APPLICATION NOTE

# Bringing wavelength agility and efficiency to software-defined networks

## With the Alcatel-Lucent 1830 Photonic Service Switch

Alcatel·Lucent

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# Introduction

Software-defined networks (SDN) offer ways to simplify network operations over a multi-vendor hardware and software infrastructure and provide a foundation for rapid deployment of new revenue-generating services. To achieve these goals, network operators need to streamline optical wavelength network connectivity with SDN control. However, optical wavelength connections have inherent complexities that must be addressed, before they can keep up with SDN agility demands.

For example, the wavelengths supporting optical services require precise planning, careful deployment, and intelligent monitoring, as well as optimal network resource utilization. How can SDN network architectures and controllers address these fundamental characteristics — while remaining dynamic enough to meet future demands for network agility?

Fortunately, agile optical networks from Alcatel-Lucent can already address these requirements, and SDN architectures can leverage these capabilities to support operationally efficient networks that can rapidly respond to existing and new service demands, take advantage of the latest advancements in colorless, directionless, connectionless Flex-grid-capable (CDC-F) optical networking to efficiently scale — and minimize total cost of ownership (TCO).

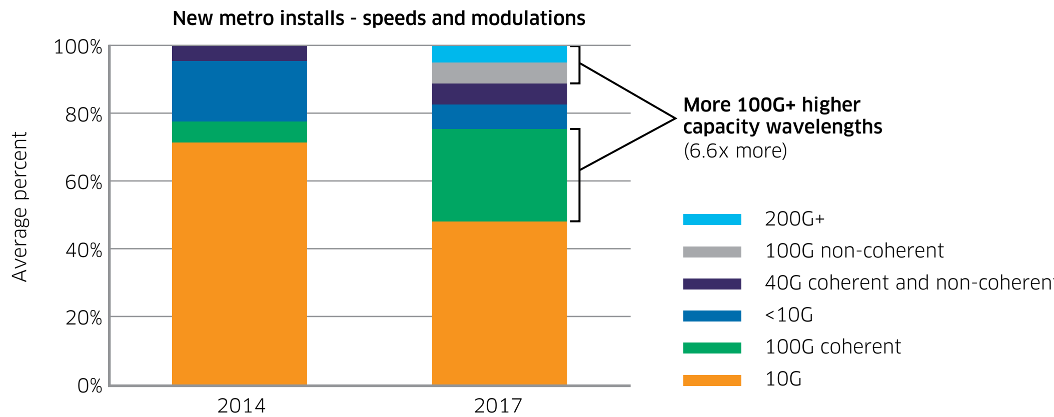
# Optical network-capacity and connectivity demands

Optical networks are continuously challenged to address capacity-scaling pressures cost effectively. For example, near-term scaling pressures include:

- Mobile networks evolving to higher capacity LTE-Advanced heterogeneous networks that drive backhaul capacity from Mb/s to Gb/s and even 10-Gb/s wavelengths in the case of Common Public Radio Interface (CPRI) fronthaul
- Fixed access speeds moving from Mb/s to Gb/s with G.fast access — and moving to 10-Gb/s and higher access with time- and wavelength-division multiplexed passive optical network (TWDM-PON) systems
- Low-latency, high-capacity 10-Gb/s and higher data-center-interconnect demands to support the efficient and reliable delivery of cloud-based services

Any move to higher access capacities at the metro network edge means that higher-capacity 100G and higher wavelengths will be created and efficiently filled, closer to the edge of the network than occurs today. Evidence for this emerging trend is provided in Figure 1, which shows an increased forecast for 100G or higher wavelengths in the metro portion of the network.

**Figure 1. Today's move to higher capacity wavelengths in the metro network**




Source Infonetics Research, *100G+ and ROADM Strategies: Global Service Provider Survey*, 2014

As networks evolve to support cloud-based architectures, these high-capacity wavelengths will be networked to fewer high capacity sites in the network, including a few:

- Mobile data centers
- Broadband services data centers
- Cloud services data centers, Ethernet/IP exchanges sites, or both

With these capacity and network connectivity trends, there will be greater need to route wavelengths optically between service endpoints. To support service growth, high-capacity wavelengths must also be added to the network easily, and fiber optic connections must scale to support the greatest wavelength capacity possible.

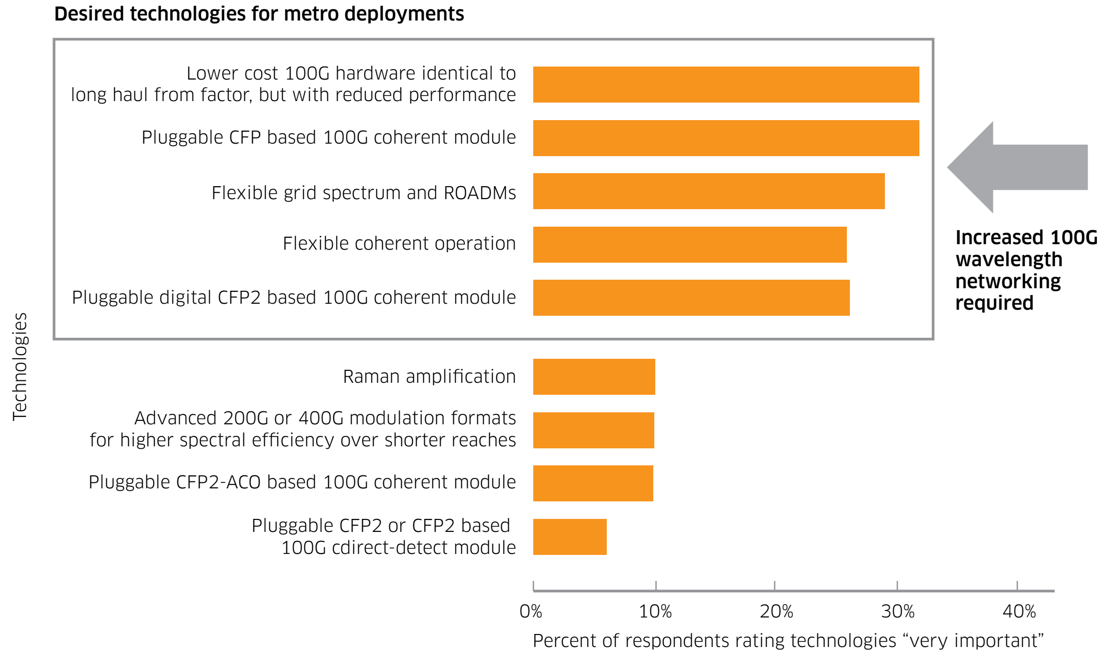
This, together with the need to more richly connect optical networks with fiber to scale wavelength capacity, are driving the need for wavelength routing. Wavelength routers which can route wavelengths between multiple fiber directions (i.e., "degrees" in optical technical terms) from 2 to 16 or more. This expanded wavelength-routing requirement must be accomplished while maintaining wavelength performance. And it must also include in-service growth for both wavelength service add-drop capacity and the addition of more fiber directions or degrees over time.

New types of equipment will be required to address these factors. There will be an increased need for optical nodes to route wavelengths more efficiently, coupled with new optical edge devices that have sufficient IP/Ethernet or optical transport network (OTN) multiplexing, or both, to efficiently fill 100G + high-capacity wavelengths.

A recent survey of network providers throughout the world highlighted the need for efficient routing of 100G wavelengths in the metro network, as shown in Figure 2. The highest-ranking responses ( > 25 percent) indicated which technologies the providers wanted most for routing support. They include:

- Lower-cost 100G hardware identical to long-haul form factor, but with reduced performance
- Pluggable C form-factor pluggable (CFP)-based 100G coherent module
- Flexible grid spectrum and reconfigurable optical add-drop multiplexers (ROADMs)
- Flexible coherent operation

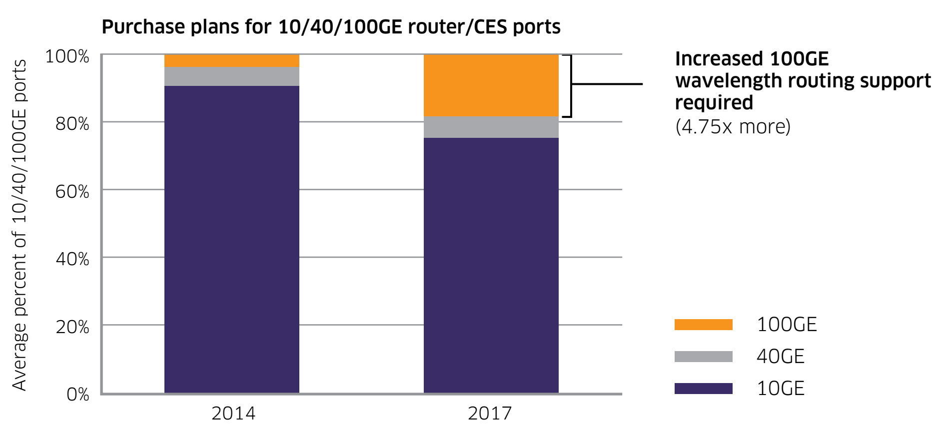
**Figure 2. The need for wavelength routing in the metro network (survey results)**




Source: Infonetics Research, *100G+ and ROADM Strategies: Global Service Provider Survey*, 2014

Increased traffic volumes are also putting pressure on optical long-haul networks (where wavelengths have to travel more than 600 km), resulting in a growing need for high-capacity wavelength routing to inter-connect routers with 100 Gigabit Ethernet connectivity. As shown in Figure 3, the number of 100 Gigabit Ethernet router ports is expected to be more than 4.5 times greater in 2016 than in 2014.

**Figure 3. The move to 100 Gigabit Ethernet networking**




Source: Infonetics Research, *100G+ and ROADM Strategies: Global Service Provider Survey*, 2014

# A more agile optical network alternative

Most of today's optical networks are relatively static, when it comes to the connectivity of high-capacity wavelengths. And as a result, they won't be able to meet future demands to scale service agility and network capacity. To address these issues, the optical industry has defined CDC-F networking technologies and architectures, which are discussed in the following sections.

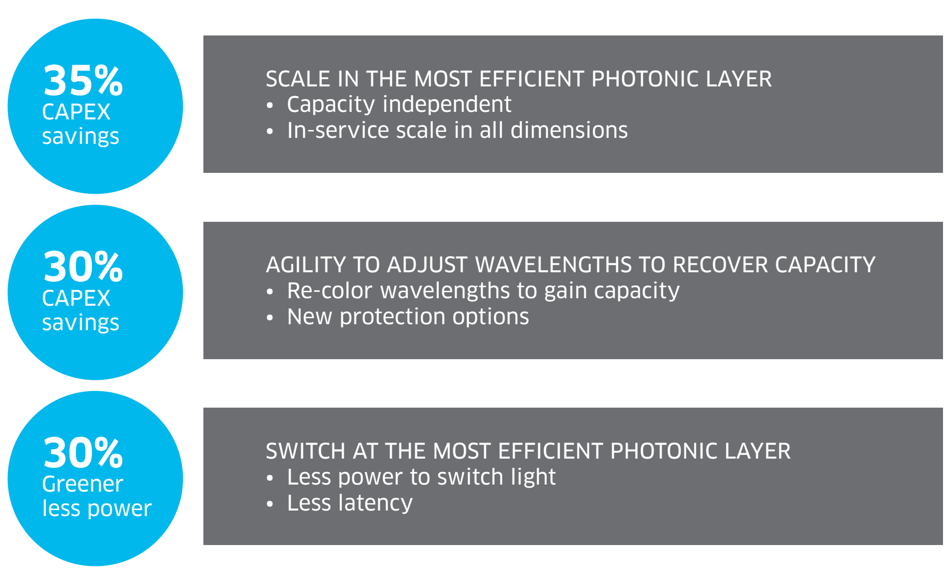
In brief, this means that optical networks will have the network agility to route high-capacity wavelengths with greater efficiency, scalability, and operational efficiency than the optical transport industry has ever seen before. On-site visits to change or adjust wavelength connectivity will no longer be required, reducing operating expenditures (OPEX). Moreover, this new wavelength agility enables wavelength connectivity to be adjusted to maximize fiber and optical network capacity — and to rapidly respond to new service innovations made possible by SDN.

## Colorless, directionless, and contentionless wavelengths, with FlexGrid

- Colorless means that wavelengths of any color can be flexibly added to optical networks without manual configuration of optical equipment. This capability leverages transponder cards that support wavelengths of multiple colors, rather than supporting only one color.
- Directionless means that a wavelength can be more dynamic, because it doesn't have to take a predetermined static path through an optical network, a path that can't be changed without costly manual configuration.
- Contentionless means that wavelength colors can be more easily reused multiple times without manual configuration.
- FlexGrid means that optical transponders and switches can support super-high-capacity virtual optical channels composed of multiple lower-speed wavelengths.

CDC-F technology delivers numerous wavelength agility benefits. They address SDN network dynamism requirements, offer significant reductions in capital expenditures (CAPEX) and OPEX, and minimize a network's total cost of ownership (TCO).

**Figure 4. Minimizing network TCO with CDC-F optical networks**



Since CDC-F technology routes wavelengths photonically, rather than electrically, CAPEX can be 35 percent lower than with OTN-only electrical-switching alternatives.[1] CDC-F nodes can also scale much more cost effectively, because CDC-F technology makes wavelength routing independent of wavelength capacity. In addition, scaling a CDC-F node for both wavelength directions and wavelength service add-drop capacity can be completed in-service, with the right implementation.

CDC-F technology also makes wavelength connection more agile, allowing wavelengths to be easily routed to optimize network wavelength capacity. For example, if a new service is best realized by using a red wavelength, then previously established red wavelengths that are blocking the new red wavelength service creation can be rerouted and/or have its color changed to make room for the new red wavelength. Using this technique, some optical network operators estimate the recovery of 30 percent of their network capacity, which also translates into a 30 percent CAPEX saving through more efficient use of existing network resources or deferring costly network upgrades. Wavelength utilization can also be reduced by using dynamic wavelength restoration, rather than having two wavelengths protect one service.

The photonic nature of CDC-F optical nodes makes them more power efficient than electrical-switch alternatives. Simulations have shown that 30 percent to 40 percent less power is needed than when using OTN only switching alternatives.[2] Switching at the photonic layer also introduces less wavelength service latency than electrical alternatives. This lower latency can be applied to low-latency wavelength service differentiation.

## The need for enhanced wavelength OAM

The move to increased wavelength capacity and agility will accelerate the need for per-wavelength operations, administration, and management (OAM). In this case, per-wavelength OAM is defined as an in-band wavelength OAM channel providing the ability to:

- Uniquely identify a wavelength regardless of its frequency/color, modulation and associated power, at any point in the network
- Support OAM commands to trace a wavelength connection and its related power throughout the network, which is the optical equivalent to ping and traceroute tools used in IP networks

In-band OAM means that the wavelength OAM channel rides on the wavelength that is being monitored. It takes the exact same path throughout the network, and it experiences the same potential performance issues as the revenue-generating wavelength. As a result, there cannot be any optical-to-electrical-to-optical (OEO) conversions along the end-to-end wavelength path to help diagnose wavelength issues. This makes the implementation of optical ping and traceroute-like commands difficult. However, the unique Alcatel-Lucent per-wavelength OAM Wavelength Tracker feature makes this possible (see Appendix for information on the Alcatel-Lucent Wavelength Tracker).

1 Source: Bell Labs
2 Source: Bell Labs

Per-wavelength OAM support is critical, because optical networks are not static. Temperature, vibrations, differences in fiber quality, fiber management, equipment aging (such as lasers), and fiber power load can severely impact wavelength performance. Wavelength errors can also be introduced by any of the following factors:

- Fiber connection error
- Inappropriate maintenance action
- Misbehaving optical switches
- Misbehaving wavelengths

Per-wavelength OAM helps ensure that:

- Faults can be accurately located and repaired quickly anywhere in the network, including between optical switches or between the optical modules within an optical switch (such as CDC-F wavelength selective switch [WSS] amplifiers, or transponders).
- Fiber or service misconnections are quickly identified and corrected.
- Fiber impairments are tracked, so that wavelength primary and potential protection paths throughout the network are not stretched to the point where service degrades or fails.

With the introduction of software-defined networking (SDN), new services and applications will require that the underlying optical wavelength network has more dynamism. In an SDN world, traditional wavelength connections that were created to stay up for lifetimes can be adjacent to wavelengths with a service connection time of only hours. This increased wavelength dynamism brings a greater likelihood of wavelength connectivity and performances issues. Without per-wavelength OAM, more time is required to correct a wavelength problem. Fault resolution that could take fractions of seconds — or be avoided altogether — could require hours, with terabits of wavelength traffic being lost. These issues can result in broken service-level agreements (SLAs), costly refunds, and customer dissatisfaction. Consequently, SDN-controlled optical networks must be able to support per-wavelength OAM.

# Bringing wavelength agility and efficiency to SDN

The technology that supports CDC-F photonic networks has been a topic of discussion for several years. But few vendors have delivered solutions that enable a move to full CDC-F networking, at the scale and efficiency many network operators require.

Alcatel-Lucent supports the move to higher-capacity agile optical networks with capabilities that:

- Scale fiber capacity to maximum levels, using unique technologies that can deliver 24 Tb/s of efficiently filled wavelengths on a single fiber
- Enable dynamic optical networks that don’t require on-site visits to change or adjust photonic wavelength connectivity
- Support operationally efficient wavelength-lifecycle optical OAM tools that leverage Alcatel-Lucent’s unique ability to perform per-wavelength OAM tracking throughout an optical network

The technologies that enable these capabilities can also be leveraged by SDN controllers and management entities to help operators evolve to operationally efficient SDN-controlled and managed optical networks. The following sections look at how these established technologies can be leveraged to support future SDN-controlled optical networks.

## Maximum fiber capacity

Maximum fiber capacity is achieved by supporting the most efficient high-capacity wavelength modulation that can:

- Optimally balance capacity and reach for 100G, 200G, 400G and higher wavelengths
- Support the maximum number of wavelength switch traversals or hops, in order to minimize the need for costly OEO wavelength regeneration
- Take advantage of flexible grid wavelength channel assignments to support the best use of optical spectrum and the creation of new 400G+ higher-capacity, multi-channel, super wavelengths

Currently, most high-capacity 100G, 200G, and 400G wavelength modulation algorithms are proprietary, requiring both ends of a wavelength link to come from the same vender. However, these proprietary wavelengths can traverse other vendors' optical networks in the pure light/photonic domain. In this case, the wavelengths are referred to as "alien" to the network they are traversing.

With the move to increased wavelength networking, more alien wavelengths could be deployed. Alien wavelengths have little or no OAM visibility to the networks they traverse as aliens. That makes them extremely difficult to monitor and troubleshoot without the addition of per-wavelength OAM.

It will take time for open, high-capacity modulation standards with per-wavelength OAM to become available and support open networking at the photonic layer. In the interim, Alcatel-Lucent supports technologies that can add in-band per-wavelength OAM to any alien wavelength. This unique capability allows wavelengths from any vendor to be traced and precisely monitored throughout an Alcatel-Lucent optical network, without the need for extraneous Optical Channel Monitor (OCM) modules.

## Network agility

Currently, most optical services have their connectivity established through OTN or Ethernet electrical switches interconnected by high-capacity wavelengths. Signaling and control protocols, such as Generalized Multi-Protocol Label Switching (GMPLS), can be used to rapidly set up end-to-end OTN and wavelength connections across various network boundaries. Integrated optical and Ethernet switching capabilities can also be used with protocols such as External Network to Network Interface (E-NNI) to support broad-reaching Carrier Ethernet services over optical infrastructure.

With the introduction of SDN, network control distribution can take on new flexibility. SDN architectures are flexible enough to leverage existing optical connection-creation mechanisms such as GMPLS. Proven GMPLS optical path-computation engines (PCEs) can also be leveraged in new SDN controllers or their components.

An Alcatel-Lucent wavelength PCE can be used to support an offline planning tool and to establish real-time wavelength connections. The PCE leverages years of Alcatel-Lucent and Bell Labs optical expertise to create reliable wavelength paths over various grades of fiber infrastructure. To do so, it takes into account factors such as:

- Accumulated optical signal-to-noise ratio (OSNR), non-linear penalties (NLP), polarization mode dispersion (PMD) and polarization dependent loss (PDL) wavelength impairments
- Frequencies or colors and the related modulations used on a fiber span
- Potential crosstalk from wavelength-switching modules

Along with wavelength propagation criteria, the Alcatel-Lucent PCE supports administrative policy for wavelength establishment, including:

- The maximum cost of a wavelength path, where cost can be flexibly defined by the network operator
- Pre-emption priority to determine the holding priority of a wavelength in the event of a failure
- Wavelength path diversity for backup wavelengths to ensure that a single failure does not impact both primary and backup wavelength paths
- The maximum number of optical switches a wavelength can traverse, which can be used to contain wavelength network agility to a certain area.

The PCE combines this policy with end-to-end tracking of fiber impairments to service wavelength connection requests.

## Top-to-bottom operational efficiency

Deploying optical wavelengths requires attention to detail, because fiber impairments can compromise the integrity of a wavelength — especially in long-haul networks where wavelengths can travel thousands of kilometers in a purely photonic domain. Efficient planning, deployment, and monitoring of wavelengths, throughout their lifespan, requires tools that simplify the complexities of running optical networks.

### Efficient planning

Planning an optical network requires:

- Accurate estimates of end-to-end fiber impairments to optical-signal propagation
- Placement of amplifiers and attenuators to keep wavelengths at the correct power levels
- The ability to deploy wavelength regeneration or re-coloring capabilities in the network, as needed

Planning tools must accurately predict network performance, so that wavelengths and their potential protection and restoration paths can be launched and maintained at the appropriate power levels. If launch power is too high, particularly in long haul systems, it can degrade reach due to excessive nonlinearities. But when a launch power is too low, it can also degrade reach due to noise limitations. An inappropriately high power of one wavelength can also impact the transmission performance of other wavelengths in the surrounding spectral vicinity.

In agile optical networks, wavelengths may change their network path as a result of network failure or load rebalancing. Alcatel-Lucent planning tools take into account this agility to ensure reliable optical network operation, even when a wavelength changes its optical path through the network. This agility can be modeled and simulated before wavelengths and their potential paths are put into production to avoid bringing down existing services.

### Efficient deployment

After the planning stage, the completed plan must be automatically downloaded to the live network to minimize operator provisioning error. Wavelengths have to be carefully powered up to avoid impacting existing services. Wavelength connection endpoints must be verified, along with end-to-end power levels. Once the wavelength is established, active power levels have to be continuously crosschecked against planned power levels using per-wavelength OAM. Alcatel-Lucent zero-touch photonics can automate these steps to support a dynamic and operationally efficient network.

With zero-touch photonics, optical services requests can be easily abstracted and require only a few high-level SLA parameters, such as service source and destination endpoints, bandwidth required, maximum allowable latency, and availability. This level of abstraction is a key requirement to support SDN abstractions of the underlying optical network. Once a service request is received, the PCE checks the SLA parameters against potential wavelength impairments and administrative policy before wavelengths are activated. Then per-wavelength OAM is automatically launched to ensure wavelength performance and availability.

### Efficient monitoring

Today, optical networks rely on well established OTN and Carrier Ethernet OAM features to ensure operational efficiency when diagnosing service faults and monitoring SLA performance. But capacity demands and SDN architectures are bringing a shift from slower-moving OTN connection establishment to more dynamic wavelength connection establishment. As a result, per-wavelength OAM must take the place of established OTN and Carrier Ethernet OAM tools to ensure continued operational efficiency.

This wavelength OAM needs to support tools like wavelength ping and traceroute, along with Carrier Ethernet-like OAM structures such as:

- Wavelength user to network interface (UNI)
- Wavelength network to network interface (NNI)
- Wavelength maintenance endpoint (MEP)
- Wavelength maintenance intermediate point (MIP)

Per-wavelength OAM must also be able to monitor new flexible, grid-enabled multi-channel super wavelengths, because their multichannel nature adds greater complexity to wavelength troubleshooting — which can also add time to fault resolution.

Wavelength span losses must be monitored as well to help pinpoint the possible root causes of wavelength performance degradations. When degrading wavelength paths are detected through Forward Error Connection (FEC) performance statistics, spans losses, or channel power levels, they must be correlated and acted upon immediately. In this way, wavelengths can be proactively switched to alternative paths, before complete failure, to avoid service interruptions.

Fiber optic cable issues can be introduced by breaks, bends, water penetration, and eavesdropping attempts. They must also be found rapidly and isolated to within meters of precision for faster repairs. This level of accuracy also minimizes disturbance to the physical infrastructure while making the repair (for example, digging up roads or sidewalks). The Alcatel-Lucent 1830 PSS supports an efficiently deployable optical time-domain reflectometer (OTDR) solution that can be used to proactively find and isolate these types of fiber plant issues.

Network operators can use OTDR functionality from a remote site. It provides the look and feel of a traditional hand-held OTDR, while permitting fiber plant quality to be visible and checked from any location. Measured data can be logged and compared with historical or benchmark scans, which helps highlight changes in the fiber plant before they impact SLAs. The same solution can be used to pinpoint the location of fiber optic cable eavesdropping attempts to keep the network secure.

# Summary

Network capacity demands are putting increasing pressure on optical networks resulting in the need to more efficiently route high-capacity wavelengths. This together with the need to more richly connect optical networks with fiber to scale wavelength capacity are driving the need for wavelength routing.

New SDN applications have the potential to create increased wavelength dynamism and better support for rapid delivery of new revenue-generating services. However, for SDN-controlled optical networks to reach their potential for service delivery speed and operating efficiency they must be augmented with features, such as CDC-F networking, per-wavelength OAM, fiber-impairment detection and isolation, and integrated plan, deploy, and monitor tools. Existing Alcatel-Lucent agile optical networks are already offering capabilities that help enable a new world of optical SDNs.

# Appendix: Alcatel-Lucent wavelength tracker

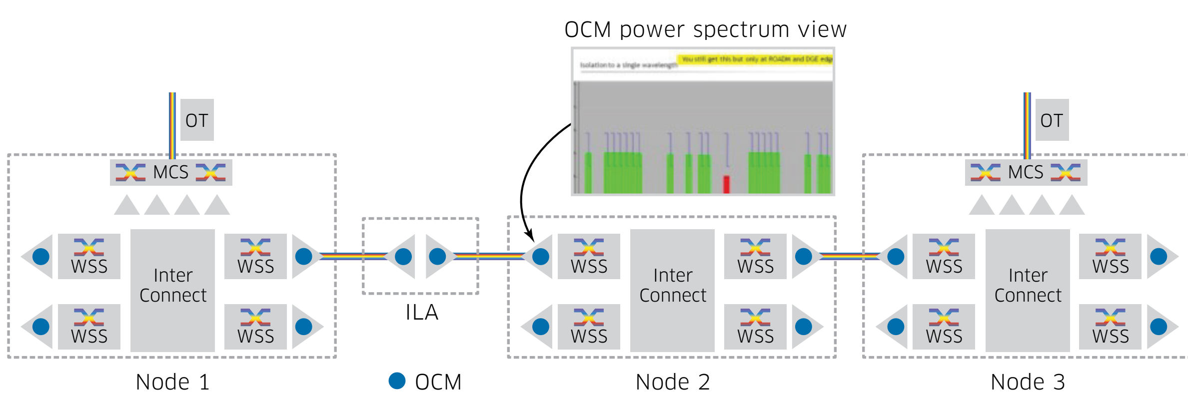
## Introduction

Early optical networks combined relatively static photonic layers with point-to-point Dense Wavelength Division Multiplexing (DWDM) links and fixed-wavelength add-drop capabilities. The corresponding OAM tools available for performance monitoring and fault management were limited to optical power monitoring at selected sites. As network providers maximize use of their optical resources with wavelength frequency re-use and other approaches, the need for comprehensive wavelength power monitoring with service instance awareness will become critical. And as optical networks grow in size to span continents and become increasingly dynamic under SDN control, OAM tools must evolve, so that OPEX does not increase as well.

## Optical power monitoring

To enable the detection of optical power degradation, an OCM can be deployed. It provides a measure of the optical power for each wavelength and raises an alarm (such as Optical Power out of Range - OPR), if that measured power is outside the range expected. This capability applies to a wavelength sourced by native equipment or an alien wavelength sourced from another vendor's equipment. OCMs can be equipped on the line side of a wavelength switch or an in-line amplifier (ILA). The power spectrum at any OCM can be viewed from a management interface. In Figure 5, one wavelength is highlighted in red, because its power level is lower than expected. Potential causes of optical power degradation include loose or dirty fiber connectors, an exceeded fiber-bend radius, component degradation, or card failure.

**Figure 5. OCM power spectrum view**




ILA: in-line line amplifier
MCS: multicast switch
OT: optical transponder
WSS: wavelength select switch

OCMs can be used to detect and isolate a per-wavelength power degradation or loss to the nodal edge of an optical node or ILA site. However, they cannot correlate that alarm to a specific wavelength service instance.

For example, say wavelengths of the same color erroneously collide at the same fiber output port. In that case, an automated power balancing system would simply readjust power levels, and OCMs would not raise an alarm. This leaves network operations personnel with no intermediate wavelength diagnostic or monitoring points that can be used to rapidly isolated and correct this type of failure.

## New per-wavelength OAM required

As optical networks evolve to CDC-F optical networks, wavelength color reuse (meaning the use of wavelengths at the same frequency in the same network) will be one of the key tools used to scale network capacity. So the ability to uniquely identify different wavelength service instances will be critical to operating the network. In addition, the dynamics of wavelength establishment and re-routing can only increase, as today's agile optical networks migrate from a distributed GMPLS control plane, designed to reduce management effort, to a centralized SDN control plane that can respond to automated requests from an ever-growing range of applications.

To address the fault-isolation limitations of OCMs and reduce monitoring costs, Alcatel-Lucent developed a wavelength OAM capability called Wavelength Tracker that can uniquely monitor wavelengths. In brief, it operates by encoding a unique in-band identifier at a specific power ratio with the optical signal, when created by optical transponders. The same technique can also be applied to an alien wavelength using specialized Alcatel-Lucent optical demarcation modules.

With Wavelength Tracker support, wavelengths are uniquely identified and can be accurately monitored throughout the optical network, including between the cards in an optical switching node. At wavelength path intermediate points, that identifier and its power can be measured and compared with the expected identifier and power level (as provisioned by the management system). In this way, Wavelength Tracker enables proactive and accurate monitoring of wavelength performance, while providing the ability to pinpoint where wavelength degradations occur.

Since Wavelength Tracker uniquely identifies wavelengths in-band, it can detect when wavelengths of the same color erroneously collide at the same fiber output port. In this scenario, the two in-band wavelength identity signatures will be detected at the collision point and downstream of the collision point, and the appropriate alarms will be raised. Locations in the network where the colliding wavelength should be are also sent an alarm. Together the alarms support rapid isolation and correction of the failure.

Without Wavelength Tracker support, network troubleshooting has the following limitations:

- A per-wavelength power degradation or loss can only be isolated to a nodal edge, leaving no wavelength path intermediate points available to rapidly correct failures.
- A per-wavelength power measurement (within specifications or outside) cannot be correlated to a specific wavelength service instance.
- A connectivity error or fault involving wavelengths at the same frequency is not always detectable within the optical network, making fault isolation very challenging — especially for alien wavelengths

## Summary

As the agility of optical networks increases with the availability of CDC-F-based optical networks under SDN control, the support for a comprehensive per-wavelength OAM toolset will be critical to operating the network. The Alcatel-Lucent Wavelength Tracker feature is a key component of this toolset, and it provides the foundation for new OAM tools, such as wavelength ping and trace, that can be used to manage open optical SDNs.

# Acronyms

| | |
|---|---|
| BTP | Backhaul Transport Provider |
| CAPEX | Capital Expenditures |
| BBU | Broadband Unit |
| BTPs | Backhaul Transport Providers |
| E-LAN | Ethernet Virtual Private LAN service |
| E-LINE | Ethernet Virtual Private Line service |
| E-TREE | Ethernet Virtual Private Tree service |
| eMBMS | Enhanced Multimedia Broadcast Multicast Services |
| eNB | Evolved Node B (LTE base station) |
| FCAPS | Fault, Configuration, Accounting, Performance and Security management |
| FEC | Forward Error Correction |
| GMPLS | Generalized Multiprotocol Label Switching |
| H-QAM | Higher order Quadrature Amplitude Modulation |
| IEEE | Institute of Electrical and Electronics Engineers |
| IETF | Internet Engineering Task Force |
| IP | Internet Protocol |
| ITU | International Telecommunication Union |
| ITU-T | ITU Telecommunication Standardization Sector (ITU-T) |
| LAG | Link Aggregation |
| LAN | Local Area Network |
| LOS | Loss of Signal |
| LTE | Long Term Evolution |
| MNO | Mobile Network Operator |
| MPT | Microwave Packet Terminal |
| MPR | Microwave Packet Radio |
| MPLS | Multiprotocol Label Switching |
| MSS | Microwave Services Switch |
| NLOS | Non-Line-of-Site |
| OAM | Operations, administration and management |
| ODU | Outdoor unit |
| OPEX | OPerating Expenditures |
| OTN | Optical transport network |
| PoE | Power over Ethernet |
| PON | Passive Optical Network |
| PTP | Precision Time Protocol |
| QoE | Quality of Experience |
| QoS | Quality of Service |
| RAN | Radio Access Network |
| RF | Radio Frequency |
| RRH | Remote Radio Head |
| RSTP | Rapid Spanning Tree Protocol |
| RU | Rack Unit |
| SAM | Service Aware Management |
| SLA | Service Level Agreement |

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