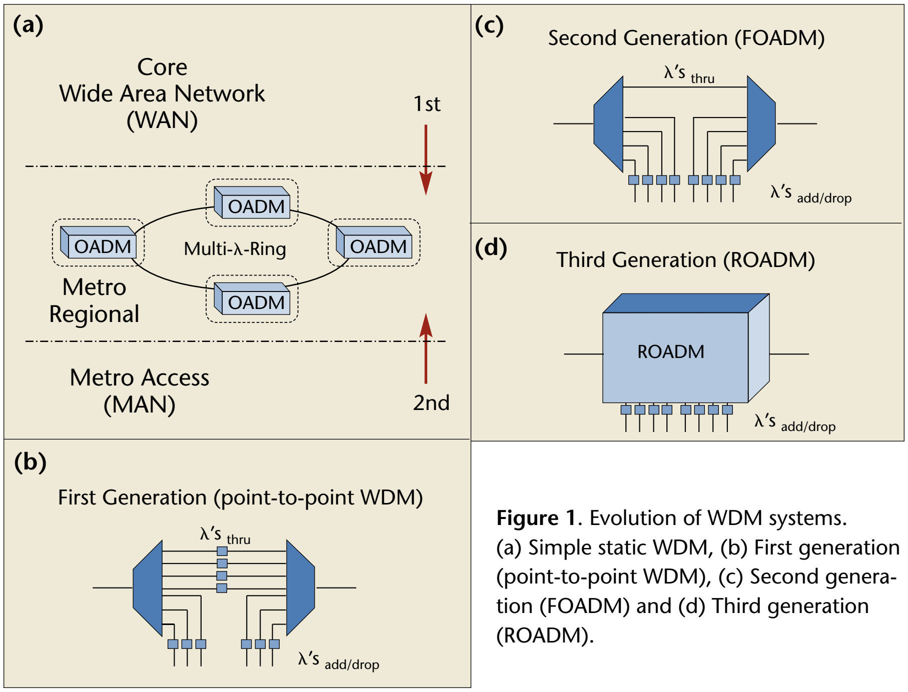

Figure 1. Evolution of WDM systems. (a) Simple static WDM, (b) First generation (point-to-point WDM), (c) Second generation (FOADM) and (d) Third generation (ROADM).

Technological advances are enabling intelligent, flexible and fault-tolerant optical networks. Seemingly relentless progress in underlying optical technologies—amplifiers, switches, fibers, lasers, filters and combiners—continues to push the envelope of all-optical networking applications. As a result, a fully automated optical layer is putting an end to the once-painful operating paradigm associated with WDM systems by removing the traditional barriers that had made WDM a last-resort solution for capacity exhaust. The benefits of using WDM systems now extend beyond simple capacity expansion to wavelength-level networking. Today's WDM systems avoid the optical-electronic-optical (OEO) regeneration "pass-through tax" (i.e., unnecessary signal regeneration at the electrical layer for traffic not destined for the regeneration point) and provide significant savings to the carrier network in terms of both capital expenditures and operating expenses.

At the same time, innovations at the time division multiplexed (TDM) transport layer are breathing new life into SONET/SDH* by allowing new applications and service support over existing network infrastructures. Optical chips and integrated optical circuits, such as SONET/SDH "add/drop multiplexer (ADM)-on-a-chip" technology, are now reducing the need for, or even replacing the earlier technologies. New SONET/SDH features, such as the generic framing procedure (GFP), virtual concatenation and the link-capacity adjustment scheme (LCAS), enable nontraditional Ethernet, storage-area networking (SAN) and digital video to be transported over SONET/SDH.

Carriers benefit from sensible integration of WDM and TDM systems, as distinct from the "God Box Syndrome" (the recent propensity to try to integrate WDM and "everything else"), because sensible integration leads to significant network simplification and cost savings. These savings are reflected in network element and interface reduction, elimination of stacked SONET/SDH rings and per-wavelength selectable optical or SONET/SDH layer-protection mechanisms. Sensible integration reflects the

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*SDH is the fiber-optic transport standard defined for worldwide use by the International Telecommunications Union. SONET is defined by the American National Standards Institute for use in North America. Exchanges between SONET and SDH are accommodated at international boundaries.

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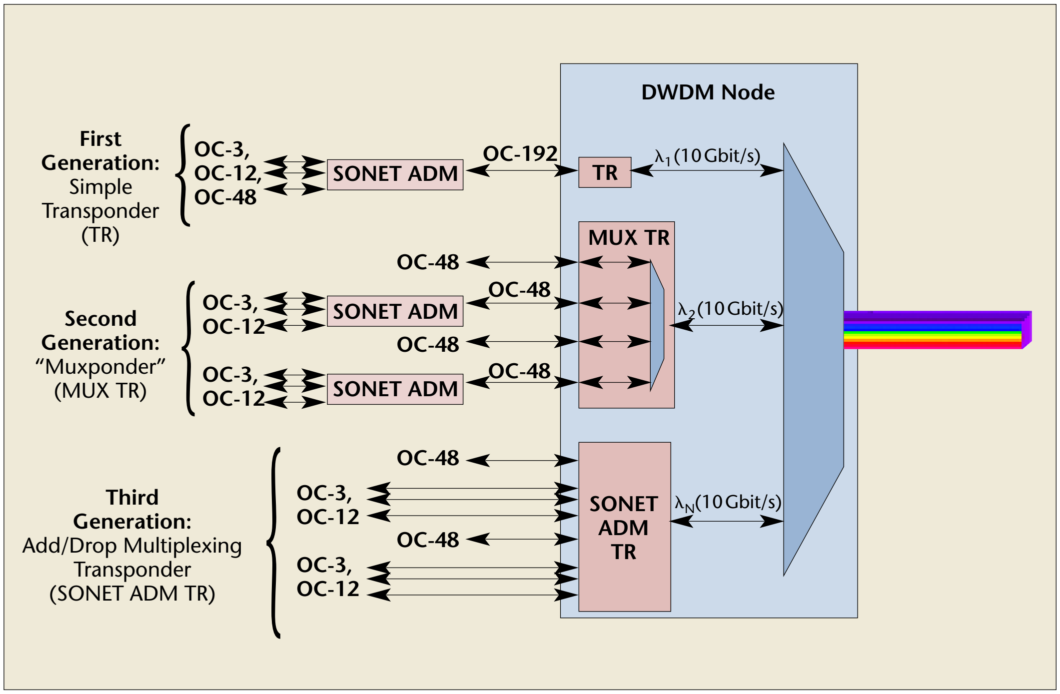

Figure 2. Evolution of transponder functionality in transponder-based WDM

integration of key third-generation WDM system features and third-generation SONET/SDH over WDM features.

Third-generation WDM evolution

Since the mid 1990s, when it was first deployed to address capacity exhaust over fiber-constrained routes, WDM has undergone several stages of development (see Fig. 1), evolving from a simple, static, point-to-point solution for capacity exhaust to dynamically reconfigurable wavelength add/drop systems.

First generation point-to-point WDM solutions were extremely efficient and cost effective for moving large amounts of traffic between two distant points in the network. The optical amplifier (OA) was the catalyst for WDM deployment, resulting in enormous savings for long-haul carriers by allowing the multiple OEO regenerators at each regeneration point to be replaced by a single OA. Carriers invariably found that not all wavelength-level traffic shared the same origin and destination in the network. To accommodate this situation, they began to "network" at the wavelength layer. This required that certain wavelengths pass through the end-offices where other wavelengths were added and dropped. The high optical losses of full WDM multiplexing and demultiplexing filters resulted in the need for OEO regeneration to mitigate optical layer impairments. Thus, while sufficient for capacity exhaust, these point-to-point WDM systems suffered from excessive OEO regeneration for pass-through wavelengths. And since they were designed for long-haul networks, the prices of these systems were typically too high to meet metro regional and metro access WDM needs.

Second-generation solutions attempted to address these shortcomings by hard-wiring pass-through wavelengths through the node—without single-wavelength multiplexing or demultiplexing—by use of fixed optical add/drop multiplexing (FOADM) filters that add/drop a selected wavelength "band" but pass through the rest. But because of cascaded filter effects, these FOADM solutions required extensive per-wavelength engineering and created undesirable ring lasing in optically amplified applications. They also required: per-wavelength engineering; manually intensive filter install and jumper cabling; and modifying optical attenuator and optical amplifier settings when adding or provisioning new wavelengths to the system. These manually intensive exercises were required not only at the endpoints of the service, but at intermediate sites as well. Because of the wavelength-banding approach they were constrained to, FOADMs also resulted in "stranded" wavelengths: rather than drop a wavelength as needed at a site, carriers were forced to drop wavelengths in groups of three or four. As a result, these systems were most often deployed in access applications where the use of OAs could be minimized, and where "hubbed" (in other words, predictable) traffic patterns predominated.

Recent innovations have resulted in third-generation, dynamic and reconfigurable optical add/drop multiplexing (ROADM) solutions that solve the problems inherent in FOADMs. The attributes of ROADMs include remotely reconfigurable single-wavelength granularity and optical pass-band characteristics. These allow for higher node-count systems without intermediate OEO requirements. The ROADM is an ideal solution for the metro regional market segment, where traffic patterns are more random in nature, the need for higher-node-count systems is more acute and optical amplification is often a necessity.

But ROADM alone is not a complete solution. To enable truly remote wave-

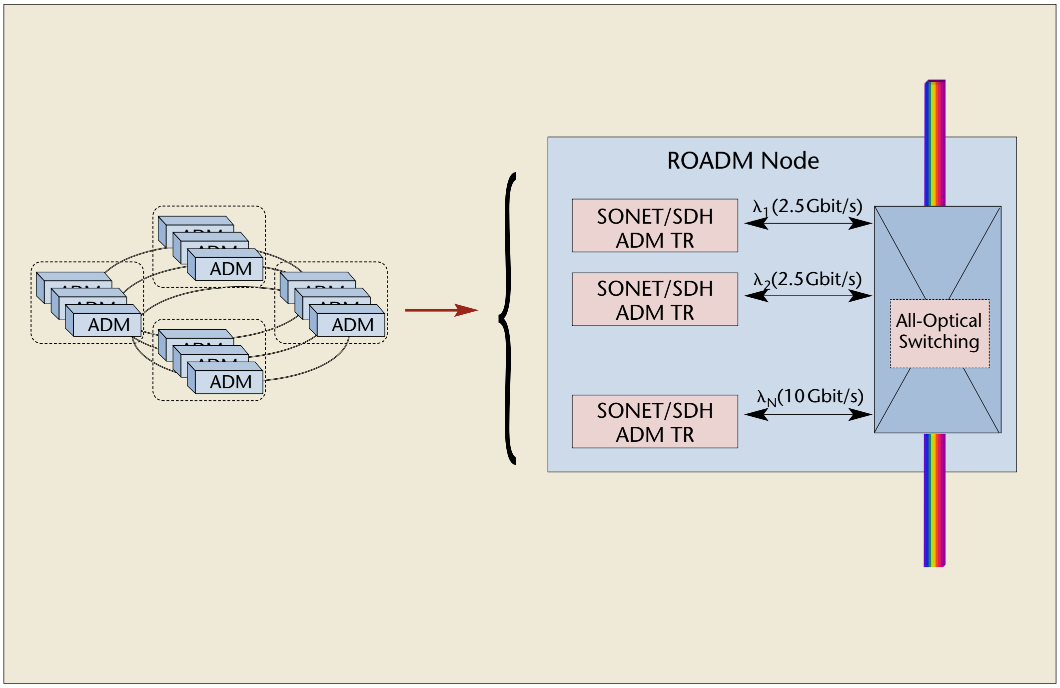

Figure 3. SONET/SDH stacked-ring replacement.

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length-level provisioning, without the need for per-wavelength engineering and manual intervention, a fully automated optical layer is required. It is enabled by ROADMs, complemented by automated power-level management, a distributed control plane and a one-time node engineering approach.

Automated power-level management leverages optical monitoring to control the variable optical attenuation function of the ROADM; this serves to maintain optimum signal levels, both at the drop to a receiver and on the express path through a node. Receiver performance is improved because it is less susceptible to dynamic changes in the network or long-term system degradation. Express wavelength power optimization, commonly referred to as per-wavelength dynamic gain flattening (DGF), is used to flatten the wavelength-dependent gain spectrum of the optical amplifier used in the automated optical layer.

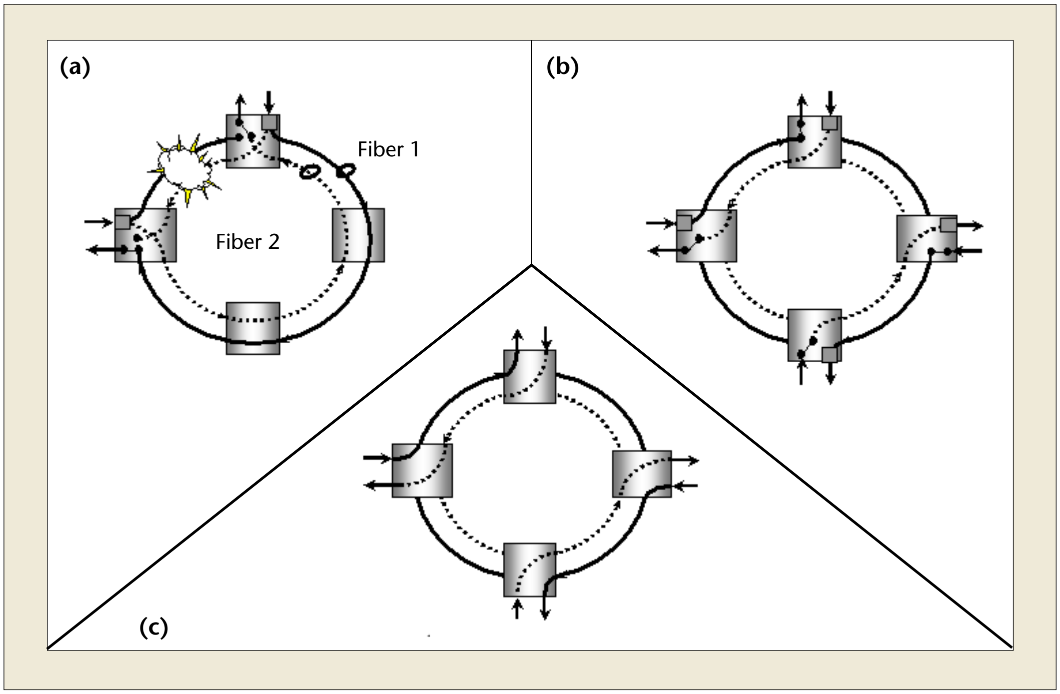
The automated optical amplifier also brings fast automatic gain control (AGC), one of the most critical features, to the metro regional network. Fast AGC (sometimes called transient control) automatically adjusts the operating conditions of the amplifier to maintain a constant gain as the number of amplified wavelengths or input signal power changes. Without effective, fast AGC, the wavelength output power will experience large transients. This effect increases in magnitude as the signals propagate through a chain of cascaded amplifiers in a WDM network. Possible sources of input power changes in a dynamic WDM network include: wavelength provisioning; fast wavelength switching to support optical protection; power adjustments by DGFs; fiber cuts; and human error.

How "fast" is fast AGC? Suppose we have a 16-node ROADM ring network with cascaded 16-wavelength OAs. To prevent any measurable errors, when 15 of 16 wavelengths are dropped in under 100 ns (because of a fiber cut, for example) the amplifier should limit the gain divergence of the remaining wavelength to less than 0.1 dB. The combination of ultrafast DGF and AGC dynamically adjusts and balances power levels of each wavelength as services are added or removed, or in response to failures such as fiber cuts.

Standards-based, generalized multi-protocol label switching (GMPLS) or automatic switched optical network (ASON) based distributed control planes offer an opportunity for proactive bandwidth allocation, auto-discovery of network topology and resources and near real-time provisioning of services with less reliance on centralized operations systems.

Optical layer automation is not complete without one-time ring or network engineering. Network configuration tools allow carriers to simulate and verify the physical and transmission layer layouts of their WDM transport networks. This is done by use of tools to identify the number of nodes, span lengths, optical amplifiers and dispersion compensating modules (DCMs) required, as well as the optimum placement of amplifiers and DCMs to serve a customer's network

Figure 4. Mixed optical and TDM (SONET) protection. (a) Optical channel dedicated protection ring. (b) Optical channel shared protection ring. (c) Optical layer unprotected services, integrated SONET ring protection, or client layer protection (e.g., subtending SONET rings, or MPLS or L2 protection).



topology and traffic growth projections at the lowest possible cost. Carriers can then deploy wavelengths from any node to any other node, without the need for per-wavelength engineering at either the endpoints or intermediate sites. WDM ring deployment will thus become a one-time node engineering exercise, similar to SONET/SDH equipment deployment.

With combined attributes of the ROADM, DGF, AGC, distributed GMPLS/ASON control plane, and a pre-planned one-time ring/network engineering approach, a fully automated optical layer allows for "SONET-like" simplicity to be applied to wavelength management. Carriers can now manage wavelengths in WDM systems like individual timeslots in SONET/SDH networks: remotely, and without the need for per-wavelength engineering.

Sensible transport integration

ADM-on-a-chip application-specific integrated circuit (ASIC) technology, incorporating classic SONET/SDH functionality and emerging SONET/SDH features, allows for the elimination of stand-alone SONET/SDH network elements. Consider the evolution of transponder-based WDM systems (see Fig. 2).

First-generation transponders served the relatively simple function of wavelength conversion from a broadband 1310 nm or 1550 nm signal to a WDM-compatible signal with spectral characteristics suitable for multiwavelength transmission. All subwavelength grooming and switching were handled by external SONET/SDH ADMs. Second-generation transponders added a simple multiplexing function that was especially useful for high-speed signals with similar origination and termination points in the network. Carriers were still forced to drop signals out to external SONET/SDH ADMs for subwavelength grooming and switching. With the emergence of ADM-on-a-chip technology, the third generation of transponders for WDM systems has arrived. The transponder can now incorporate all of the external, stand-alone SONET/SDH ADM functionality. For carriers, this implies fewer network elements and fewer interfaces to manage between network elements and between network elements and management systems.

The evolution of SONET/SDH over WDM also addresses significant network application issues for carriers. For example, the integration of SONET/SDH ADM transponders in ROADMs has immediate application in addressing the "stacked SONET/SDH ring" problem characteristic of many large carrier central offices (see Fig. 3). Today, these carriers continue to use and deploy SONET/SDH ADM "farms" because of the familiar paradigm of pulling additional fiber and deploying more SONET/SDH network elements. This approach forces carriers to: add redundant interfaces; pull much more fiber than necessary; find space; and provide additional power. It also introduces the burden of finding 10 Gbit/s-capable fibers every time a new SONET/SDH 10-Gbit/s ring is deployed. This model can now be replaced with a single ROADM node populated with "as needed" SONET/SDH ADM transponders.

When coupled with integrated SONET/SDH ADM transponders, a fully automated optical layer leveraging ROADMs with single-wavelength add/drop granularity enables per-wavelength selectable protection innovations, including optical layer protection, along with SONET/SDH layer protection, or unprotected wavelengths selectable on a per-wavelength basis, on the same physical ring/network (see Fig. 4).

The integration of third-generation WDM and TDM features results in big

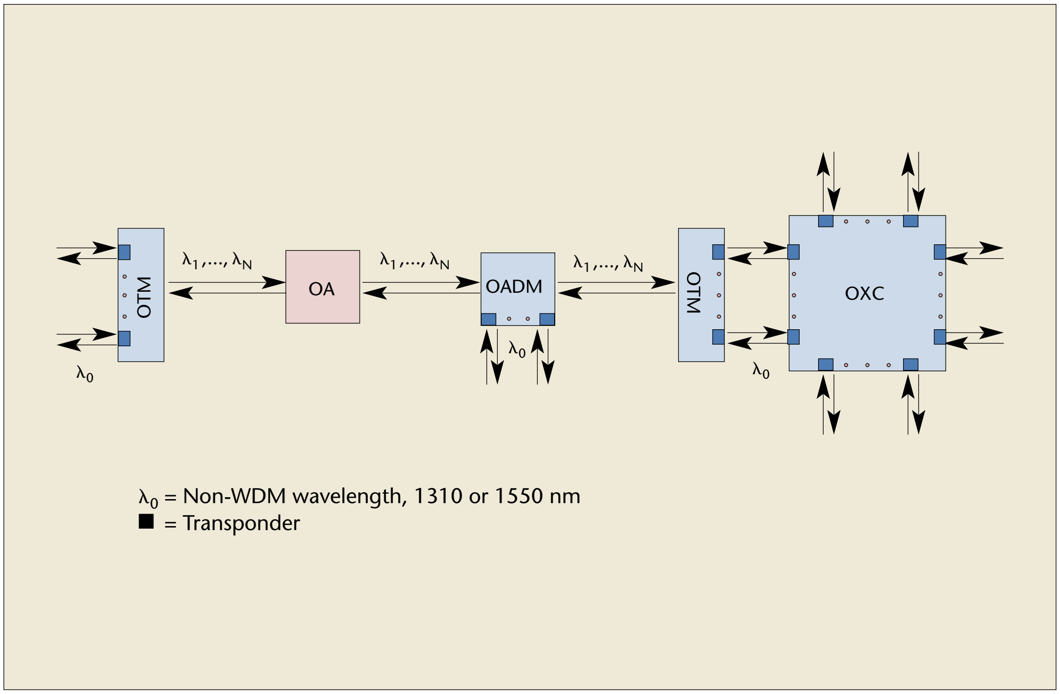


Figure 5. Roles of optical terminal multiplexer (OTM), optical amplifier (OA), optical add/drop multiplexer (OADM) and optical cross connect (OXC).

The integration of third-generation WDM and TDM features results in big savings in capital expenditures and operating expenditures for carrier networks.

savings in capital expenditures and operating expenditures for carrier networks. The savings result from simplified provisioning and reductions in both the number of required network elements and the need for manual intervention and site visits for per-wavelength engineering. Further savings are generated by the provisioning efficiencies inherent in reconfigurable, single-wavelength optical add/drop and per-wavelength selectable optical/SONET/SDH protection schemes.

What is “sensible” integration, as compared with integration for integration’s sake? Sensible integration is the least disruptive to existing operating paradigms. Today there is a rush to integrate transport functionality into cross-connects, including SONET/SDH ring termination functions, or WDM line system and OADM functions. Consider the current network infrastructure, where cross-connects serve as the demarcation point between single-vendor transport (point-to-point, linear add/drop chain and ring) systems, i.e., as the point of multivendor interoperability in carrier networks. Given the similarity between TDM and WDM, we should expect the optical network to evolve in a similar fashion (see Fig. 5). The cross-connect has evolved as the point of multivendor interworking in SONET/SDH networks, thanks in large part to the focus of cross-connect manufacturers on the grooming and switching functions. This leaves the transport-specific functions to multiplexer, add/drop multiplexer and amplifier vendors. Integrating the switching and transport functions forces carriers further into single-vendor solutions, rather than multivendor networks. New generation optical layer cross-connects will and should continue to be used just as their predecessors were—for multivendor ring interconnection and grooming between lower and higher-rate transport systems.

Conclusion

Leveraging the evolution of complementary WDM and TDM technologies offers attractive integration opportunities to reduce complexity, simplify and accelerate service provisioning and improve bandwidth efficiency in transport networks.

Optical innovations that enable a fully automated optical layer include reconfigurable, single-wavelength granularity optical add/drop, automated power control in the form of DGF and AGC, distributed control-plane signaling and a pre-planned one-time ring/network engineering approach.

These features allow SONET/SDH-like provisioning and network maintenance to be applied to WDM systems for the first time.

Innovations include ADM-on-a-chip technology, concurrent with life-extending data over SONET/SDH features. Sensible integration of these third-generation WDM and SONET/SDH features is the logical next step in transport evolution, where the existing infrastructure is complemented by, rather than replaced by, WDM technology.

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