IP + Optical Networks

The enduring value of IP + optical

Ian Redpath

June 2022

OMDIA

Omdia commissioned research,
sponsored by Huawei

Table of Contents

Executive Summary

Introducing L0-L3 network architectures

The IP over WDM (IPoWDM) concept has been around for many years. Its fundamental premise has always been the ability to deploy transmission optics within routing platforms to delayer and simplify networks. Communications service providers (CSPs) have picked up on IPoWDM, attracted by its purported network simplification and economic improvements. For CSPs, however, network and operational requirements are far more complex than that of a niche within the cloud service provider (cloud SP) community. The communications industry has become slightly torn about the allure of IPoWDM, which will succeed in a very narrow, designed-for niche, but will be untenable for many CSP networks and applications.

CSP challenges and network layer integration

In contrast to the cloud SP niche (where IPoWDM may work for some), communication service providers (CSPs) have more complex network needs. CSP optical network requirements include the following:

- Multiple system reach requirements from DCI, metro, national, and subsea
- Many CSP networks are ROADM rich, meaning wavelengths must pass through many ROADMs
- A desire to maximize spectral efficiency
- A desire to maximize total system capacity
- A need to support a multitude of client-side speeds: legacy sub-rates, 1G, 10G, 25G, 50G, 100G, and FlexE
- A desire to support maximum line speeds per distance, leveraging programmable modulation formats for traditional and specialised line speeds: 200G, 400G, 600G, and 800G and 150G, 300G, and 500G

The devil in the IPoWDM details

CSPs were attracted to network delayering and purported TCO savings enabled by IPoWDM. However, once a CSP's network needs and requirements are factored, the promise of IPoWDM falls apart, leaving CSPs with a multi-variant problem: for IPoWDM to work, very small form-factor pluggables are required. However, to get the pluggables down to QSFP-DD size, key capabilities and performance are sacrificed. To meet CSPs' true network needs, the form factor size and power draw must increase, but if this happens, the optics can no longer pair with the router host paradigm.

Conclusion: The enduring value of IP + optical

The application of IPoWDM has begun in a unique market niche, with many design trade-offs at play. For CSPs, IPoWDM's promise will yield disappointment because it cannot cater to most CSP network requirements. CSPs may deploy IPoWDM in niche situations, but scale belongs to IP + WDM and mature and functional ecosystems. CSPs will continue to track developments in IPoWDM but will deploy IP + WDM.

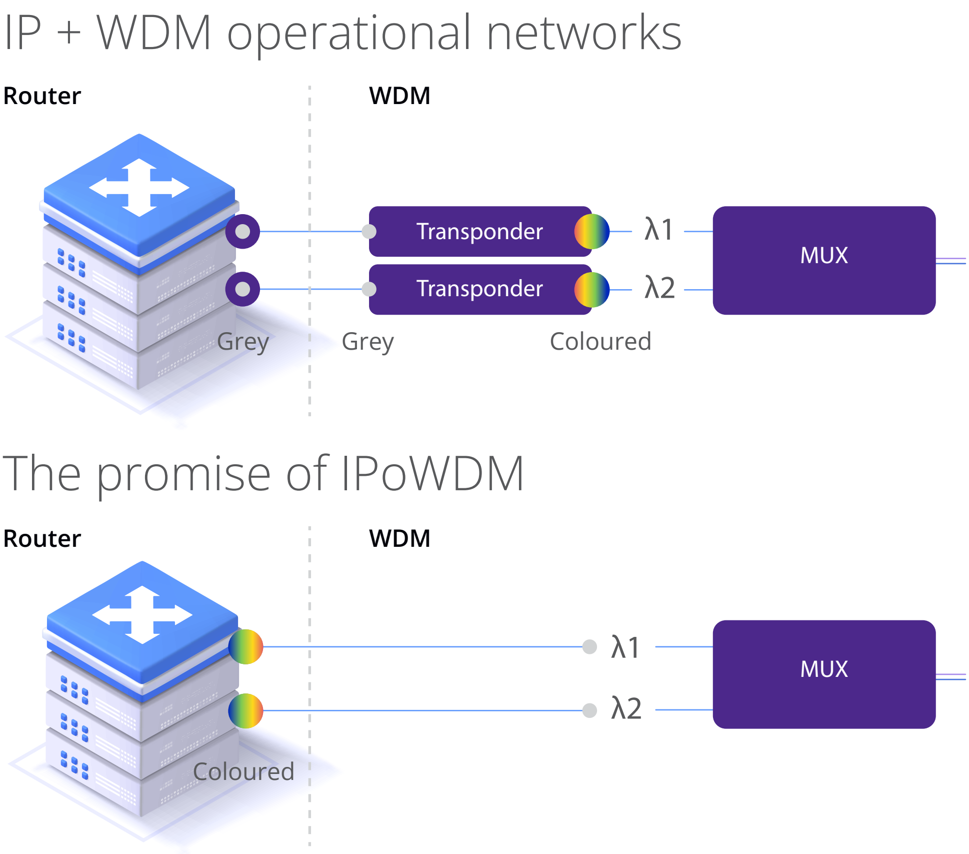
Introducing L0-L3 network architectures

The promise of IPoWDM

IPoWDM in the 100G era

IPoWDM as a concept is not new; it has been around for many years. Its fundamental premise has always been the ability to deploy transmission optics within routing platforms to delayer and simplify networks.

Figure 1: IP + WDM vs. IPoWDM



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Additional purported benefits of IPoWDM include cost reduction via the elimination of short-reach network element interconnect optics and optical common equipment to house the optics.

IPoWDM failed to affect historical change in industry dynamics during the 100G era because optics were far too large and consumed way too much power to practically fit into router platforms. The physically large optics with high power consumption would have reduced the IP network element's basic routing capabilities.

IPoWDM in the 400G era is designed for a very specific cloud SP niche

Today, the industry has advanced. Optics (specifically for shorter-reach point-to-point [P2P] limited metro applications) can be housed in much smaller form factors. The power required to support pluggable optics is also much lower.

A select group of cloud SPs, including Microsoft and Amazon, latched onto the IPoWDM concept and pushed the industry forward. IPoWDM's application here was specific, with several niche application design trade-offs. Cloud SPs wanted to interconnect their data center properties, many of which ranged up to 40km in distance, with IPoWDM optics. Their unique requirements and specifications were as follows:

- Very short metro and data center interconnect reach, much under 40km
- A focus on low power consumption and optimised faceplate density
- Simplified line-side requirements: supporting 400G only, with limited modulation formats
- Simplified client-side requirements: supporting data center-to-data center, spine-to-spine switches only, excluding any other speeds or services
- Relaxed spectral efficiency requirements because cloud SPs are fiber-rich in this context
- IPoWDM solutions would be deployed in greenfield scenarios with no legacy support

The 400G ZR solution was designed for a very specific cloud SP IPoWDM niche. 400G ZR will deployed in that niche but will struggle to extended beyond to more complex communications network applications.

The wider communications industry takes an interest in IPoWDM

The wider industry picked up on IPoWDM concept, attracted by its network simplification and purported economic improvements. CSPs' network and operational requirements are far more complex than that of a niche in the cloud SP community. The communications industry has become slightly torn because the allure of IPoWDM holds, but practicalities make IPoWDM untenable for so many networks and applications.

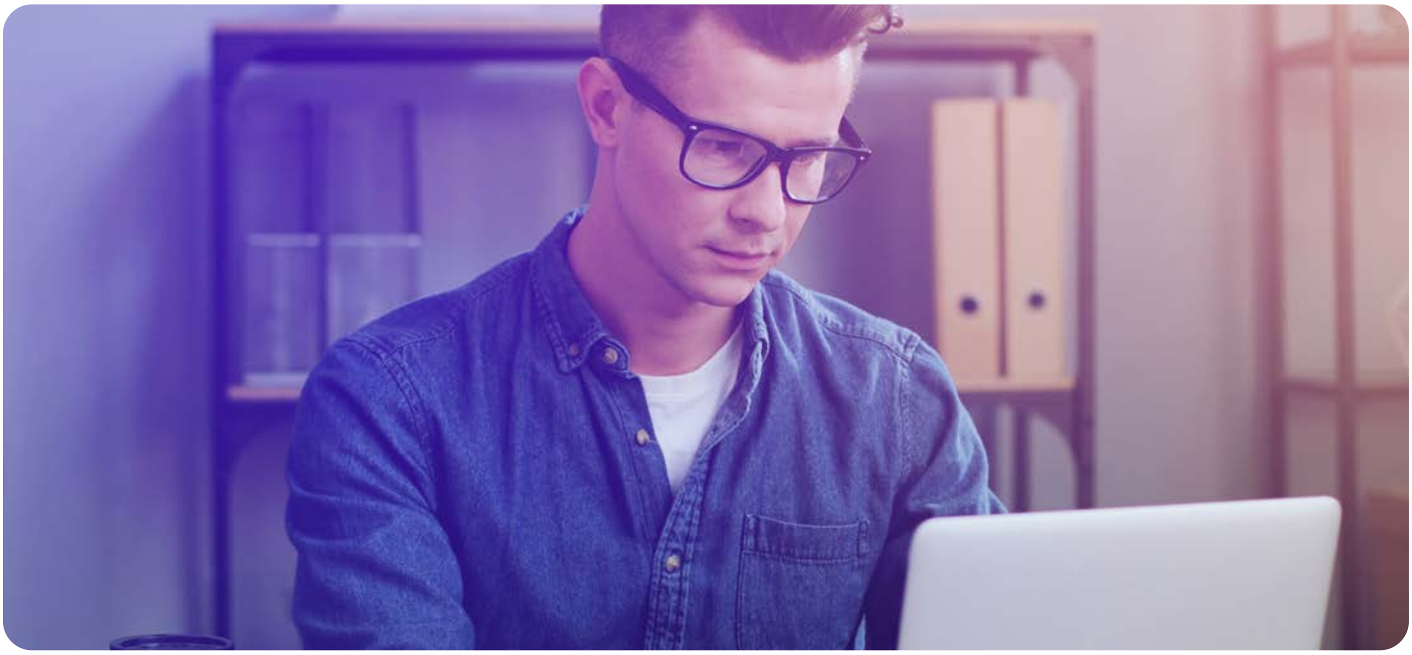
CSP network/OAM challenges

CSPs have complex network needs

In contrast to the niche case of cloud SPs (where IPoWDM may work for some), CSPs have more complex network needs. CSP optical network requirements include the following:

- Multiple system reach requirements from DCI, metro, national and subsea
- Many CSP networks are ROADM-rich and wavelengths must pass through many ROADMs
- A desire to maximize spectral efficiency
- A desire to maximize total system capacity
- A need to support many client-side speeds: legacy sub-rates, 1G, 10G, 25G, 50G, 100G, and FlexE
- A desire to support maximum line speeds per distance, leveraging programmable modulation formats for traditional and specialised line speeds: 200G, 400G, 600G, and 800G and 150G, 300G, and 500G
- Data center communication and telecoms are advancing at different speeds. CSPs desire to deploy best-of-breed solutions when ready
- Standardised operational models are followed. IPoWDM implies tighter interworking between network layers and network vendors. The industry has not yet implemented completely mature operational models for IPoWDM. Automation will require a high degree of vendor-to-vendor interworking, which does not currently exist.

- Both L1 and L0 are utilised for protection. CSPs do not rely solely on L2 or L3
- Networks can be managed with existing skill sets and resources



IPoWDM introduces a complex multi-variant architectural problem

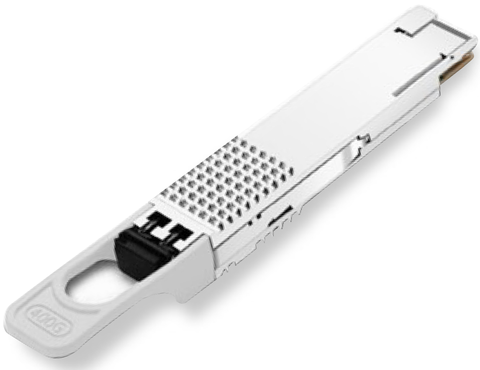
CSPs are grappling with a complex multi-variant architectural problem, but can the optics they need fit into a router?

- Will the optics have sufficient launch power and OSNR tolerance to pass through meshed metro ROADM networks?
- Will multi-vendor interoperability be supported via a standardised FEC and modulation algorithm?
- Will a modern, standardised operational model exist that supports automation?
- Will requirements be met with a piecemeal approach, leading to sub-scale micro-markets? Or will all needs be met, leading to a high-volume, capex-friendly environment supporting new business growth?

At a glance, the industry's topline fundamental questions appear straightforward but the devil is in the details. A multitude of vexing challenges lie beneath each topline question.

Figure 2: The "multi-variant challenge"

IPoWDM with QSFP-DD



IPoWDM promise
- Faceplate density
- Low power draw
- Fit for router hosts
- Attractive economics

IPoWDMs challenges
- Limited reach and ability to pass through ROADMs
- Client-side limitations
- Spectral efficiency is not optimal

Result for CSPs
- To meet CSPs' full requirements, pluggables need better performance, which consumes more power and requires a larger form factor
- Negates the original purported value proposition

IP + WDM with CFP2

IP + WDM attributes
- CSP-grade reach and ROADM pass through
- Highest spectral efficiency
- Leverages ROADM installed base
- Leverages optical bypass economics

IP + WDM maintain separation
- Preserves router power and faceplate for router functions
- Comprehensive set of client-side interfaces
- Mature network protection and restoration capabilities

IP + WDM results for CSPs
- Practical solution for CSP needs and networks
- No operational upheaval

Source: Omdia

CSPs are initially attracted to the IPoWDM solution's small form factor and its ability to host within a router. However, a second-order analysis immediately reveals the product's limitations which negate the original value proposition and appeal for CSPs.

The devil in the IPoWDM details and the enduring value of IP + optical

Multiple system reach requirements from DCI, metro, national, and subsea

IPoWDM shortfalls to CSP requirements

Subsea and long-haul backbone networks require the highest performance capabilities available. Long-distance transmission requires high launch power and sophisticated optical impairment mitigation techniques. The coherent digital signal processor (DSP) must be a full- featured variant capable of handling more-involved polarisation mode dispersion (PMD), chromatic dispersion, and the state of polarisation impairments. In the IPoWDM case, many impairment mitigation functions can be removed because they are not needed in short-reach applications. Removing the mitigation functions enables a lower power draw, which in turn can be housed in a very small form factor. The most demanding, high-performance links do require all optical impairment mitigation functions, leading to greater power draw which then must be housed in a a larger form factor.. However, it is not practical to house the larger form factor in a router host.

The enduring value of IP + optical

A fully capable optical platform is best suited for the long-haul and subsea application market segments. The economic cost of optical systems is driven by the cost of line-side optics. The optics are right sized for the performance requirement. The cost of optical common equipment makes up a minimal portion of the overall system cost. Housing optics within routers also incurs a common equipment cost, while the cost of the grey network element interconnect optics makes up a small portion of the optical network system cost.

Many CSP networks are ROADM-rich and wavelengths must pass through many ROADMs

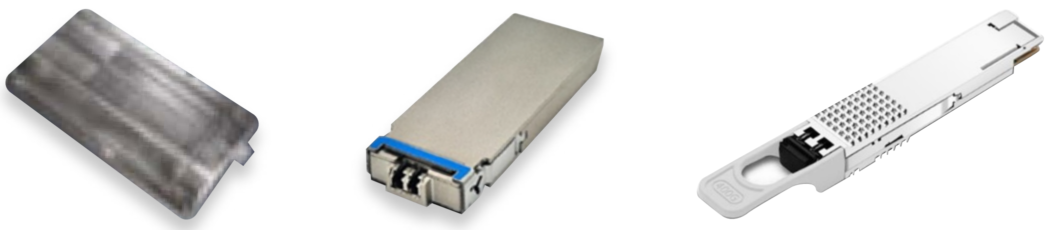
IPoWDM shortfalls to CSP requirements

CSP metro networks are typically “ROADM-rich” in that reconfigurable optical add-drop multiplexer (ROADM) technology is widespread. Many A–Z transmission paths would typically pass through multiple ROADMs from source to sink. The most widely touted IPoWDM solution, 400G ZR, was designed with very small launch power and weaker optical signal-to-noise ratio (OSNR) tolerance to fit the power envelope of a QSFP-DD pluggable. Given these factors, optical signals cannot effectively pass through ROADM networks. For many CSPs, the lack of ROADM pass through is a bigger deal killer than limited system reach. The industry may opt for a larger form factor, such as CFP2, to improve launch power and OSNR tolerance, but this would bring the multi-variant challenge back into play. A CFP2 would utilise more front faceplate real estate, negating one of IPoWDM’s key value points.

The enduring value of IP + optical

From an economic standpoint, dedicated optical platforms can match the combination of performance with the required power and form factor, as shown in Figure 3.

Figure 3: MSAs, CFP2s, and QSFP-DDs



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Subsea, long-haul, and high-performance metro-regional routes will continue with embedded systems, **full features, and maximum capability and performance**

Metro-regional routes can use CFP2: **matching form factor and power with reduced reach requirements**, but with complete client and line support options and substantial ROADM pass through

QSFP-DD: **Specialty niche, P2P, spine-to-spine, and greenfield networks**

With less rigid form factor requirements, optical platforms can support more powerful transmission capabilities to pass through all ROADM deployment scenarios. Transmission can be supported as far as regional and ultra-long-haul distances.

CSPs desire to maximise spectral efficiency and total system capacity

In the IPoWDM scenario, spectral efficiency requirements are relaxed as part of the design trade-off to minimise space and power. With IPoWDM, achieving 400G transmission requires a spacing of 100GHz, and in cases where service providers are very fiber-rich (in the foreseeable future), this may be acceptable. Yet, with IP + WDM, the spectral efficiency is dramatically improved with 800G transmission at 100GHz spacing. For most CSPs, maximizing spectral efficiency is a standing requirement.

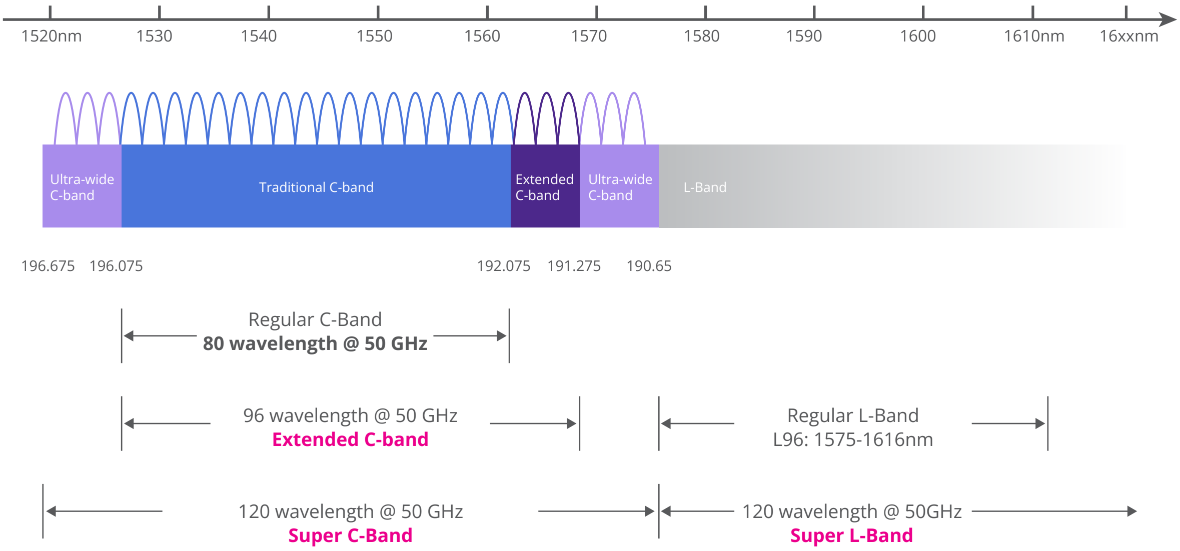
In addition to spectral efficiency, CSPs typically seek to maximise their use of the available spectrum. Historically, the industry utilised 80 wavelengths within the C band. The industry has increased available spectrum within the C band to Super C, transmitting 120 wavelengths. The L band is also seeing rapid development. While niche L-band usage has existed for decades, now fiber-constrained service providers with limited access to fiber pairs have requested C+L to expand capacity. With increased interest and volumes, L-band solutions are becoming increasingly mainstream and cost-effective. In the future, the industry will also push into other bands, such as the S-band. With the limited capabilities of the space- and function-constrained IPoWDM solutions, CSPs would not be able to take advantage of advanced spectrum utilisation.

With IP + optical systems, optics that maximise spectral efficiency can be deployed. High-performance coherent DSPs can be operated at the highest GBaud levels, maximizing bandwidth throughput for the available spectrum.

IP + optical systems also support Super C and L-band spectrum, and in the future, will support S-band spectrum.

Figure 4: Maximizing spectrum utilisation with Super C and L bands

The Super C band uses the ultra-wide C band (C120) spectrum, beyond the traditional C band (C80) and extended C-band (C96). It increases the available wavelength range.



Note: "@50 GHz" indicates that the channel spacing is 50 GHz

Source: Omdia

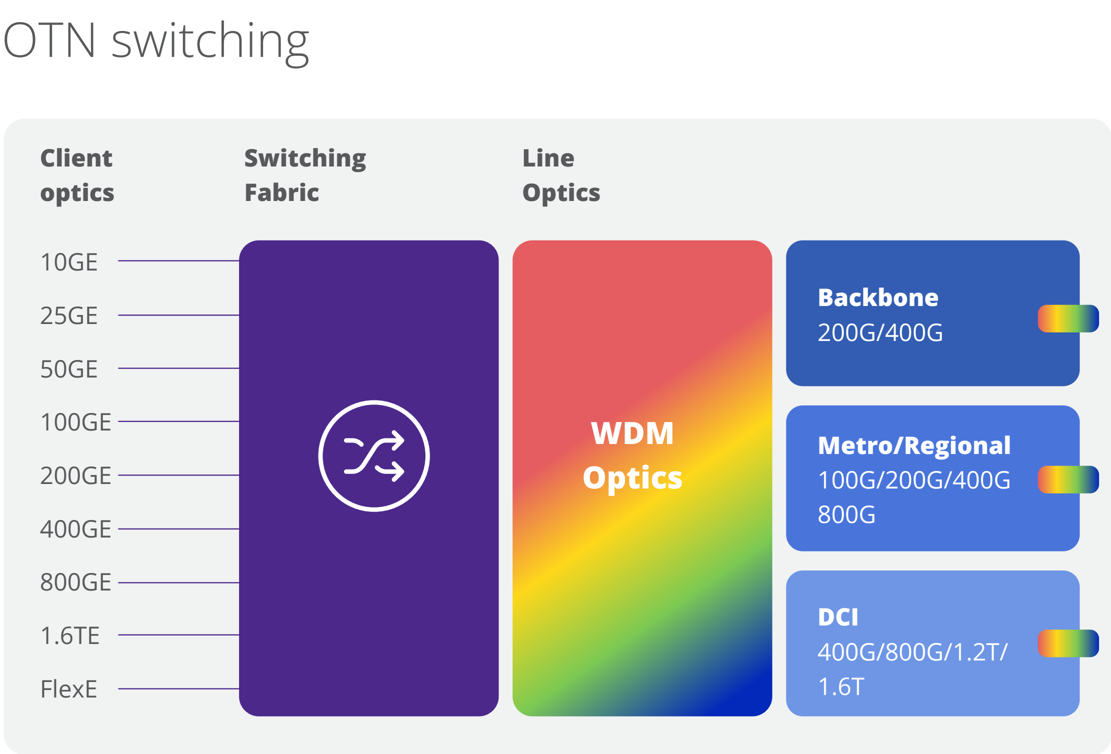
CSPs require a complete set of client-side interfaces

CSP networks are an evolution of brand-new capabilities deployed alongside many older technologies. On the client side of optical networks, CSPs serve residential, enterprise, and mobile customers. CSPs' residential access networks often evolve from xDSL and DOCSIS to passive optical network (PON) access technologies. The latest generation of PON OLT uplinks would be 10–100G, but copper-based access technologies also need support. Similarly, 5G xHaul will be in the 10G, 25G, and 50G range, but pre-5G RAN still exists and requires support. Enterprise access can range from Mbps up to 100Gbps.

An IPoWDM architecture requires all varied client-side traffic to be aggregated via specific IP router ports, such as 400G, potentially not the most economical option for many carriers.

An IP + optical solution could take advantage of the aggregation capabilities within access networks and utilise an optical transport network (OTN) switching capability to efficiently match varied client-side speeds with different wavelength speeds. CSPs must contend with a complex set of new and brownfield clients and a mix of line distances and speeds. Maximum flexibility is required, but the IPoWDM's limited propositions will not support the varied array of client and line needs.

Figure 5: OTN switching for client-to-line aggregation and grooming



Source: Omdia

The dual trends of proliferating client-side speeds and line-side options are growing more complex. OTN switching enables economic aggregation with “as-needed” switching granularity levels.

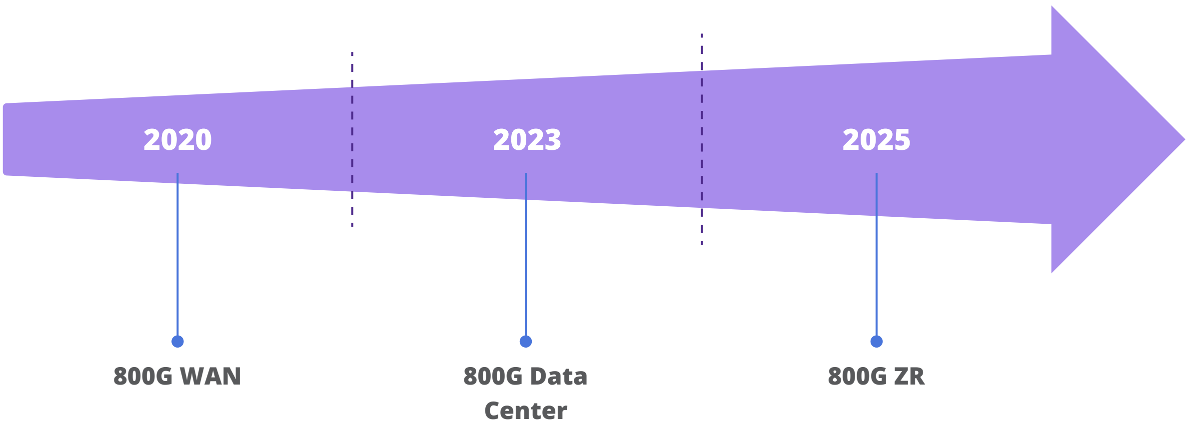
Data center and WAN speeds evolve at differing pace

The data center (short-reach optics of up to 2km in reach) market evolution is driven by the largest cloud SPs, and the market is sufficiently large to support its own supply ecosystem. The short-reach (up to 2km) 400G for data centers, embedded large-form-factor 400G for the WAN market and 400G ZR, and QSFP-DD small form for the cloud point to point (P2P) market all reached maturity at different times.

While IPoWDM purports to offer flexibility, it actually introduces rigidity in a system. Because of the power management engineering challenges in developing a WAN solution for a very small form, 400G ZR was the last 400G solution to come to market. The desire for 400G ZR came about over two years before technical maturity and volume was delivered. This delay was so significant that major 400G ZR proponents had shifted their strategy to adopting 200G in the near term with longer-term plans to adopt 800G and intentions to skip 400G ZR altogether. Tying the technology paths together can slow elements of technology adoption. IPoWDM attempts to couple the data center’s evolution to WAN evolution, limiting industry adoption of both technologies to the pace of the laggard technology.

By decoupling WAN evolution from data center evolution, advances in either market can be placed into network production sooner. Omdia expects the 800G market to follow a similar pattern with 800G WAN with an embedded large form factor now available, followed by 800G datacom, and 800G ZR small form factor being the last to market. By tying multiple technologies together, IPoWDM will slow the introduction of 800G datacom. On the other hand, decoupling technologies will catalyse technology adoption.

Figure 6: 800G roadmap for WAN, data centers and ZR



Source: Omdia

Flexible modulation formats maximise bandwidth

Today, coherent systems support flexible modulation formats. For a given system reach requirement, the optimal modulation format can be chosen that supports the maximum bandwidth throughput. For example, for a given reach, the maximum bandwidth achievable may be a non-traditional rate such as 150G or 300G. With an IPoWDM solution, CSPs are locked into less flexibility.

With an IP + optical solution, CSPs can take advantage of flexible modulation formats and maximise the bandwidth for selected reach requirements.

Standardisation yet to finalise for high-volume production CSP networks

Hardware standardisation: Not quite mature
There are two major elements required for integrated packet optical environments: L0-L1 hardware interoperability and multi-vendor transport SDN network management-control interworking. For IPoWDM, standardisation is not yet mature enough for high-volume deployment. From a practical standpoint, there are phases to achieving truly scaled high-volume deployments. Standards can be “completed” and published while vendors can update solutions to adhere to their interpretation of the standard. CSPs can test multi-vendor interoperability within multiple network scenarios and environments. In many cases, CSPs find there can be different interpretations to implementing a standard. CSPs then request “tightened” standards to achieve true interoperability.

Vendors can purportedly connect via 400G ZR with an open but lower-performing FEC. Many CSPs evaluating IPoWDM solutions are practically considering “book-ending” the optics. Book-ending requires a CSP to deploy the same vendor on both ends of a single transmission path. While book-ending would ensure better performance, it negates one of the purported open benefits of IPoWDM, which is truly open interoperable optics.

Multi-source agreements (MSAs) exist for 400G ZR+ but are short of a standard. The ZR+ will also likely present form factor-function tradeoffs because the larger CFP2 may be needed, bringing the multi-variant challenge back into play.

To date, many service providers are opting to deploy “book-ended” configurations to side-step the lack of truly mature multi-vendor interoperability. The interoperability promised through IPoWDM has not quite been achieved.

With IP + WDM, CSPs can interconnect multiple vendors in their networks via standard L2 Ethernet and L1 OTN.

Software standardisation: A work in progress

To implement IPoWDM, CSPs must also implement a multi-vendor transport SDN solution. While the industry has been advancing multi-vendor transport SDN, it remains a work in progress. Although many standards organisations and industry fora have contributed to standardisation efforts the industry has yet to reach a unified consensus. Such efforts by multiple organisations have actually led to a degree of uncertainty within the CSP community. Once again, while individual standards can be considered "complete," upon further multi-vendor interoperability testing, standards can require further "tightening." While the industry continues to work toward developing and implementing multi-vendor transport SDN, CSPs must be prepared for a work-in-progress environment.

The evolution from today's networks to IPoWDM is not elegant

CSPs have been investing in ROADM-centric WDM networks for over two decades and have deployed vast amounts of optical networks with many ROADM network elements. The IPoWDM proponents propose IPoWDM as an overlay. Network overlay approaches are inherently inefficient because network resources are often left stranded—paid for but not used.

IPoWDM takes CSPs a generational step backward in wavelength management, removing the ability to "reconfigurable" from the optical layer. CSPs are left with either P2P or fixed OADM networks. Meanwhile, there have been great strides in wavelength management technology development. For the network edge, access-orientated and cost-optimised ROADMs have been developed. Meanwhile, the network core has seen multiple advances in wavelength management, such as the following:

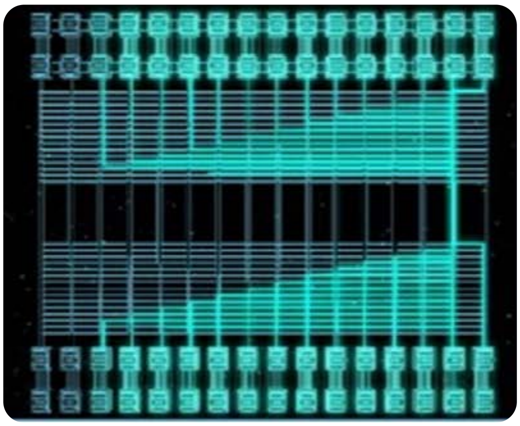
- Advances in enabling wavelength selective switch (WSS) technology: twin high port count and NxM switching
- The optical cross connect has matured and been widely deployed, with the following:
  - Featuring a massive scale
  - Low cost and power/bit to switch
  - Optical backplane for elegant fiber management
- Wavelength management has a substantially lower cost, relative to total system cost, leading to widespread adoption
- Flexgrid support for multiple transmission speeds
- Wavelength management supports Super C and L-band capabilities

Figure 7: Fiber management with P2P networks vs. the optical backplane

Fiber management

Fiber management with P2P networks

The elegant optical backplane



Source: China Telecom

An IP + WDM approach continues to utilise the optical core as intended, leveraging the deployed and operational optical networks.

Utilising both L1 and L0 for protection without merely relying on L2 or L3

In an IP + optical environment, ROADMs and optical cross-connects (OXCs) incorporate WSS hardware. If a fiber cut or an equipment outage occurs, traffic can be optically re-routed. Software control and management is provided by an automatically switched optical network (ASON). ASON supports many functions, including the following:

- Network topology discovery
- Fast and automatic end-to-end provisioning
- Fast and efficient re-routing
- Dynamic setup of connections

The net result is a dedicated optical layer that can endure multiple fiber cuts and survive, while service interruptions can be minimised with very rapid switching.

Network protection scenarios are challenging in an IPoWDM environment. In such environments, with P2P configurations, higher network layers must be drawn upon for protection. L2 or L3 network protection intelligence must be used and paired with additional optical network resources. Given that protect paths are also often longer than primary paths, the net result is that a non-IPoWDM solution may have to be relied upon for protection.

IP + optical is a rapid, cost-effective, and higher-performing protection mechanism capable of surviving multiple fault scenarios.

Engineering and operations resources

Collapsing IP and optics introduces a final personnel challenge: staffing for combined IPoWDM network operations. The packet and WDM skill maps differ substantially. Packet and WDM are two different subjects with unique lineages, terminologies, and languages; only a select few skilled practitioners are adept and possess deep capabilities in both domains. Engineering and operational staff typically rise through their careers in one domain. While capable staff with proper training could also pick up skills required for the other domain, the level of upskilling required should not be underestimated.

Maintaining the IP + WDM paradigm will minimise organisational upheaval.

Conclusion

IP + optical value endures

CSP networks have distinct core and edge needs. Out at the edge, space and power need to be preserved, and functional integration is highly valued. In CSP network cores, the equation changes, with scale becoming imperative. Optical systems must be massively scalable. IP functionality is optimally delivered with best-of-breed routing capabilities, not muddied by non-core functions.

A very high degree of convergence and integration is desirable at the network edge. Convergence in the core would lead to performance penalties.

IPoWDM is demonstrating a similar dynamic in that integration will be valuable in selected network niches, such as its initial design intended for very short-reach DCI applications. IPoWDM has turned out to be restrictive in core network situations where best-of-breed, functional specialisation, and scale are design imperatives.

IPoWDM claimed to bring great network economic benefits, but it has fallen short for the CSP community. The following purported common equipment savings have not materialised:

- **The "cage" for a pluggable will see costs for both a dedicated optical platform and a router**
- **IPoWDM architectures are low cost only in short-reach P2P scenarios**
- **Grey optics are scaled and continue to see rapidly reduced cost**
- **IPoWDM introduces a step function management and control cost**

IP + optics continue to demonstrate enduring value for the CSP community in the following areas:

- **"The cheapest transponder is no transponder." CSPs will continue to leverage optical bypass**
- **Major advances in wavelength management continue, both in the core, at scale, and at the edge**
- **CSPs can continue to quickly leverage best-of-breed technology developments**
- **Meets CSP's desire to maximise spectral efficiency**
- **Meets CSP's desire to maximise total system capacity**

IPoWDM has begun in a unique market niche, with many design trade-offs at play. For CSPs, the promise of IPoWDM results in disappointment since IPoWDM will not meet the bulk of CSP network requirements. CSPs may deploy IPoWDM in niche situations, but scale belongs to IP + WDM and mature and functional ecosystems.

Appendix

Methodology

Omdia used a combination of primary research and secondary sources to complete this report. Primary research included relevant Omdia research supported by qualitative interviews with global providers of BNG solutions and vendors that provide network software and virtualisation portfolios and services.

Author

Ian Redpath
Research Director, Transport
askananalyst @omdia.com

Get in touch
www.omdia.com
customersuccess@omdia.com

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