# How Integrated Photonics Enhances Capacity and Scalability for Fiber Deep Networks

A Technical Paper prepared for SCTE/ISBE by


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# Introduction

The Cable MSO industry is at the beginning of the next major chapter in the evolution of their access network story. The deployment of fiber deeper into the access, with N+0 targets, and the introduction of digital optics to support new Remote PHY Nodes, MAC/PHY nodes, PON and/or wireless access points, the Cable MSOs will position themselves to deliver high capacity 10G+ bandwidth services to their customer. To complement these next generation broadband access networks, the Cable MSOs will also need to invest in capacity between aggregation sites (e.g. Secondary hubs), Converged Cable Access Platform (CCAP) sites (Primary Hubs) and Headends. This paper will explore how fiber deep solutions that integrate photonics, coherent modems and open intelligent software & applications will enable optimal scalability and deliver maximum total capacity.

# Content

## 1. Integrated Photonic Solution

An integrated photonic solution is an architecture that makes use of scalable, programmable, and instrumented hardware with sophisticated software applications to change the way fiber deep networks are engineered, deployed, maintained, and operated. This in turn enables the optical layer to fully participate in multi-layer network optimization which adapts and optimizes network behavior and resources for the specific service metrics required at a specific point in time. Key components of an integrated photonic solution are outlined below.

a. Integrated coherent optics including variable-bit-rate capacity modems that allow operators to optimize capacity for any stage of the network's life
b. Flexible Reconfigurable Optical Add-Drop Multiplexers (ROADM) for the ability to increase service availability and optically switch traffic across any path in the network
c. Flexible grid photonic lines, for the ability to maximize fiber capacity using next generation coherent technologies
d. Highly instrumented physical layer to ensure real-time monitoring and predictability of the programmable infrastructure
e. Application Programming Interfaces (APIs) and SDN applications to drive the infrastructure

## 2. Integrated Coherent Optics

Integrated photonics refers to the inclusion of high performance optics directly into the aggregation and distribution components of the fiber deep solution.

A fiber deep network must be designed to physically reach the intended number of subscribers and adapt to the changing capacity needs of the subscribers which are expected to grow significantly throughout the life of the network. To meet these requirements, it must include components that support many physical interfaces, and support differing levels of throughput and transport capacity. One such device is the Remote PHY (RPHY) aggregation platform located in the secondary hub or primary hub. This device will terminate the 10G signals from the fiber nodes and efficiently aggregate the traffic for local hand-off to the CCAP or to a packet optical platform for transport upstream towards the hubs which house CCAP's.


**Figure 1 - Hub to Fiber Node**

In addition to being low cost, low power, and low footprint to optimize the capacity and scalability of the solution, the aggregation solution should be able to scale to support full capacity on the subscriber interfaces along with the associated line side transport bandwidth. Coherent line side optics deliver the highest capacity and performance and enable these benefits with minimum cost and cabling.

The spectral efficiency and operational simplicity advantages associated with coherent technology is the reason 100G coherent systems form the foundation of backbone networks today, and why this technology is the optimal solution servicing headend locations in fiber deep architectures. Coherent optics use advanced Digital Signal Processing (DSP), with the ability to detect amplitude, phase, and polarization of a signal, to impart significantly more information across fiber optic cables than traditional intensity-modulated direct-detect 10G systems. Moreover, coherent systems also enable a simpler network, as they electronically compensate for signal distorting effects such as Chromatic Dispersion (CD). By deploying coherent systems, operators can completely eliminate optical compensators, and the associated Capital Expenditure (CAPEX), latency, and manual planning associated with these from the network.

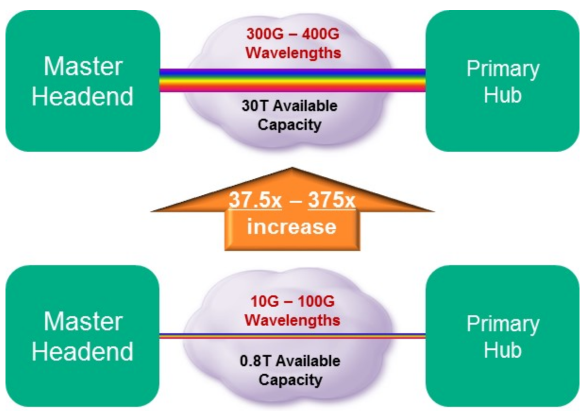


**Figure 2 - Headend to Hub**

Using coherent technology, numerous 10Gbps signals arriving from the fiber node can be efficiently mapped into a 100G coherent Dense Wave Division Multiplexing (DWDM) system and support up to 10T of capacity over a single fiber pair. Moreover, new imminently available coherent innovations are making it possible to radically drive down transport costs and improve scale of fiber networks. By leveraging the latest advancements in coherent optics and photonic capabilities, operators can now architect networks that can support up to three times that capacity between the headend and primary hub, as well as between the secondary to the primary hub segments, significantly improving scale and spectral efficiency of their fiber distribution networks.

 

Coherent systems today operate at symbol rates of 30-35Gbaud, and support up to 200Gbps of capacity per wavelength. Next generation coherent solutions, coming to market in 2017 and 2018, can operate at higher symbol rates and can process more information while still using a single set of electro-optics, dramatically reducing transport costs. Next generation coherent solutions can transport higher data throughput, such as 400Gbps of capacity, over a single wavelength. Resulting benefits include:

- Reduced transport costs, reduced footprint, and reduced power consumption, all resulting from the deployment of fewer coherent transponders
- Ability to maximize spectral efficiency and scale to higher capacity per fiber pair
- Simpler operations through the management of fewer wavelengths

These next generation coherent solutions also leverage more dense constellations and advanced DSP to offer a wide range of tunable capacity rates. An example of a programmable coherent modem, that can be tuned from 100G to 400G capacities in 50G increments, is shown in the figure below. Programmability in 50G increments allows cable operators to better match system capacity to available system margin.  This translates into more bits carried at longer distances without requiring expensive Optical-Electrical-Optical (OEO) signal regeneration. The Forward Error Correction (FEC) implementation and DSP algorithms of the coherent solution will dictate its resulting system performance (how much capacity and unregenerated reach per channel), and how much ultimate capacity is achievable over fiber assets.

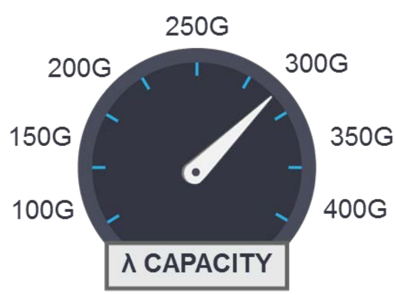


**Figure 3 - Programmable coherent optics**

In the future, coherent optics will also extend in to the access plant to support aggregation of 10G traffic from the fiber nodes to Outside Plant Aggregation Solutions.  These optics will be optimized for reaches of 40 km to100 km and drive capacities of 100G to 200G per wavelength.

## 3. Photonic Line System

The photonic line system is an important consideration in a fiber deep architecture. Providing the physical layer connectivity with as flexible an architecture as possible will enable maximum capacity but also enable new protection schemes increasing the availability of service without reserving bandwidth. Components of an integrated photonic layer include ROADM with directionless, colorless and contentionless capability supporting flexible grid applications. The photonic line system deployed for fiber deep can also be leveraged to provide connectivity for other services in the area thus increasing value and scalability of the network.

Flexible grid ROADMs provide several important functions including wavelength add / drop, switching, restoration and equalization required to optimize performance and allow the line side interfaces to operate at their maximum capacity. There are multiple configurations that can be deployed each providing different levels of programmability: colorless (supporting any wavelength on any port), colorless and directionless (adding the ability to change the direction remotely) and contentionless (supporting multiple instances of the same wavelength on the add / drop device). They are programmable components critical to optimizing the benefit on an integrated photonic solution.

There are two primary benefits of flexible grid systems. First, a flexible grid photonic layer future proofs the network so it can carry any next generation higher bandwidth signal associated with higher baud rate coherent technologies. To achieve the desired system performance while operating at a faster symbol rate, wavelengths from these next generation modems will require larger spectrum than the traditional 50GHz seen in fixed grid systems today. MSOs will need to migrate to flexible grid systems to realize the full extent of economic savings associated with the new coherent technology.

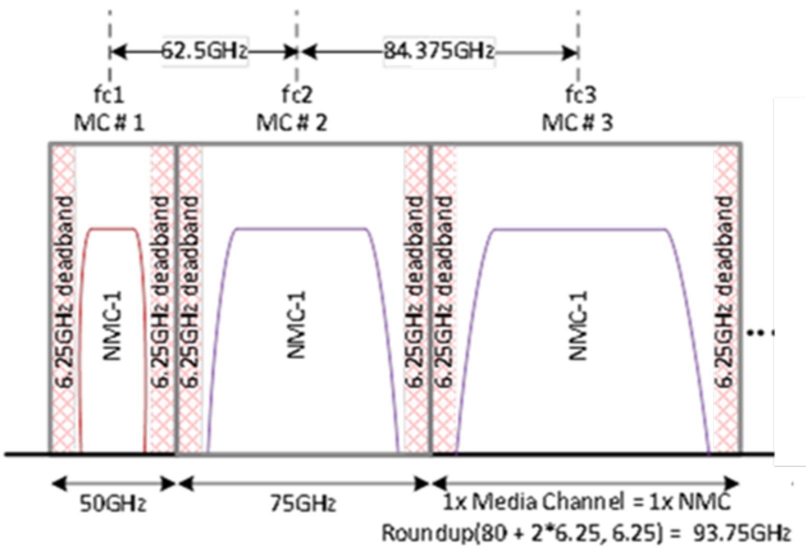


**Figure 4 - Example of optical signals requiring greater than 50GHz spectrum**

The second benefit of a flexible grid photonic layer is that it allows the operator to squeeze carriers closer together, as shown below, and carry traffic across the least amount of spectrum. The operator manages the resulting media channel, also known as “superchannel”, as a single entity across the network, even though it may in fact consist of many optical signals. This use case is suitable for point-point applications, and is relevant for connections between secondary hub, the primary hub, and the headend node in MSO networks.

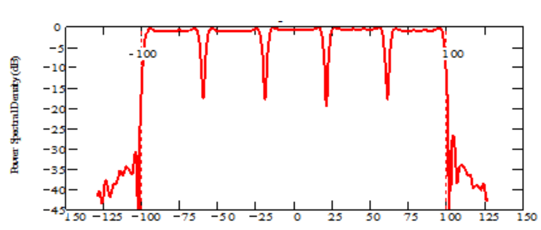


**Figure 5 - Squeezing of Multiple Optical Signals Into One Media Channel**

## 4. Instrumentation and intelligence

Optical Networks are largely perceived as rigid, static networks, which must be engineered for worst case scenarios. Worst case predicted A-Z capacity demands, worst case Service Level Agreements (SLAs), worst case margin allocation for worst case propagation conditions, etc. Essentially a one size fits all scenario, where the “one size” is engineered against best-guess predictions of worst case conditions. If the prediction turns out to be incorrect (e.g. A-Z demand is either larger or smaller than predicted), either more equipment needs to be ordered and installed with long lead time (demand larger than predicted), or deployed equipment remains unutilized/stranded (demand smaller than predicted). An intelligent integrated solution promises to radically change the way optical networks are engineered, deployed, maintained, and operated, by taking full advantage of agile, reconfigurable, and instrumented hardware with sophisticated SDN applications. This in turn enables the optical layer to fully participate in multi-layer network optimization which adapts and optimizes network behavior and resources for the specific service metrics required at a specific point in time. The implementation of real-time monitoring and intelligence capabilities in the photonic layer are becoming increasingly strategic capabilities of the network, as they allow cable operators to automate such tasks as configuration, provisioning, and troubleshooting. Full value of these capabilities is realized when the coherent optics and optical line system are part of an integrated solution, as full communication and visibility is possible between optics and line system, resulting in accelerated wavelength provisioning cycles and optimal system performance.

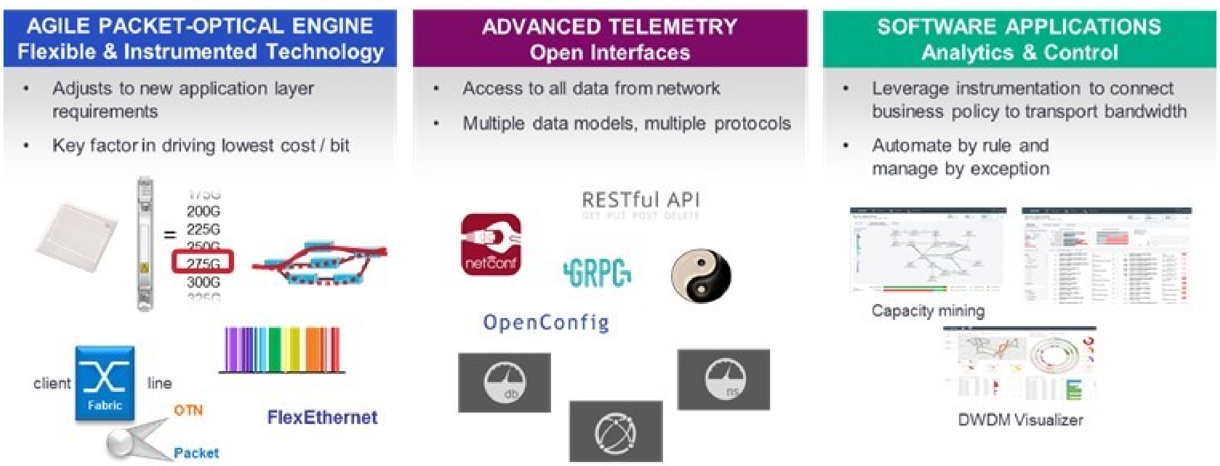


**Figure 6 - Programability, Telementry, and Analytics**

An application that is enabled by the real-time monitoring and intelligence in the integrated solution is a Layer 0 (L0) control plane. A L0 control plane is an important component in simplifying optical network processes. It automates numerous network functions, using real-time network information to provide automated topology discovery and accelerated single-step service provisioning for faster turn-up of wavelengths, increased automation for efficient planning and operations, and photonic restoration for increased availability. Another important benefit of a Layer 0 control plane is the alternative protection architectures that it enables by facilitating wavelength re-grooming and switching without reserving bandwidth enabling operators to support higher overall capacity perform proactive network maintenance in a condensed maintenance window with fewer truck rolls.

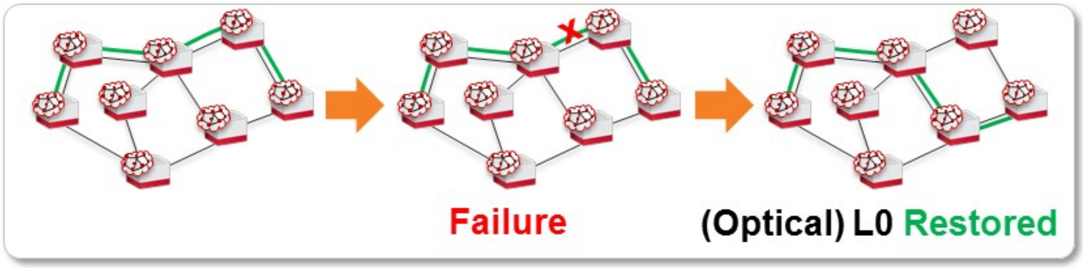


**Figure 7 - L0 Restoration**

Another example of monitoring capability that can be used by the system to optimize performance and availability is the integrated Optical Time Domain Reflectometer (OTDR). Being able to find the location of fiber cuts and other impairments for the fiber deep network is critical to its operation. OTDRs can be expensive and require professional resources to run. The OTDR functionality can be integrated within the photonics platform and with the right software tools pin-point the fiber cut down to the streel level. This capability eliminates the traditional lengthy troubleshooting step of sending technicians with test sets to either end of the failed span to localize the failure. Instead, the technician is dispatched to the precise fault location to promptly execute the repair. This quick turnaround results in increased network availability and reduced outage times. Integrated OTDR traces that can be run in-service provide additional benefits. Now, cable operators can proactively check for fiber degrades or bad repairs and ensure their network is operating with optimal performance.

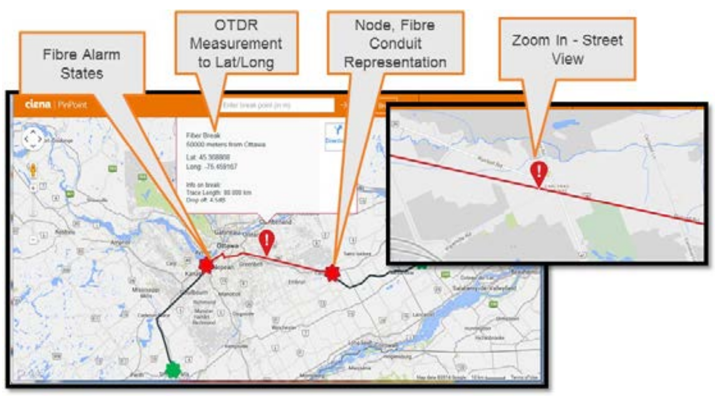


**Figure 8 - Integrated OTDR Functionality**

## 5. APIs and Advanced applications

As new platforms are built to support the hardware flexibility and programmability described above, they must also incorporate industry-standard, open APIs and common management interfaces. Modern, normalized data models and APIs are required to access the instrumented fiber deep network, and use high-performance telemetry to measure and predict, at any time and for various scenarios, system performance margin and resulting efficiency of the network.

New platforms built to support fiber deep applications must be designed to offer a simple, server-like deployment and operational model. Designed for intuitive installation and ease of operation, these fiber deep platforms can offer rapid scalability and rack-and-stack simplicity to facilitate massive rollouts with minimal engineering effort.

By leveraging open APIs, such as REST, NETCONF, and gRPC, unique operational tools and scripts can be designed to specific MSO requirements. Examples include applications for network visualization, fault management, capacity management, and performance monitoring. Alternatively, the fiber deep platforms can be integrated into an existing operational paradigm via the open APIs.

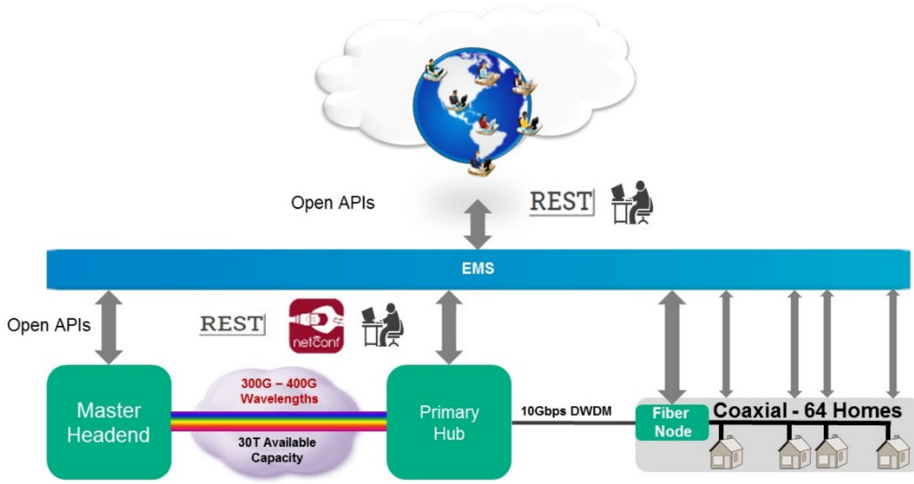


**Figure 9 - System Automation**

Platforms can also be managed through more traditional means with typical management interfaces, including CLI (Command Line Interface) and SNMP (Simple Network Management Protocol), or full lifecycle management software which enables out-of-the box planning, commissioning, and operation of the platforms without requiring any code development. This flexibility gives MSOs the choice to manage the platform through rich management software or through customized applications and scripts or back-office integration. Either way, open APIs, along with ease of use, let MSOs focus on growing their fiber deep networks without wasting effort on complex operations and integration.

## 6. SDN Applications

Advanced software applications abstract the complexity associated with advanced flexible technologies, enabling cable MSOs to fully operationalize and realize benefits associated with a fiber deep network. Applications should run 'off-box' in the cloud to take advantage of typical cloud computing and scale properties. Some examples of SDN applications include Bandwidth Optimization and Dynamic Restoration.

A Bandwidth Optimization application can be used to scale operations of the network, as well as convert the traditional static network to a dynamic, more strategic asset that can be used to generate new revenue streams. By accessing photonic instrumentation and exploiting properties of variable bit-rate coherent optics, the app can dictate the optimized capacity configuration and channel placement based on customer-definable margin policies so that cable MSOs can drive more efficiency from deployed assets. Taking it one step further, cable MSOs can leverage this intelligence and automation to convert excess system margin to additional capacity that can be used to drive new revenue streams such as Bandwidth-on-Demand services, without the need to deploy new hardware.

Another example of an advanced application that can be enabled by a solution with integrated photonics is Dynamic Restoration. Today's optical restoration is limited in that the restoration path must be pre-engineered so that the per-lambda capacity which is viable in the working path is also viable in the restoration path. This implies that either the length/propagation impairment of the restoration path is similar to (or shorter than) the working path, or regens must be pre-deployed. It also implies that the exact amount of spectrum that the restorable traffic occupies in the working path is available on the restoration path (and if it is not available, lower priority traffic that may be present on the restoration path needs to be pre-empted/dropped).

With Dynamic Restoration, a wider range of protection options are available, helping MSOs increase service availability and provide a higher quality experience to their end users:

a. "Partial" restoration: If the restoration path is more challenging than the working path (typical situation), one has the option to "downshift" the capacity of the modems which are being re-routed to better match the more challenging propagation impairment of the restoration path. In this case, instead of all traffic being dropped, some of the traffic is restored along the more challenging path. The user can pre-determine which service to drop when the partial restoration option is used
b. "Temporary full" restoration: Even when the restoration path is longer than the working path, it is possible in some scenarios to borrow sufficient dBs of margin to temporarily restore the full capacity and maintain services for end users

Advanced SDN applications, such as those mentioned above, will bring more capacity, scalability, and flexibility to the fiber deep network.

## 7. Small Cell MBH Application

With increased capacity and scalability, brings an abundancy of new business opportunities. One such opportunity, being the growth of small cell Mobile Back Haul (MBH). Continued popularity of accessing applications and content is forcing Mobile Network Operators (MNOs) to continually expand their mobile network. As MNO's expand to Long Term Evolution (LTE) and LTE-Advanced (LTE-A) to accommodate packet-based mobile data services, whether man or machine.

Wireless networks are increasing becoming more between application end-users and their associated content, making the network a dominate factor in customer Quality-of-Experience (QoE). Small cells bring end-users and their mobile devices closer to the mobile network radio, vastly improving access performance. There are many emerging small cell technologies, including femto cells, pico cells, micro cells, WiFi cells, and small cells, the latter often assumed to include some or all terms, but all benefiting from integrated photonics. Small cells are deployed in two manners, as shown below one aggregating small and macro cell traffic to the Mobile Telephone Switching Office (MSTO), and secondly, they can be homed directly to the MSTO. Both applications are in use today, and deployed based on specific network requirements, deployment constraints (indoor or outdoor), and optical fiber availability.

 

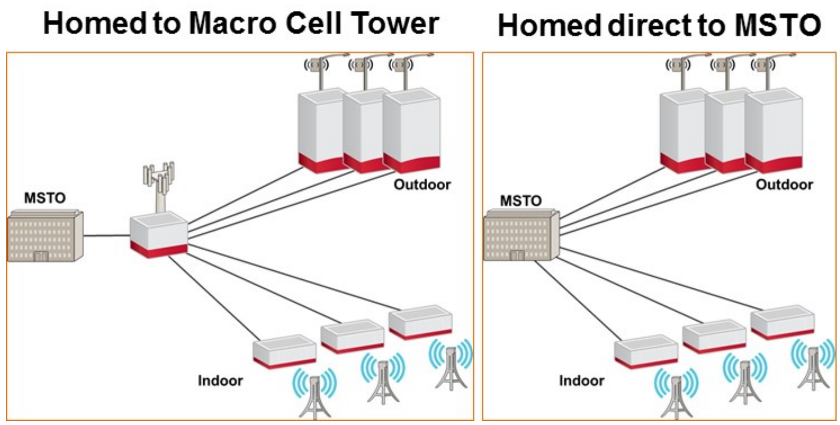


**Figure 10 - Small Cell Back Haul Deployment**

Current mobile radio technology (e.g. 2.5G 2.75G, 3G, pre-4G and 4G) are all deemed as 'best effort', in that most rarely achieve their maximum download or upload speeds. There are many factors why this happens, including large distances from mobile devices to macro cell towers, line-of-sight obstructions, indoor usage, transmission signal interference, and mobile device performance limitations. Removal of excessive equipment and optical transmission paths, as shown below can improve both active and protection distances.

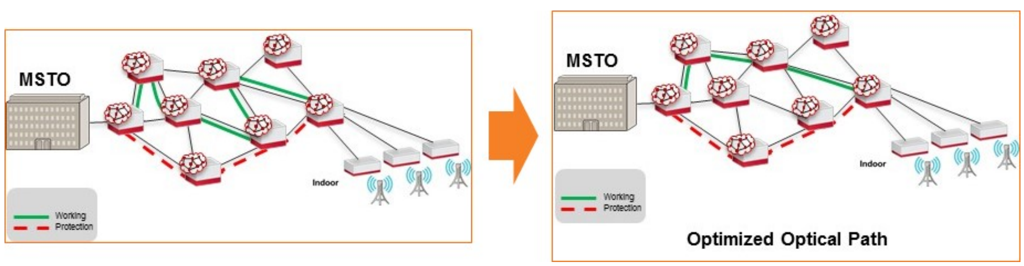


**Figure 11 - Optimized Optical Path**

Small cells allow MNOs to better utilize wireless spectrum by offloading macro cell traffic, cable operators can ensure rigid Service Level Agreements (SLAs) using simple to own and operate packet based Operations, Administration, and Maintenance (OAM) tools and optimized optical path resiliency.

# Conclusion

The advent of fiber deep is to push the optical-to-electrical conversion closer to the subscriber, resulting in a lower service group size, enabling higher throughput and capacity. "Fiber deep" means there will be more fiber nodes, fiber, and optical transceivers. Integrating optical connectivity and functionality can be seen as a viable and valuable approach to cost effectively improve network utilization.

Integrating DWDM optics and advanced coherent optical technology into switching and aggregation platforms can groom traffic from fiber nodes, enabling maximum capacity, optimal spectral efficiency, and ultimate economic savings - reducing space and power, while improving operational efficiency and performance. Moreover, advanced applications can be used to simplify the automation of services, enhance network reliability and enable new revenue opportunities using software enabled API's.

# Abbreviations

| | |
|---|---|
| API | Application Programming Interface |
| BSS | Backend Support Systems |
| CAPEX | Capital Expenditure |
| CCAP | Converged Cable Access Platform |
| CD | Chromatic Dispersion |
| CLI | Command Line Interface |
| CMTS | Cable Modem Termination Systems |
| DOCSIS | Data Over Cable Interface Specification |
| DWDM | Dense Wave Division Multiplexing |
| DSP | Digital Signal Processor |
| FEC | Forward Error Correction |
| IEEE | Institute of Electrical and Electronic Engineers |
| HFC | Hybrid Fiber Coax |
| ITU | International Telecommunication Union |
| L0 | Layer zero |
| L2TP | Layer 2 Tunneling Protocol |
| L3VPN | Layer 3 VPN |
| LTE | Long Term Evolution |
| LTE-A | LTE-Advanced |
| MBH | Mobile Back Haul |
| MNO | Mobile Network Operator |
| MSO | Multiple System Operator |
| MTSO | Mobile Telephone Switching Office |
| NMS | Network Management System |
| OAM | Operations, Administrations and Maintenance |
| OEO | Optic-Electrical-Optical |
| OSI | Open Systems Interconnection |
| OTDR | Optical Time Domain Reflectometer |
| OTT | Over-The-Top |
| PMO | Present Mode of Operation |
| QoE | Quality of Experience |
| ROADM | Reconfigurable Optical Add-Drop Multiplexer |
| RPHY | Remote PHY |
| SDN | Software Defined Networking |
| SLA | Service Level Agreement |
| SNMP | Simple Network Management Protocol |
| SNR | Signal-to-Noise Ratio |
| VLAN | Virtual Local Area Network |
| VPN | Virtual Private LAN |
| Web UI | Web User Interface |
| WDM | Wave Division Multiplexing |

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