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VIAVI Solutions

White Paper

# Fiber in 5G Networks

## Fronthaul, midhaul, everywhere – fiber will be pervasive in 5G

Unlike LTE, 5G will impact every nodal component of the network and deliver on varied use cases, from enhanced mobile broadband to ultra-reliable low latency on the same network. A 5G network will require resources to be optimized such that each use case can meet the specific SLA for that application. The challenge is that this means 5G network resources such as RF, fiber, hardware and networking elements, while shared at a macro level, will offer a separate network at a granular level for each specific application. For example, a user in a connected car watching a video will demand a higher throughput, a bigger RF and network resource, while the same connected car will require ultra-low latency and reliable connectivity. To make this network of networks successful, all resources must be flexible yet agile to offer different SLAs in an efficient manner. We all know the value of the RF resource which connects every user to the cell tower or access point, but what is connecting that access point to the network core and cloud is as important, if not more, for a successful delivery of 5G. In most cases the connection between the radios and the 5G cloud will be made up of fiber. In fact, 5G is one of the key reasons driving service providers to invest billions in new fiber deployments and/or upgrading fiber infrastructure.

## Role of Fiber in 5G

While deploying fiber is costly, the benefits in most cases outweigh the deployment challenges. Fiber offers higher bandwidths with less attenuation, resists electromagnetic interference, offers lower latency and with improving multiplexing technologies, can accommodate capacity growth on the same fiber infrastructure.

In addition to the commercial and logistical aspects, following 5G network architectural changes will drive the growth and topology of the fiber infrastructure:

- Support for mid-band and mmWave in 5G will lead to significant growth of base stations in urban and suburban environments. mmWave uses large amounts of spectrum; however, coverage of mmWave is limited. This will drive a significant number of base stations that are deployed in a smaller service area.
- Network function virtualization (NFV) will allow control and user plane to be separated and for low latency applications, decentralized user plane will move closer to terminals.
- Dividing the base band functions and creating new nodal entities called distribution unit (DU) and centralized unit (CU) to optimize transport functions per application need.
- Active Antenna system (AAS) with massive MIMO and beamforming support needing higher bandwidth and direct fiber connectivity, which will move more fiber downwards and will create additional transmission nodes.

Another key use case for fiber investment is the convergence of fiber in the access network. In the past, fiber access networks were designed for a single use case (i.e., fiber to the home or fiber to the antenna).  Now service providers are designing fiber infrastructure that can support Fiber to the x, or FTTx (x = anything). 5G disaggregated architecture will allow service providers to take advantage of the existing and new fixed network resources, reducing the overall cost of managing multiple networks and allowing a more agile and flexible resource pool. As discussed earlier sharing of fixed and mobile resources can now be done by the overall planning and upgrade of access sites, and fiber optic infrastructure.

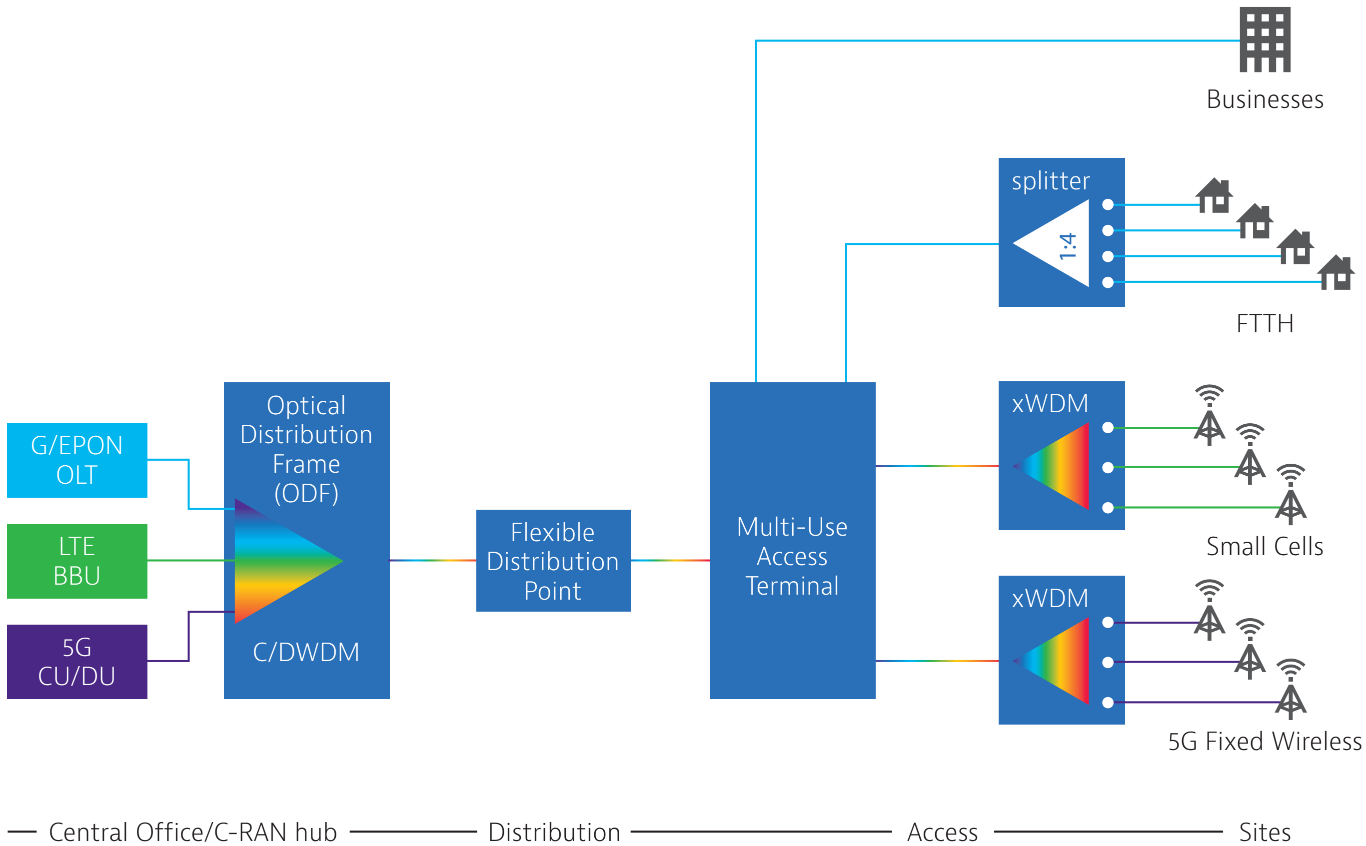



Figure 1.  example of converged fiber access network
Source : CommScope

The bottom line is the fiber network topology for 5G services will vary and evolve based on the amount and cost of dark fiber (unlit, available fiber, also known as gray fiber,), use cases for different 5G applications supported on the network, business cases for fiber upgrade, and the cost of managing multiple FTTx networks.

## 5G Fronthaul Evolution

Not too long ago optical fiber was used only in long-haul networks, but a continuous and steady broadband growth (with no end in sight) has demanded fiber as the main transmission medium, not only in the core, but in metro and access networks as well. Similarly, mobile network subscriber hunger for higher bandwidth and higher capacity services has driven fiber deeper and higher into the radio access network (RAN).

As radios became more robust and mean-time-to-replace (MTTR) has improved, vendors began offering remote radio solutions. Radios have moved closer to the antenna to avoid the significant losses caused by long coaxial cables and connectors. This strategy not only helped with improved RF footprint, it also reduced the cooling cost at the radio equipment enclosure located at or near the base of the tower. However, to support remote radio units (RRU), new interfaces were introduced. These connected the digital equipment also, called baseband units, (BBU) to the RRUs through a physical fiber link. The new link introduced between the BBU and RRU is called fronthaul, in contrast to the backhaul that connects the BBUs with the core mobile network. The most common technology used to communicate RF information over the fiber fronthaul is the Common Public Radio Interface (CPRI) protocol.

CPRI provides a dedicated transport protocol specifically designed to transport radio waveforms between the RRU and BBU. CPRI frames expand with increase radio channel bandwidth and the number of antenna elements. CPRI is not very efficient in statistical multiplexing and cannot scale to the demands of 5G, especially for massive MIMO and larger bandwidth increments. The required bandwidth and antennas in a 5G scenario would push the CPRI bandwidth requirements above 100 Gbps (Table 1).

| Antenna | 10 MHz | 20 MHz | 100 MHz |
|---|---|---|---|
| 1 | 0.49 Gbps | 0.98 Gbps | 4.9 Gbps |
| 2 | 0.98 Gbps | 1.96 Gbps | 9.8 Gbps |
| 4 | 1.96 Gbps | 3.92 Gbps | 19.6 Gbps |
| 64 | 31.36 Gbps | 62.72 Gbps | 313.6 Gbps |

Table 1: CPRI Bandwidth as a function of bandwidth and antenna ports

These bandwidth allocations would be extremely expensive for larger 5G network rollouts. Standard bodies including 3GPP, IEEE, ITU-T and others have been working to:

1. Study different split options (as shown in figure 2) of the BBU functions and its implications

2. Identify optimal requirements for different applications and services (throughput, latency, jitter, etc.)

3. Identify potential challenges and solutions for dividing the different BBU functions to meet the application and network demands

4. Provide guidance for flexible fronthaul splits

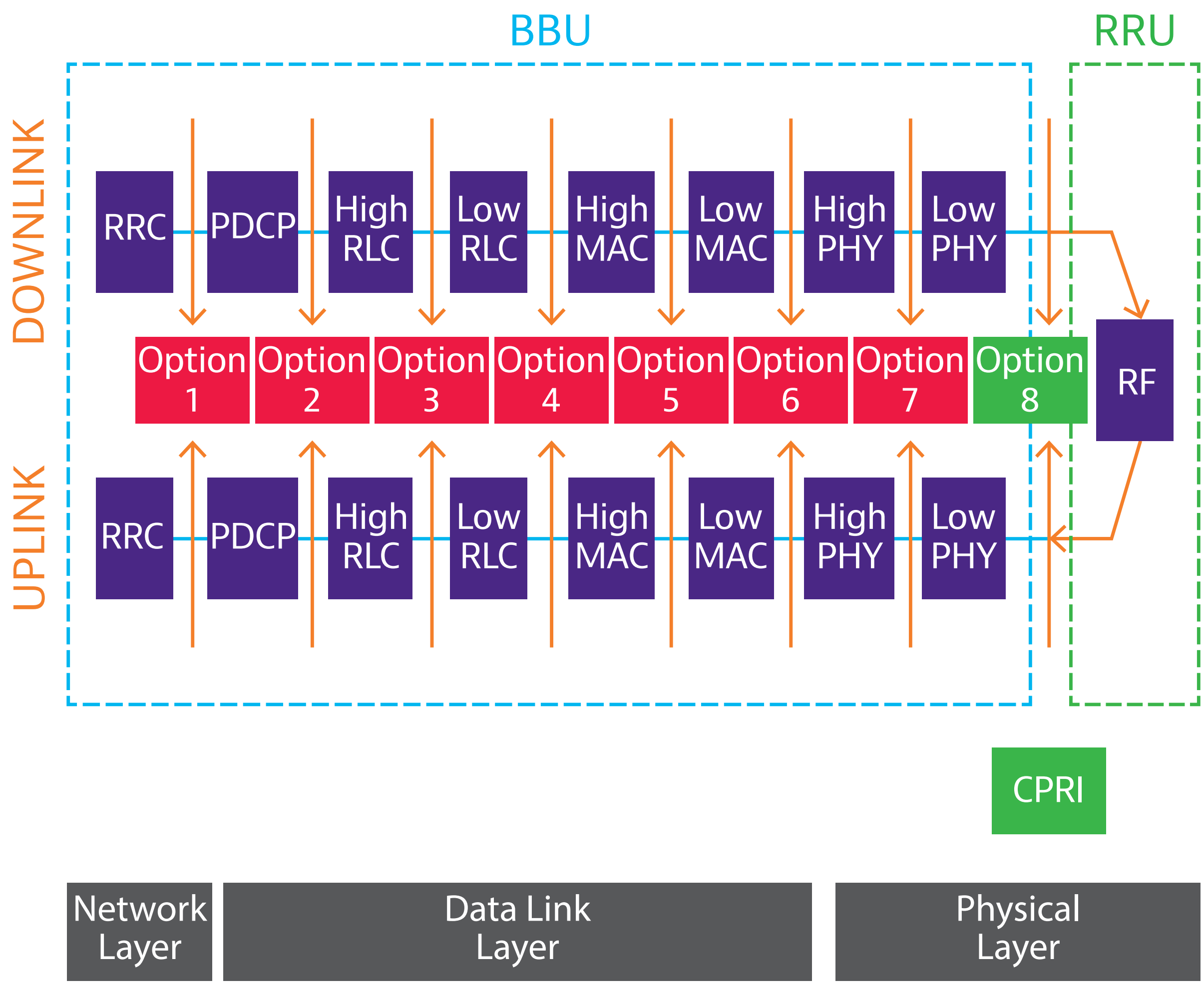



Figure 2. Functional split options

Beyond the key disadvantage of bandwidth inefficiency, CPRI also has a very limited delay budget. In practice, this means that the distance between BBUs and RRUs will be very limited. The distance is determined by the delay budget and the type of transport technology deployed in the fronthaul. Dark fiber is the simplest one allowing for maximum distance. Transport equipment that contains some processing elements reduces the delay budget, sometimes substantially, as with Optical Transport Networking (OTN). As it is often the case, operators must look at the individual use case and conduct a trade-off analysis to determine the best transport technology. Key inputs in the analysis include the availability of fiber and equipment rooms, as well as the number and locations of radio endpoints. The following are high-level requirements for the fronthaul vendors and service providers are driving:

a. Reduce bit rate (capacity usage) on the front haul, especially separating fronthaul usage from antenna port capacity as in the case of CPRI.

b. Manage stringent latency requirements for URLLC type application.

c. Optimize timing and jitter requirements for coordination features such as coordinated multipoint (CoMP) and carrier aggregation (CA).

d. Reduce overhead cost and deployment cost because fiber is an expensive resource to deploy.

To deliver on these requirements, the next-generation RAN has evolved such that functions performed by the BBU are split into three parts:

1.Central Unit (CU)

2.Distributed Unit (DU)

3.Radio Unit (RU)

Some of the physical layer radio functions, e.g. resource mapping, will migrate to the RUs. The RU will oversee the generation of I/Q signals and radio carriers for the antennas. This will allow a drastic reduction in the bitrate support required on the fronthaul. The link between CU and DU is called the midhaul, midhaul characteristics will be similar to a 4G backhaul. The CU carries non real time functions which allow the CU it to be placed much further from the radio, depending on the application type DU may be very close to the RU or centralized. For example, for coordination applications like mobility or coordinated multipoint (CoMP), centralization of DUs would make more sense.

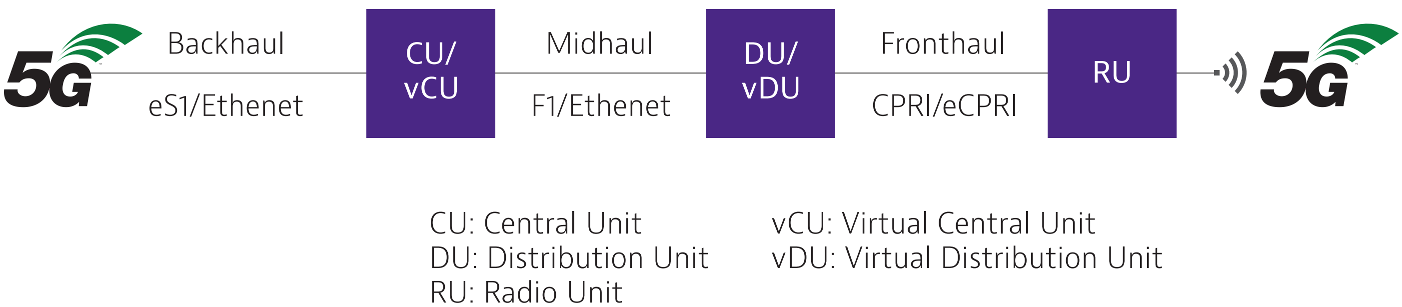



Figure 3. DU / CU Split

This new architecture helps resolve bandwidth challenges and offer flexibility in terms of latency, which drives the location of these functional elements and the applications the network supports. One thing that the standards bodies are driving is to offer a more flexible packet-based technologies for the transportation of the user plane over the front haul. Using Ethernet for transport on the fronthaul is very practical because it is backwards compatible, allowing for commodity equipment, enabling greater convergence of access networks, and enabling statistical multiplexing which will help lower the aggregate bit-rate requirements. The use of standard IP/Ethernet network switching/routing will also make functional virtualization and overall network orchestration relatively easy.

## eCPRI

Before we discuss the fiber backhaul, Midhaul and fronthaul topologies, let's review the evolution of 5G fronthaul interface. eCPRI technology is based on a functional split in the Physical Layer (PHY) component. The eCPRI specification recommends that split option $I_U$ be used for uplink, and either $II_D$ or $I_D$ be deployed for downlink, which maps to the 7.x split with respect to 3GPP as shown in figure 4. eCPRI connects the eCPRI Radio Equipment Control (eREC) and the eCPRI Radio Equipment (eRE) via fronthaul transport network. The goal of eCPRI compared to CPRI, is to decrease the data rate demands between the eREC and the eRE via a functional decomposition while limiting the complexity of the eRE. In addition, eCPRI is designed to enable efficient and flexible radio data transmission over a packet based fronthaul transport network like IP or Ethernet.

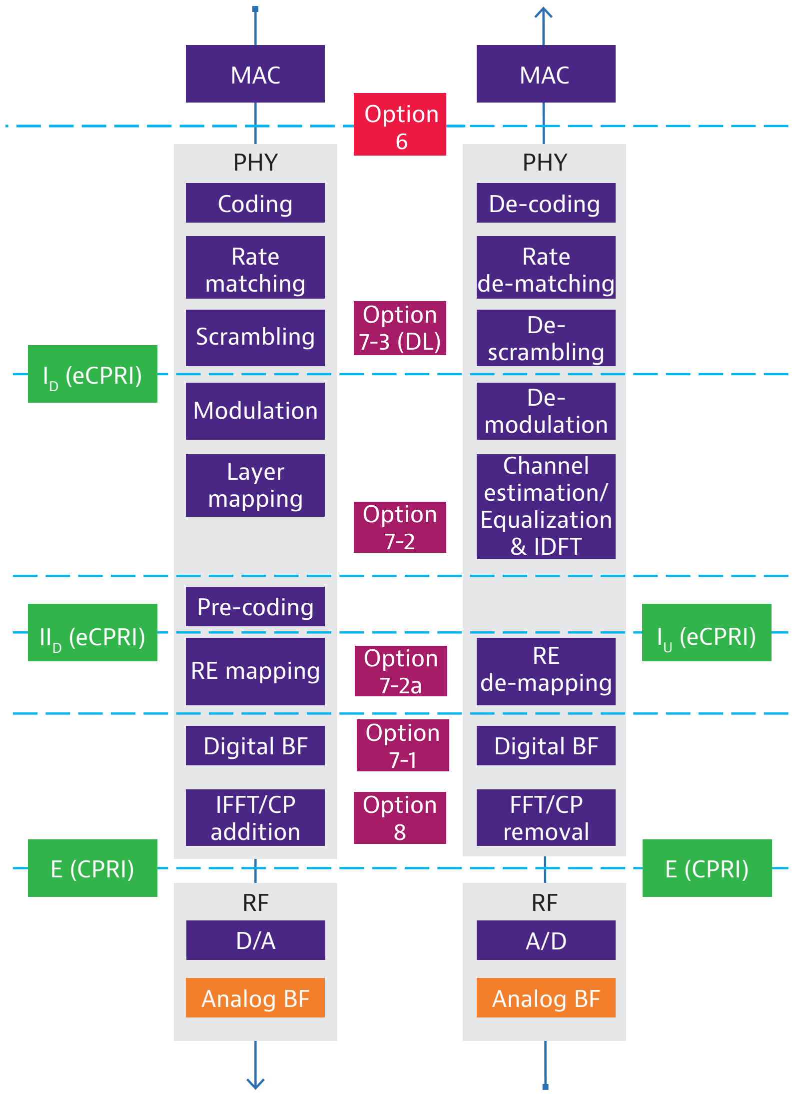



Figure 4. Functional split in PHY

For eCPRI, three planes are necessary for interaction between the eREC and the eRE: 1) user plane, 2) sync plane, and 3) control and management (C&M) plane. The eCPRI standard defines the user plane and refers to other standards for the definition of the other planes. For example, an operator is free to choose precision timing protocol (PTP) or global positioning system (GPS) for synchronization.

eCPRI also mentions packet-based technologies for the transport of the user plane. Both Ethernet (layer 2) and Ethernet/IP/UDP (layer 2/3/4) are possible. For the physical layer, eCPRI refers to Ethernet rates 10 Gbps to 100 Gbps. The point of this discussion is not to rehash eCPRI, but to identify the difference between CPRI and eCPRI. And further, where CPRI becomes a limited interface, eCPRI opens it up for 5G by reducing the throughput on the fronthaul and it uses a frame format that supports an Ethernet or Ethernet/IP/UDP frame transmission. The frame includes an eCPRI header that follows layer 2 or layer 2/3/4 header and is followed by the eCPRI payload.

Synchronization plane is carried independently over any ethernet layer and is not restricted to specific protocol. Global positioning system (GPS), precision time protocol (PTP), synchronous Ethernet, or something similar can be used for timing and synchronization.

To summarize, splitting the BBU function is essential for 5G services because CPRI is not scalable for eMBB and massive MIMO, and it does not offer the flexibility required for MMTC and URLLC applications. Moving some of the BBU functions to reduce the fronthaul bitrate (CPRI bit rate is proportional to the number of antennae to user throughput) can impact the latency requirements for coordination features and real-time applications including URLLC. By using NFV and flexible split options for different application types, a more optimal mid-haul and fronthaul (also known as x-haul) can be implemented. This new x-haul architecture allows for scalable, packet-based transport technologies but the downside is operators now must address timing and synchronization issues. However, those can be addressed using standards-based timing and synchronization technologies such as GPS, PTP, synchronous Ethernet, or something similar. The bottom line is that 5G front haul and mid-haul networks will vary based on the applications offered, network topology, medium availability (fiber, microwave, etc.), and service provider business case. There is no one size fits all.

## Fiber Fronthaul Technologies

Fiber is poised to be the primary medium for fronthaul networks. By using the above 5G and fronthaul evolution discussion we can characterize the requirements for a fiber fronthaul network. A variety of fronthaul network topologies and technologies can be planned and implemented based on the proper understanding of the requirements of a specific network. The following are key requirements of a 5G fiber fronthaul network:

1. **Cost Efficient**: deploying fiber is expensive. If dark (unlit) fiber is available, it should be used initially and as capacity demand increases deployment of a next level of multiplexing (WDM) system and future planning can increase network capacity.

2. **Flexible**: fronthaul should allow different applications with different latency and jitter budget to be implemented on the same fiber fronthaul infrastructure.

3. **Transparent**: fronthaul should allow multiple services with varying quality of service (QoS) to be implemented, where QoS for specific applications and services can be managed by the higher layers.

4. **Agile**: agility will enable quick delivery of new services, allowing for dynamic allocation and release of network resources required by different services, and the ability to dynamically optimize network connectivity will be a key component of 5G fronthaul.

5. **Timing and Synchronization**: latency and jitter are extremely important especially for mobility and URLLC applications, hence a very important requirement for 5G FH.

6. **Management and Maintenance**: fronthaul must be easy to manage and maintain, so network failures are quickly resolved and high reliability for time sensitive application can be achieved.

Another key aspect for service providers with multiple service offerings would be to deploy a scalable access fiber architecture that can easily support residential, business, enterprise, and 5G midhaul/fronthaul on the same platform. Fiber to the home (FTTH) providers can leverage existing fiber networks, either by leasing dark fiber or by densifying fiber capacity to offer fronthaul services. In any case, fronthaul solutions deployed will vary and will evolve as new services are offered and data usage grows. Some of the different fronthaul network solutions that we see being discussed, planned, and implemented are:

### Dark Fiber

Dark fiber is a point-to-point solution where service providers with excess fiber capacity can offer the easiest fronthaul solution. In this case, there is no need for any transmission equipment between the DU and the RU, for higher throughput multiple fibers can be installed between the two nodes. Where this solution offers the simplest deployment and the best latency, it also is the most inefficient in terms of fiber resources, some service providers may start with point to point dark fiber but with mobile broadband growth and/or new services offering may implement multiplexing or fiber sharing at a later stage.

This solution may be the easiest to install as only basic fiber inspection and certification is required. In cases where multiple fibers are used for a single radio, we may see Quad Small Form-Factor Pluggables (QSFPs) that may require an MPO test solution for validating multiple fiber strands simultaneously.

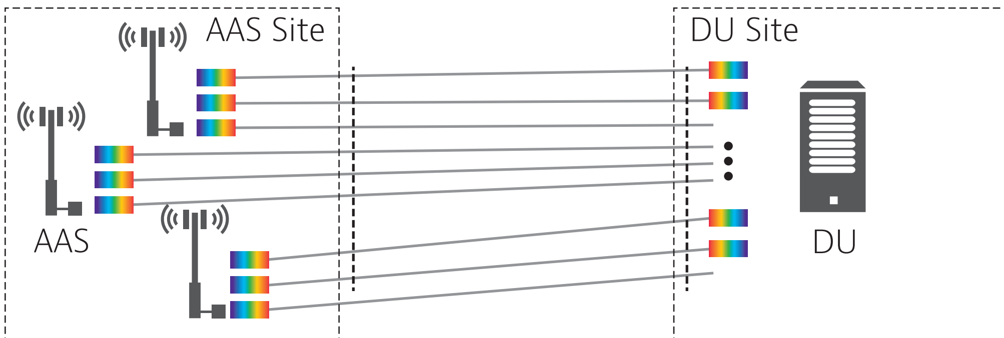



Figure 5. Point to Point Fiber

### Passive WDM

In a passive xWDM network, multiple data signals are transmitted over a single dark fiber network on different wavelength channels. Colored transceivers are directly connected to the Ethernet switch and output signal is then connected directly to the multiplexer and vice versa. Passive equipment does not need to be powered on. Its maintenance is simple, but due to the need for colored optical interfaces or reconfigurable SFPs, cost can be relatively higher, especially because of component types and spares cost. Since there is no optical-electrical-optical conversion happening latency is low as in the case of active WDM. As with any other optical network, power budget will drive the transmission distance in most cases, typically for fronthaul this should not be a major issue. Deployment will be a little more involved, validating power level, and the correct transmission and reception of wavelengths between the right transceiver interface is key.

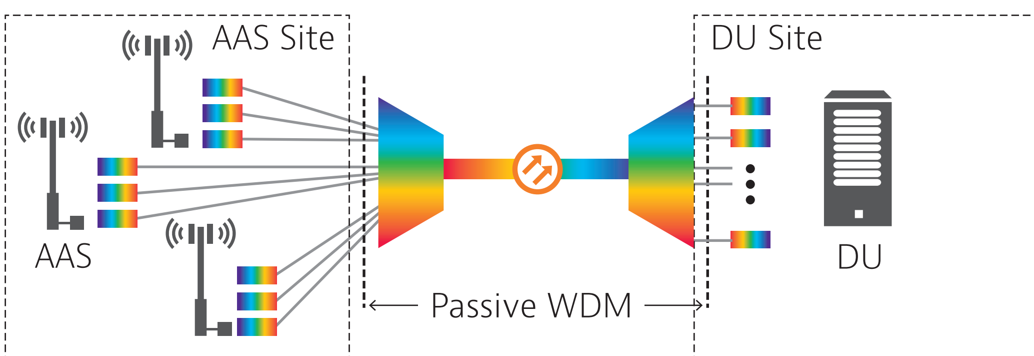



Figure 6. Passive WDM

### WDM-PON

One immediate solution to support wireless fronthaul is to overlay new wavelengths in a legacy PON, without sharing the bandwidth with legacy fixed access services. Both NG-PON2 technologies (TWDM and PtP WDM, also known as WDM-PON) could be used for this scenario.

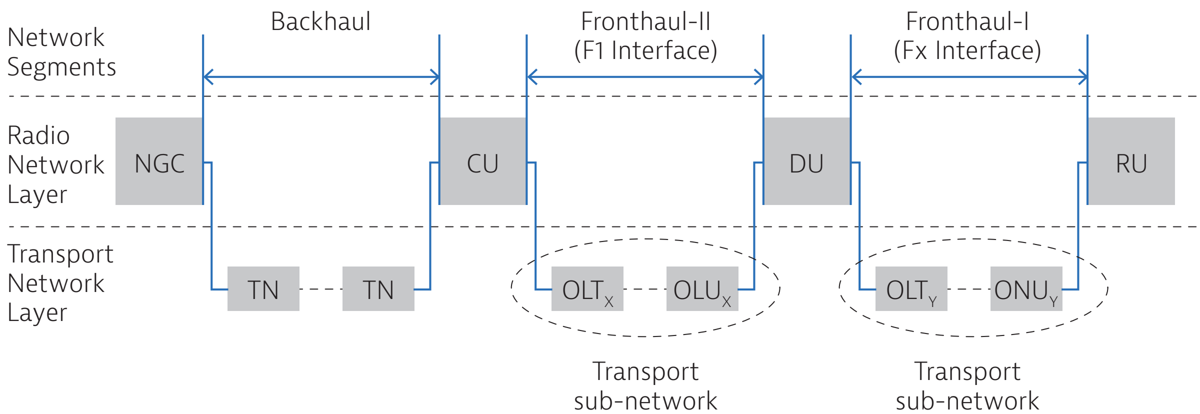
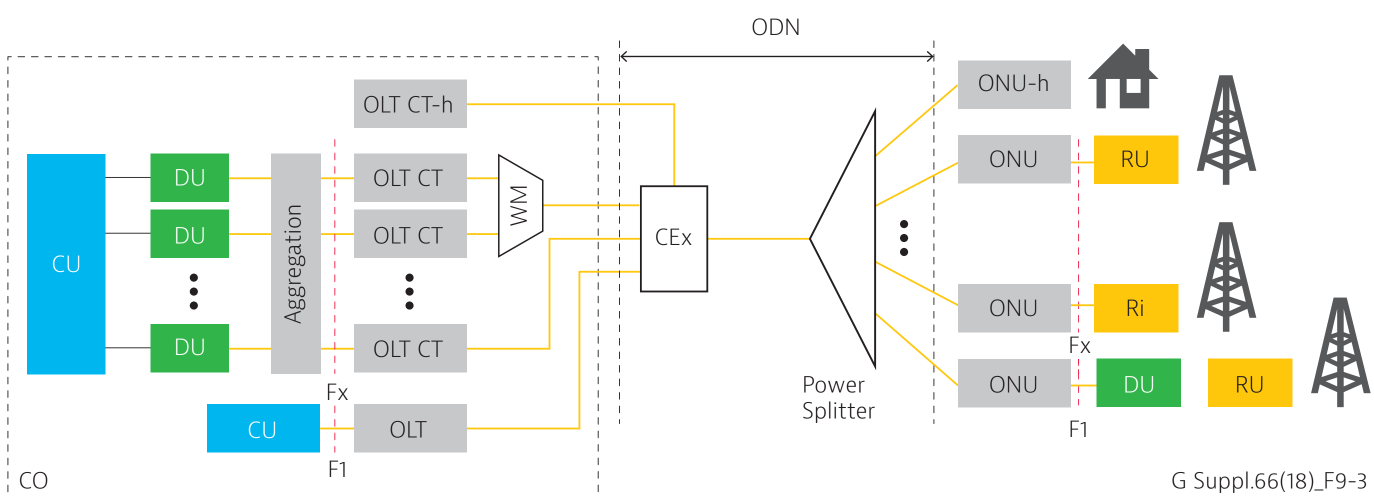



Figure 7. Concept of layered structure showing radio network layer (CU, DU, RU) and the transport network layer [3GPP TS 38.401]

WDM-PON is an access network technology. It creates a wavelength-based logical point-to-point architecture upon a physical point-to-multipoint fiber topology. WDM-PON is being considered as a potential technology for a converged access network carrying data from residential, business and fronthaul/midhaul for wireless networks. WDM-PON offers a simple inventory control as colorless, pluggable transceivers can be used, and this method uses star networks.




NOTE - Each OLT Ct can support multiple ONUs, which is not shown in the figure for simplicity.

Figure 8. Higher layer and lower layer split fronthaul based for legacy PON with WDM overlay

Split options (higher layer or lower layer split), can create a wide variation in the latency and bandwidth requirements on the same PON, as wavelength resources and processing function requirements may vary depending on the split. Path loss due to multiplexer/demultiplexer and connectors may impact the link distance. WDM processing will also impact the link delay. Separate links for data, management, and synchronization (Synced/PTP) may be needed.

## WDM/OTN

Optical Transport Networking (OTN) technology provides functionality for transport, multiplexing, switching, supervision and management of optical channels. Basically, OTN is a digital wrapper that can wrap each client payload transparently into a container for transport across optical networks, preserving the client's native structure, timing information, and management information. Enhanced multiplexing capability of OTN allows different traffic types such as Ethernet, digital video, SONET/SDH etc. to be carried over a single Optical Transport Unit frame. OTN offers transparent transport of client signals with Forward Error Correction (FEC).

In the 5G realm, access WDM/OTN devices can be configured at the RU and at the DU hub. Multiple fronthaul signals share fiber resources based on the WDM technology and are managed and protected using OTN overheads to guarantee quality. Access WDM/OTN devices and wireless nodes are connected using standard gray optical ports, reducing cost and complexity in managing colored optical interfaces. The active WDM/OTN solution supports both point-to-point (P2P) networking and ring networking.

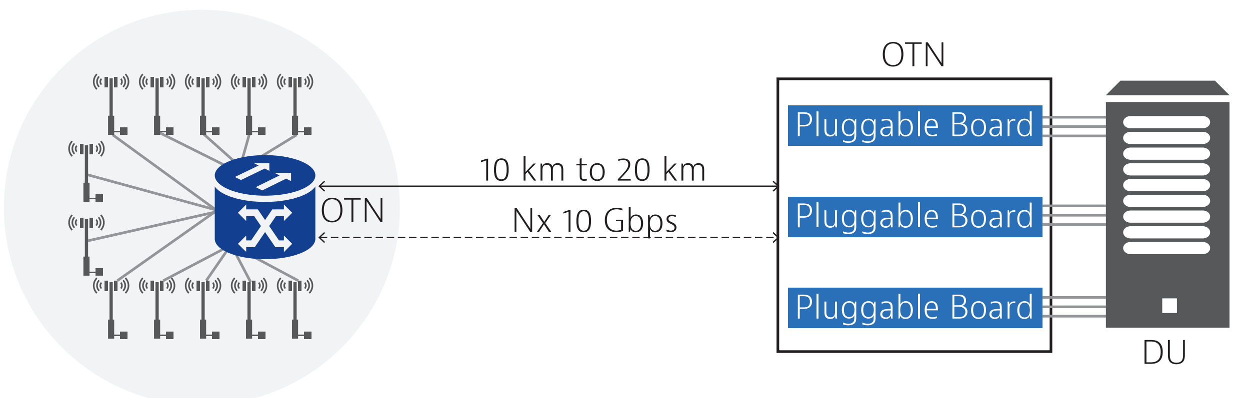



Figure 9 a: P2P architecture of an active WDM/OTN solution

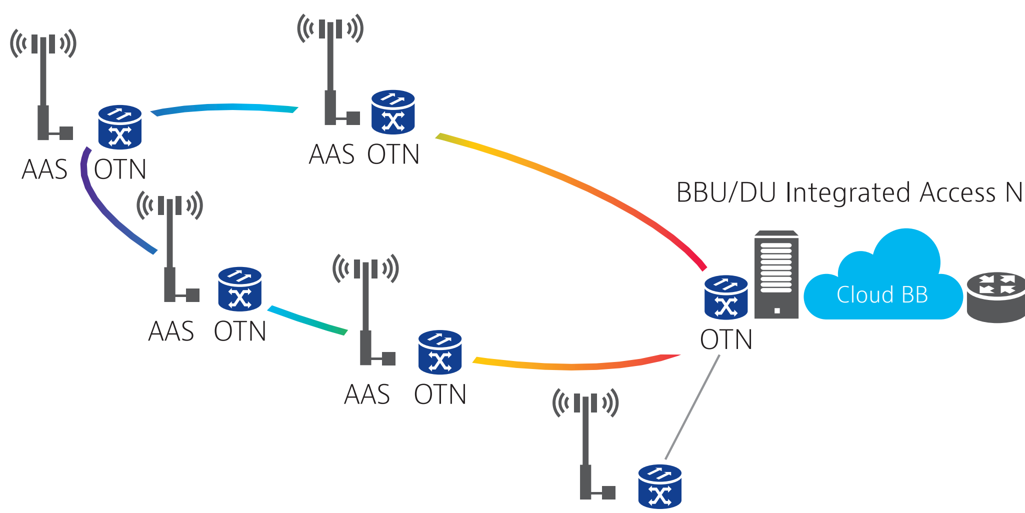



Figure 9 b: Ring network architecture of an active WDM/OTN solution

Ring architecture offers higher network reliability and resource utilization, cost of active WDM/OTN solutions is relatively high. In order to make OTN a preferred 5G fronthaul technology more work is needed to improve the cost and latency added by active component processing.

### Ethernet/TSN

Time sensitive networking (TSN) defines a set of IEEE standards primarily developed for Ethernet to provide deterministic services over Ethernet. This means guaranteed packet transport with low and bounded latency, low packet delay variation, and low packet loss. In situations where limited fiber fronthaul capacity is available, service providers can use TSN based Ethernet switching solutions to deploy an efficient fronthaul, this solution offers the most efficient use of fiber, as implementing packet based switching on the fiber fronthaul offers statistical multiplexing to achieve traffic convergence and improve bandwidth. Using TSN based Ethernet switching can help deliver on the stringent latency requirements for the fronthaul. Remember, applications like autonomous cars and augmented reality dictates latency in the 1 millisecond range, but mobile fronthaul puts even stricter requirements to delay: Maximum 100 microseconds (0.1 millisecond) one-way delay between the RU and the DU. TSN technology requires optimized switches for delay sensitive fronthaul which will be costly and maintenance and management will be relatively expensive.

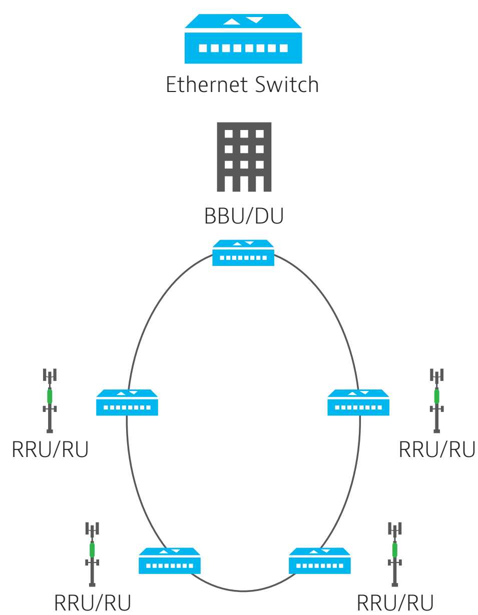



Figure 10. Passive WDM

To summarize, there are multiple options for 5G fiber fronthaul access. Factors that drive the adoption of the type of fiber fronthaul technology will vary with the service provider, the service they are offering and most importantly the amount of fiber assets they have access to. If a service provider has access to low cost dark fiber or if deploying dark fiber is cheaper, then point-to-point fiber is the best choice as it offers the most capacity and lowest FH delay. If access to fiber is costly or limited then sharing fiber is an option, still FH capacity demand and latency of the offered service will drive the fiber fronthaul technology. Options may vary from passive WDM, WDM-PON and TSN-based Ethernet switching solutions. The key will be the overall cost of deployment, impact on other wired services, technology availability and management and maintenance of the access network. In places where fiber may not be available or may be too expensive to deploy (for example, rural areas), in those situations, microwave or wireless optical links may offer a more viable solution. Again, capacity and application latency may need to be considered during planning of those fronthaul networks.

## Testing Fiber Fronthaul

As we discussed earlier, the scale of 5G will be much more significant compared to its predecessor, especially with the introduction of mmWave (>24GHz) and 5G service offering in the midland's (3GHz to 6GHz), as these bands have relatively poor RF propagation compared to low band frequencies. More radios and cell-sites will be required per square kilometers. Also, in 5G much larger bandwidths are used to offer gigabits of throughput, hence a higher dependency on a much denser fiber fronthaul, midhaul and backhaul network. Higher density fiber FH, MH and BH does not only mean more fiber cables and end points, it also means higher order of multiplexing. All of this will increase the complexity and scale of fiber testing. In the past we had a pair of fiber cable connected to a radio. This has now evolved where we are seeing twelve or more fiber pairs per RU (figure 11), a visual fault location tool will not be enough to validate fiber signal integrity. Technicians may see light at the other end but will have no way to validate a specific wavelength path is correct. Also, in a WDM system testing for correct power levels will require different set of instruments. Many fibers will drive more MPO connector deployments, which will require an MPO light source and an MPO tester. All in all, fiber field installations will be more complex with significantly more MPO and xWDM deployments, this will drive the SPs and their contractors to require simple, easy to use fiber instruments with test process automation to scale 5G deployments.

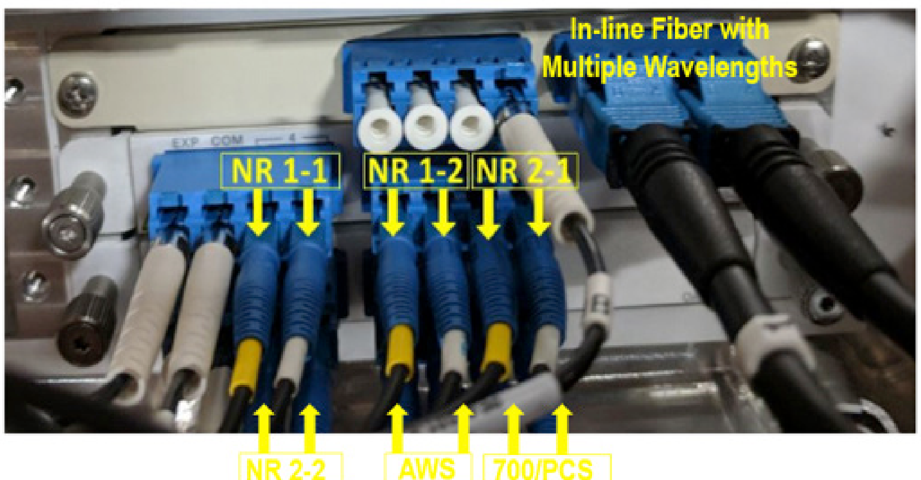



Figure 11. Fiber with multiple wavelengths in one fiber exploding into many wavelengths going to different radios

In principle, basic fiber testing and hygiene will not change but 5G will evolve fiber fronthaul testing; new test methods and solutions will be required. Some of those tests are explained below:

1. **Fiber Inspection:**

   Contaminated connectors are a leading cause of problems in fiber optic networks. A single particle mated into the core of a fiber can cause significant back reflection, insertion loss, and even equipment damage. Operators should follow the "Inspect Before You Connect" process to ensure fiber end faces are clean prior to mating connectors. For MPO connectors, MPO test solution like Sidewinder can be used.

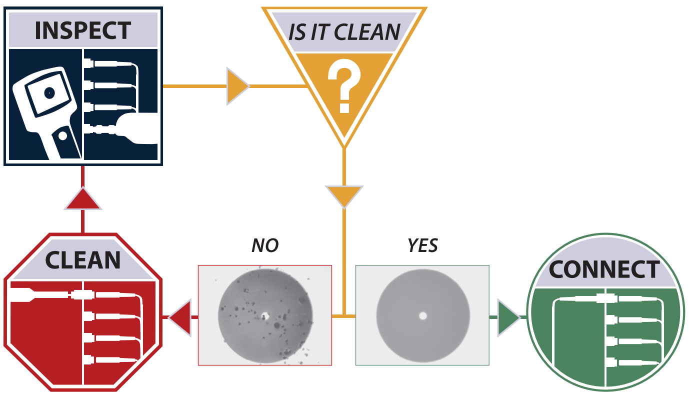



Figure 12: Inspect Before You Connect process

Figure 13: VIAVI FiberChek Probe and Sidewinder

2. **OTDR Test:**

   An optical time-domain reflectometer (OTDR) allows technicians to detect, locate, and measure events on fiber links such as mated connectors, splices, bends, ends and breaks, and the following properties can be measured by having access to only one end of the fiber (unidirectional testing):

   - Attenuation – The optical power or signal loss or the rate of loss between two points along the fiber span.
   - Event Loss – The difference in the optical power level before and after an event.
   - Reflectance – The ratio of reflected power to incident power of an event.
   - Optical Return Loss (ORL) – The ratio of the reflected power to the incident power for an optical link.

   The VIAVI SmartOTDR allows technicians at any skill level to perform all essential fiber tests. The Smart Link Mapper (SLM) application displays each event as an icon, giving technicians a schematic view of the entire link, helping them use an OTDR more effectively, without the need to be able to interpret and understand OTDR trace based results.

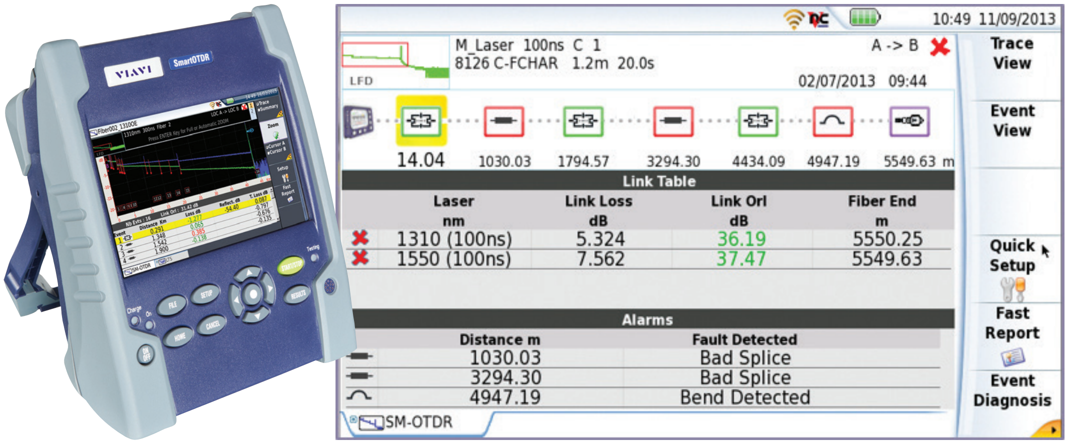



Figure 14: SmartOTDR and SmartLinkMapper application6 Test guide to 5G network deployment

In order to more accurately characterize fiber links and individual events, and to try to uncover additional events that may have been concealed by an OTDR's own dead zone performance when testing unidirectionally, dark fiber providers or the fiber owner/operator can perform bi-directional tests. This allows for more accurate measurement of events (losses and reflections, etc.), and to confirm they are the same in both directions, there are situations due to fiber tolerances, mismatches or splicing that can result in excessive or differing optical losses (or apparent gains) when viewed from different directions.

Keep in mind you can never be 100% sure what direction of service a fiber will be used for when it is installed. A lot of applications are dual fiber with one Tx and one Rx fiber, but there are also single fiber implementations with different wavelengths being used for Tx and Rx on the same fiber in opposite directions.

VIAVI FiberComplete™ is an all-in-one, automated and single test port solution that tests bi-directional insertion loss (IL), optical return loss (ORL), and OTDR.

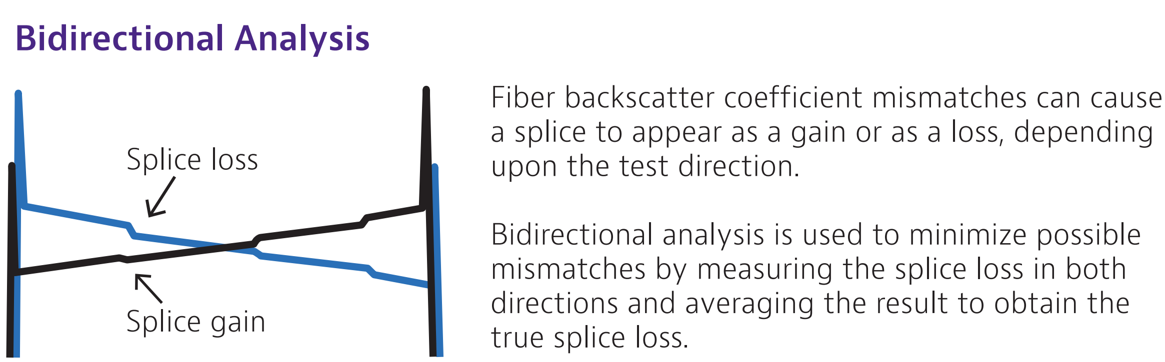



Figure 15: FiberComplete application

## WDM (Wavelength Division Multiplexing)

WDM allows service providers to increase capacity by adding new equipment at either end of a fiber strand and combine multiple wavelength/channels on a single fiber strand. Multiplexers are used to combine wavelengths onto a single fiber, and demultiplexers are used to separate the wavelengths are the other end. There are four main technologies employed:

1. **Coarse Wave Division Multiplexing (CWDM)**, provides up to 18 channels (or wavelengths) on a single fiber to allow for higher capacity. CWDM networks are typically passive with no active amplifiers in order to save cost and complexity. Due to the wider channel spacings it can utilize cheaper components (SPF transceiver Tx/Rx, MUX/DeMUX and filters) which again makes it cheaper to deploy. Keep in mind that a key driver for access networks is price/cost. In addition, with only 18 channels, it is easy to manage and maintain (there are only 18 variations of SFP to manage during deployment and maintenance). Passive CWDM is typically only used for distances up to 80km, however, for distances between 40 to 80km there can be a reduction in the number of usable channels to only the upper 8, this is because of the fiber's attenuation of wavelengths below 1470nm due to things like water peaks. The losses per wavelength across all the transmission bands are known as the fiber's attenuation profile (AP). The AP varies between fibers and fiber types and will partially dictate the number of useable channels which will have an impact on capacity scalability. Low water peak fiber has been available for some time but unless you are certain about the fiber in the ducts it is best to check. Ultimately for passive links the optical budget of the transceivers, passive element losses, splice/connector losses and the fiber's AP (i.e. optical loss per wavelength per km) will define the max link length achievable.

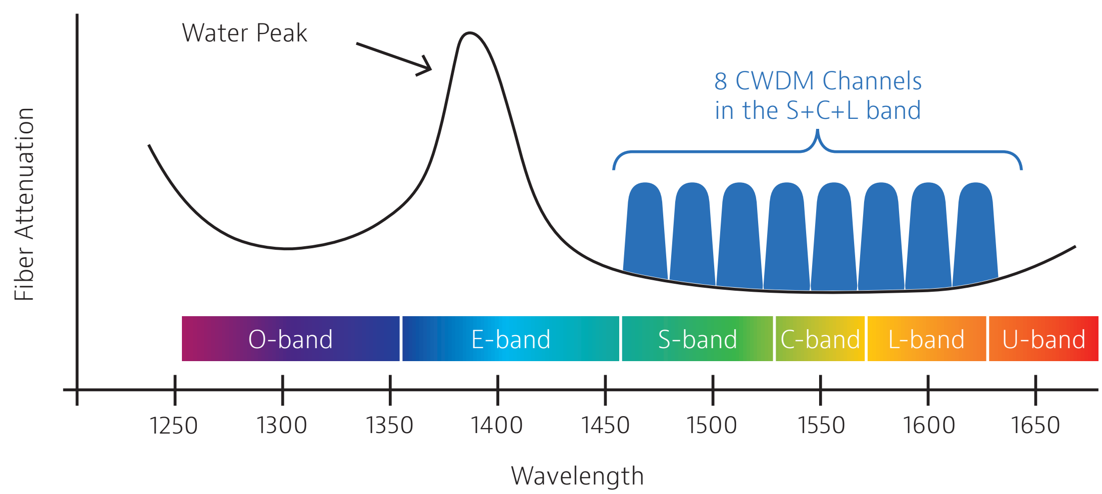



Figure 16: CDWM channels in the S +C +L band

2. **Dense Wave Division Multiplexing (DWDM)**, provides up to 96 channels per fiber depending on the spacing used. Spacing of 100 GHz is still the most common, but today's DWDM systems can support 50 GHz (0.4 nm) and even 25 GHz spacing with up to 160 channels is possible. To put this in perspective, CWDM has a spacing of 20 nm per channel. DWDM networks can be passive or active, which approach is used will depend mostly on the distances involved, current data requirements and future capacity need. As for passive WDM the maximum distance for passive DWDM system will depend on the transceiver's optical budget and the fiber loss per km for each wavelength (its AP).

3. **Hybrid CWDM & DWDM (xWDM)**, provide the possibility to expand the capacity of CWDM infrastructure by using an appropriate CWDM channel to accommodate multiple DWDM wavelengths. In this hybrid environment, the DWDM wavelengths typically use 100GHz spacing, this is for two reasons, first; to allow for small drifts in transmitted wavelengths so filtering doesn't impact other services and second; to keep the cost of transceivers, filters, and MUX/DeMUX to a minimum allowing for the utilization of cheaper components with wider tolerances.

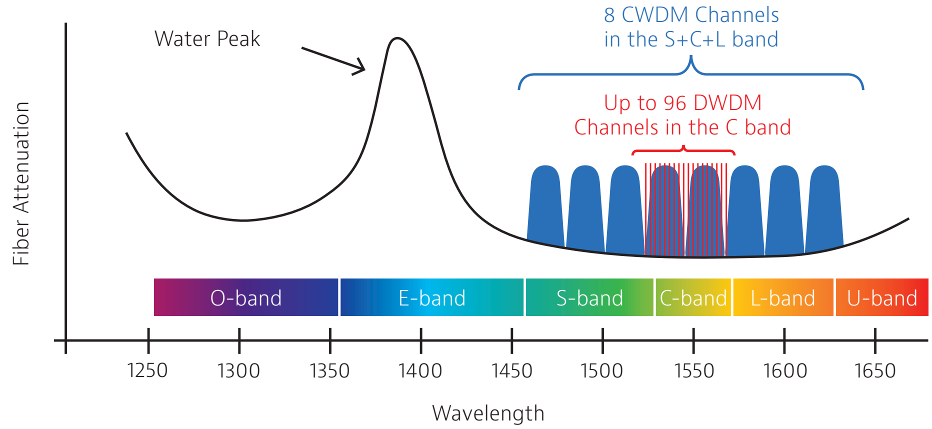



Figure 17: Hybrid CWDM and DWDM

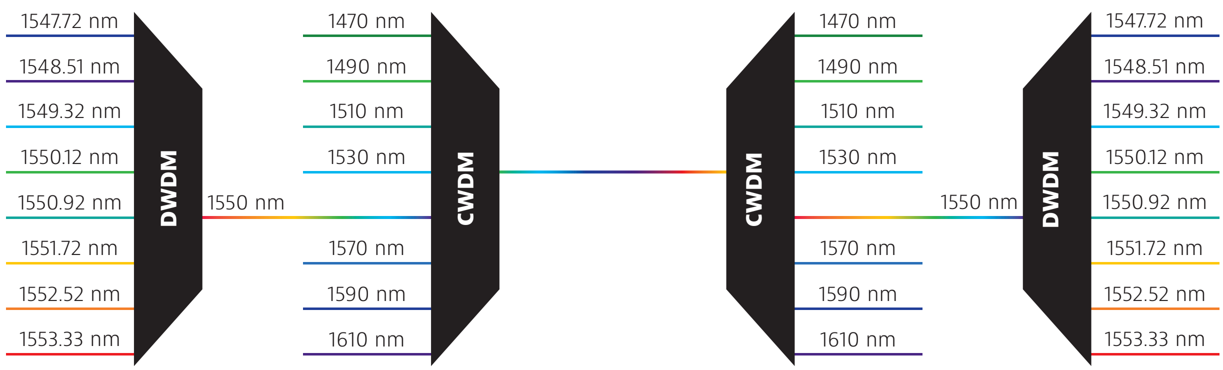



Figure 18: Example of 8 DWDM channels (100GHz spacing) added to an existing 8-channel CWDM network8 Test guide to 5G network deployment

4. **Passive Optical Network (PON)**, is a point to multi-point architecture using passive splitters to serve more end devices in the mid haul (Central Unit (CU) to Distribution Unit (DU)). Network architectures with single verses cascaded splitters are possible however, the actual split ratios will vary according to the distances involved and the optical loss budgets for transmitters/receivers (OLT/ONT).

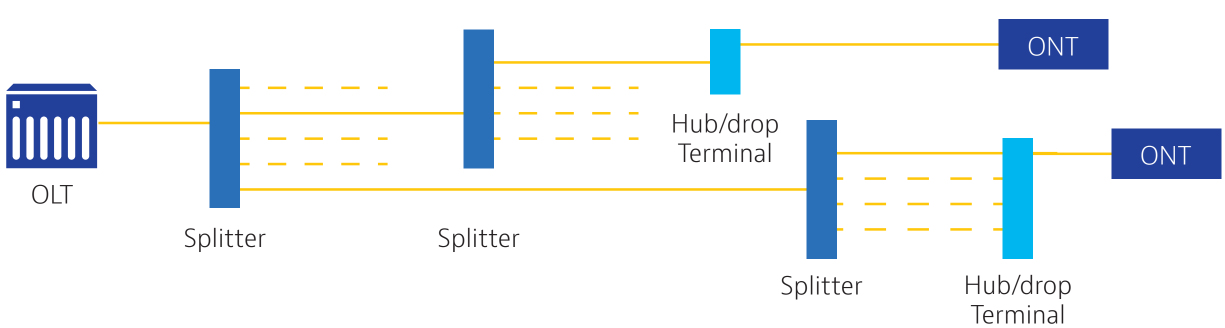



Figure 19: Cascade split PON architecture9 Test guide to 5G network deployment

Probably the biggest impact on split ratio will be down to the data capacity required for each DU and the PON standard used – keep in mind that PON services are shared services. As a rough example XGS-PON can deliver a symmetrical 10Gbps service, if each DU requires a fixed 1Gbps then an XGS-PON service can support 10 DU, so a 10-way split. It is a little more complicated than that. You may be able to support more DUs with an XGS-PON service once you consider average vs. peak data requirements per DU (plus headroom) and by using future PON features like Dynamic Bandwidth Allocation. Distances of between 40-60km can be achieved and newer PON standards like NG-PON2 can deliver a symmetrical 40Gbps capacity via use of multiple 10G wavelengths both up and downstream. This should suffice for the short to medium terms. Longer term, eCPRI will demand 25G PON on a single wavelength instead of the 10G PON being offered today.

## xWDM Test

It is expected that most of the fiber network infrastructure will be upgraded to take advantage of higher multiplexing technologies to offer higher throughput. However, testing xWDM networks is not trivial, especially since DWDM channels are so close, DWDM transmitters require precise temperature control to maintain wavelength stability and operate properly, and wavelength filters must do their job of passing the correct wavelength while blocking others. This means that an issue with one channel could easily create issues with the channels on either side, making testing and maintaining DWDM networks more complex. DWDM networks must be tested for loss, connector cleanliness, and spectral quality. The following tests are essential for xWDM networks.

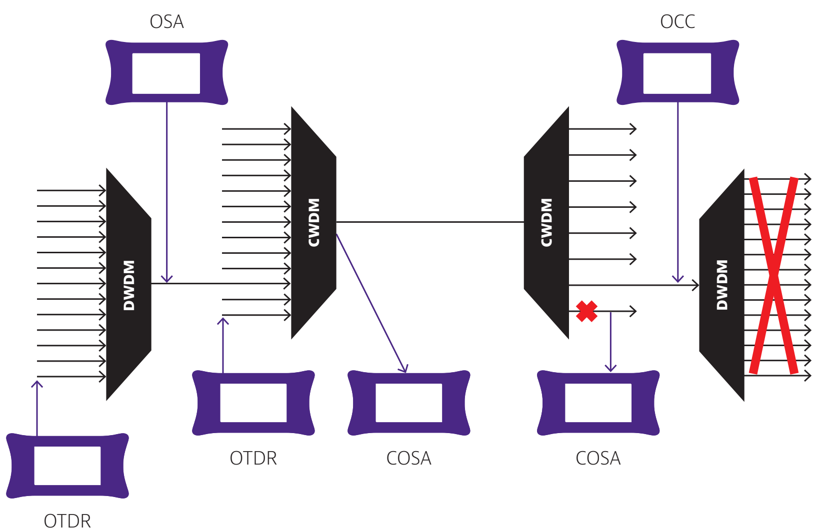



Figure 20: xDWDM testing

## Channel Check

A CWDM or DWDM power meter (aka Optical Channel Checker (OCC)) such as the VIAVI OCC-55 (CWDM) and OCC-56C (DWDM) can be used to perform basic checks for wavelength presence and power levels to validate correct wavelength routing.

A small form factor CWDM or DWDM optical spectrum analyzer/optical channel checker, COSA (CWDM) and OCC-4056C (DWDM) 4100 series module for the T-BERD/MTS-2000, 4000, 4000 V2 and 5800 V2 mainframes, can also be used to perform the same wavelength presence and power level checks. However, with the added capability to report ITU-T channel numbers, technicians can quickly measure actual wavelength to check for drift or offset and report actual channel spacing (particularly important for DWDM). While dual integrated SFP bays allows technicians to verify wavelength/channel of colored and tunable SFPs which also provides the option to become a tunable light source which can be used for link routing/insertion loss test.


Figure 21: OCC-55

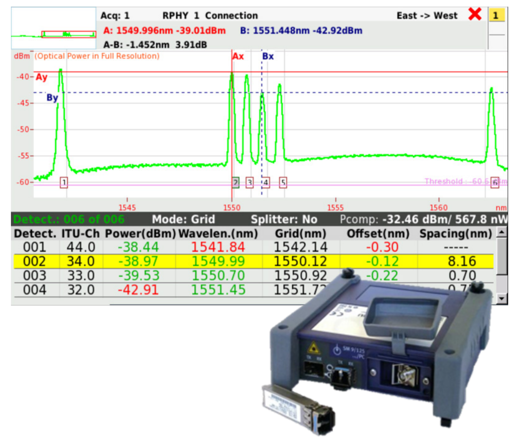



Figure 22: OCC-4056C DWDM Optical Channel Checker Module10 Test guide to 5G network deployment

## WDM OTDR Test

A CWDM or DWDM OTDR such as the VIAVI 4100 series CWDM and DWDM OTDR modules, for the T-BERD/MTS-2000, 4000, 4000 V2 and 5800 V2 mainframes, can be used to validate a core fibers ability to transport all the xWDM wavelengths during build certification and prior to the connection of the WDM MUX/De-MUX. They can also be used after MUX/De-MUX connection to validate the end to end wavelength routing and losses for specific wavelengths or for maintenance and troubleshooting to expose and locate any bends, breaks, bad connectors or splices. Standard OTDRs using traditional 1310/1550nm wavelengths for test can't be used for this second level of testing due to the wavelength filtering implemented in the MUX/DeMUX devices.

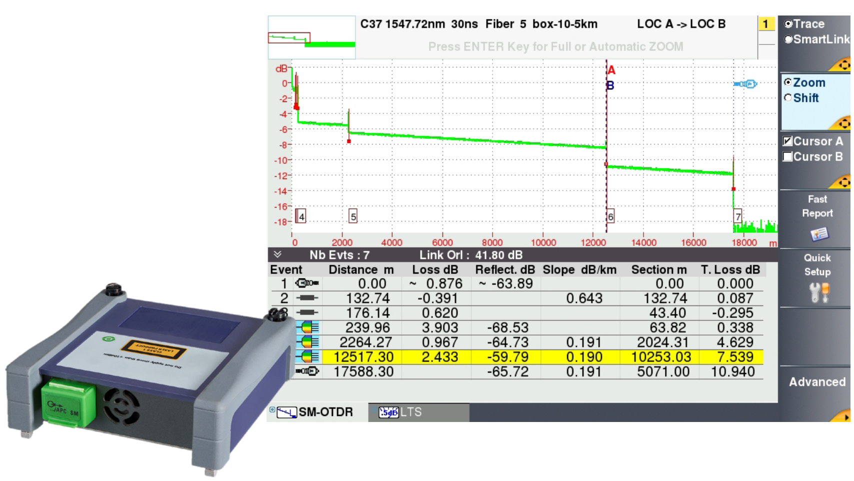



Figure 23: DWDM OTDR Module

## PON OTDR Test: During Fiber Build/Laying/Construction

A CWDM or DWDM OTDR such as the VIAVI 4100 series CWDM and DWDM OTDR modules, for the T-BERD/MTS-2000, -4000, -4000 V2, and -5800 V2 mainframes, can be used to validate a core fibers ability to transport all the xWDM wavelengths during build certification and prior to the connection of the WDM MUX/De-MUX. They can also be used after MUX/De-MUX connection to validate the end to end wavelength routing and losses for specific wavelengths or for maintenance and troubleshooting to expose and locate any bends, breaks, bad connectors or splices. Standard OTDRs using traditional 1310/1550nm wavelengths for test can't be used for this second level of testing due to the wavelength filtering implemented in the MUX/DeMUX devices.

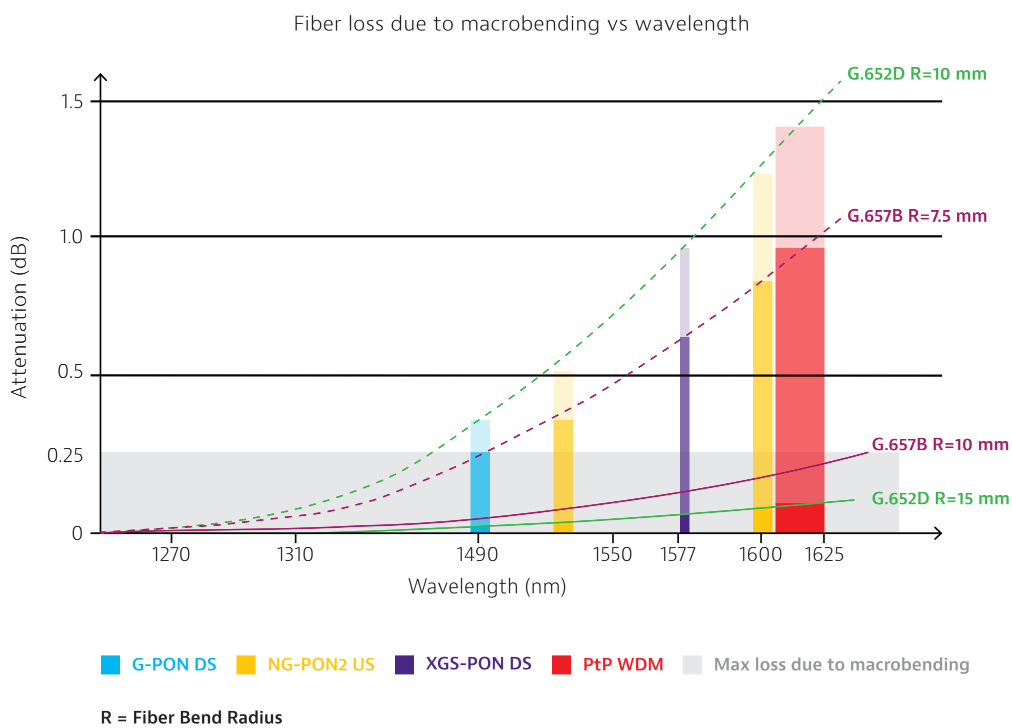



Figure 24: Bending losses – Wavelength vs Fiber Type for minimum bend radius

For improved accuracy of OTDR results, it is highly recommended to perform bi-directional tests. This allows technicians to identify potential faults that might be hidden by OTDR dead zones. Bi-directional tests will certify fiber performance in both directions (remember PON fibers carry light in 2 directions, up and downstream). Automation of the bi-directional testing and reporting process, presenting results in an easier to read format (Smart Link Mapper), along with performing tests via a single test port will significantly reduce test time, improve test workflow and reduce complexity (i.e. the risk of mistakes and re-test). VIAVI FiberComplete solution automates bi-directional IL, ORL and OTDR fiber certification.

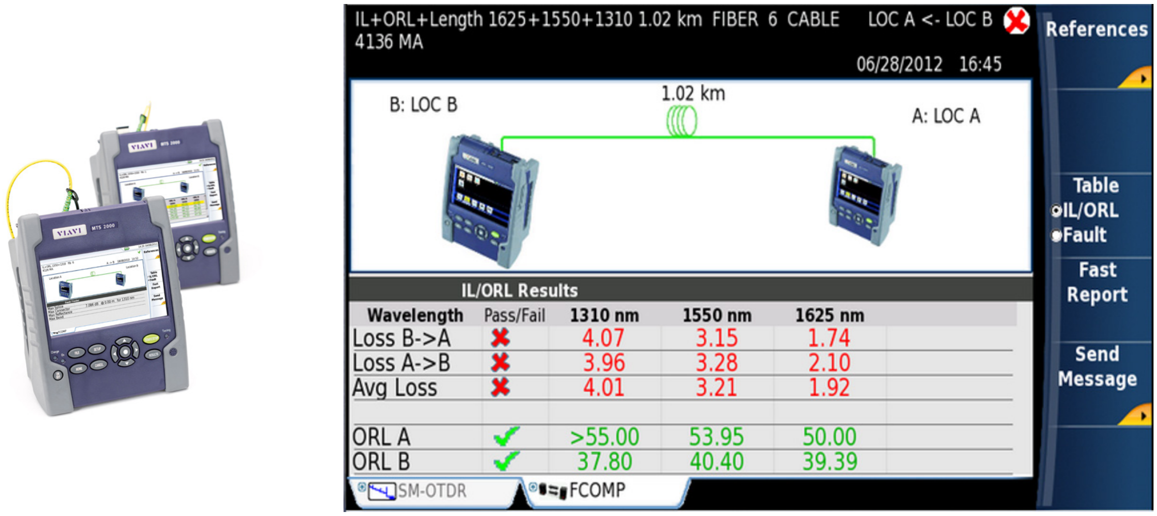



Figure 25: FiberComplete for T-BERD/MTS-2000, -4000 V2, -5800 V2

After connection of splitters, OTDR certification is required to confirm the final PON build. Technicians are required to check total end-to-end losses including splitter losses. This is typically carried out uni-directionally from the ONT (Optical Network Terminal)/ONU (Optical Network Unit) side of the network, looking back towards the local or central office, using an OTDR which utilizes a multiple pulse acquisition technique coupled with a dedicated PON/FTTx test application in order to test through splitters (single or cascaded) and characterize all sections of the PON. A single FiberComplete unit with the FTTH-SLM application OR a SmartOTDR with the FTTH-SLM application has these capabilities.

Figure 26: SmartOTDR

The Smart Link Mapper (SLM) application displays each event as an icon, giving technicians a schematic view of the entire link, helping them use an OTDR more effectively, without the need to be able to interpret and understand OTDR trace based results. The dedicated SLM version for FTTH/PON uses specific naming, labels, and icons unique to PON environments.

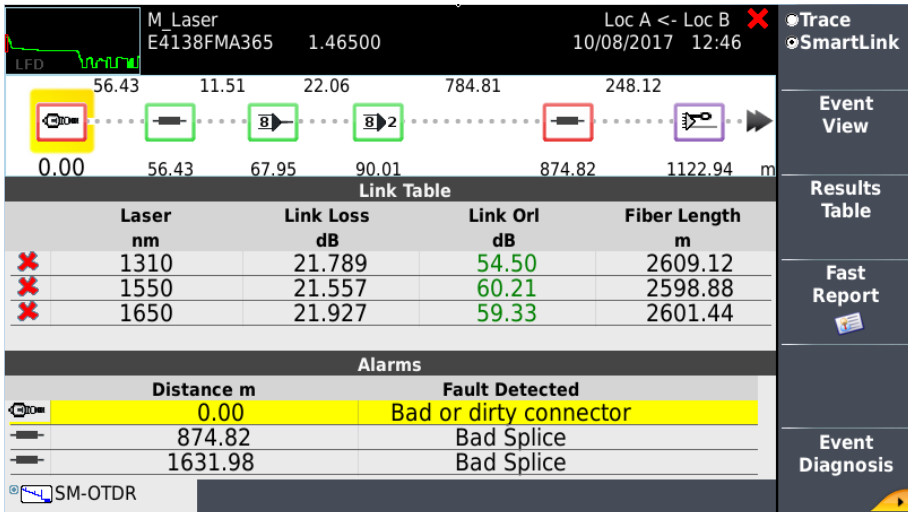



Figure 27: FTTH-SLM

## Optical Power Measurement: During Network Activation

As part of PON network activation technicians must validate that downstream and upstream optical power levels are within expected ranges prior to final connection of ONT/Cell/Radio. For 5G it's anticipated that XGS-PON and then NG-PON2 will be adopted while future standards such as 25G-PON are considered by the ITU-T and IEEE standards groups. For G-PON and XGS-PON or NG-PON2 the OLP-87 PON power meter can perform wavelength selective power level measurement. It also supports through mode operation and upstream burst mode measurement enabling both upstream and downstream power level measurements. It also helps in validating the ONT/ONU device by checking if the device is active and responding to the PON network equipment (OLT (Optical Line Terminal)).


Figure 28: OLP-87 G & XGS-PON or NG-PON2 Selective PON power meter

## Fiber Monitoring

As discussed earlier, PON and its variations will be used in fiber infrastructure for 5G, and as the scale of PON network will increase so will the demand for troubleshooting and maintenance. Automating physical layer tests of a PON system from a centralized location such as a mobile telephone switching office (MTSO) can reduce provisioning time and maintenance cost and can improve network quality of service. As discussed earlier, an OTDR can pinpoint the location of faults in a fiber link and certify the workmanship involved in an installation. VIAVI ONMSi (Optical Network Monitoring System) can test and certify PON during the build and construction phase and then switch to on-going monitoring for multiple PON networks during their operational phase. ONMSi allows a single technician to test the network during installation. After service activation, the system accurately detects and locates fiber infrastructure degradation, alerting operators and managers with the details of faults.

With more and more fiber being deployed, service providers are seeing a service activation failure rate of 25-30% due to improper installation of optical distribution networks (high loss splices/connectors/splitters, macrobends, wrong splitter/port connection, etc.). A fiber monitoring capability maximizes responsiveness to fiber-induced failures and resulting network outages.

VIAVI ONMSi enables continuous 24x7 monitoring, detection, and localization of faults based on OTDR traces comparison. Notifications are generated by SNMP/SMS/email with attachments of OTDR traces with geo-location on Optical Fiber Mapping (OFM) or external GIS for selected FTTx topologies. ONMSI helps scale optical network deployment and maintenance. This solution can also be delivered as a point solution, SmartOTU, with all hardware and software installed in a single chassis.

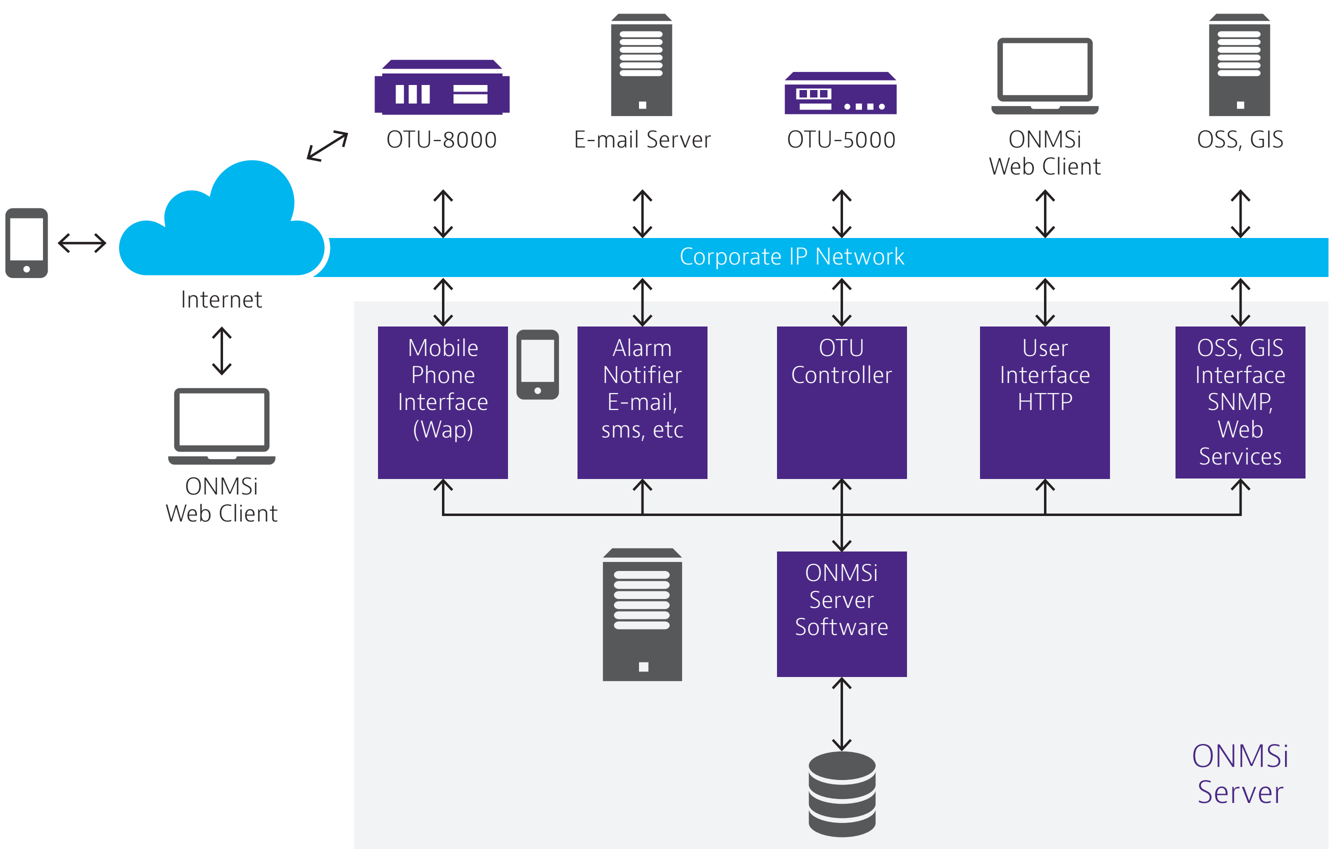



Figure 29: ONMSi solution architecture

## Conclusion

The supporting optical infrastructure serving fronthaul, midhaul and backhaul must be flexible, agile and future-proof in order to meet 5G high bandwidth demands and significantly higher cell-site density. Topology of the fiber infrastructure chosen must be considered to maximize return on investment from short-term deployment to long-term network growth models. As discussed in this paper, topology will vary with service provider business cases for deployment and access to low-cost fiber. Fundamental to fiber deployment is the maintenance and management cost of fiber infrastructure. Managing and maintaining fiber infrastructure will be a constant operational expense that must be considered at the time of deployment. Having the right test solutions for maintaining fiber networks will be key in delivering high quality of service at low OPEX. VIAVI is the industry leader in fiber test and is best positioned to deliver the most comprehensive end-to-end network test solution. With a fully-integrated portfolio of cloud-enabled instruments and systems, software test automation, and services for network testing, performance optimization, and service assurance, VIAVI is positioned to assure operators and their partners a smooth network roll-out and sustainable network lifecycle.

**electrorent.com**
**1.800.553.2255**
**sales.na@electrorent.com**

VIAVI Solutions

Contact Us **+1 844 GO VIAVI**
(+1 844 468 4284)

To reach the VIAVI office nearest you, visit viavisolutions.com/contact


fiber5g-wp-fop-nse-ae
30191002 901 0320