# Next-generation WDM technologies offer choices to meet rising bandwidth demands

**Jan Watté, Cristina Lerma Arce & Vivek Panapakkam**

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## Introduction

Transition to the cloud, smart city development, spreading deployment of the internet of things and the advent of 5G are converging on service providers and multiservice operators (MSOs) in a perfect storm. According to recent research, the world spent a combined 1.25 billion years online in 2020 alone. With 40 percent of the global population yet to connect to the internet,[i] the demand for bandwidth will only continue to grow.

Historically, the answer to the bandwidth crunch has been to lay more fiber. This is due, in part, to a couple of factors. Firstly, network operators have, for decades, worked tirelessly to build out their fiber plant—the end goal being an all-FTTH outside plant (OSP) theoretically capable of delivering as much capacity as an end user would need.

**In 2020, the world's internet users spent a cumulative 1.25 billion years online.**

**Source: Digital Trends 2020, thenextweb.com**

Secondly, and perhaps more importantly, for all but the largest MSOs, there were few other commercially feasible options for keeping up with the explosive demand for bandwidth. So, while trenching and laying fiber is expensive and can be highly disruptive, especially in densely populated urban areas, more fiber made the most sense.

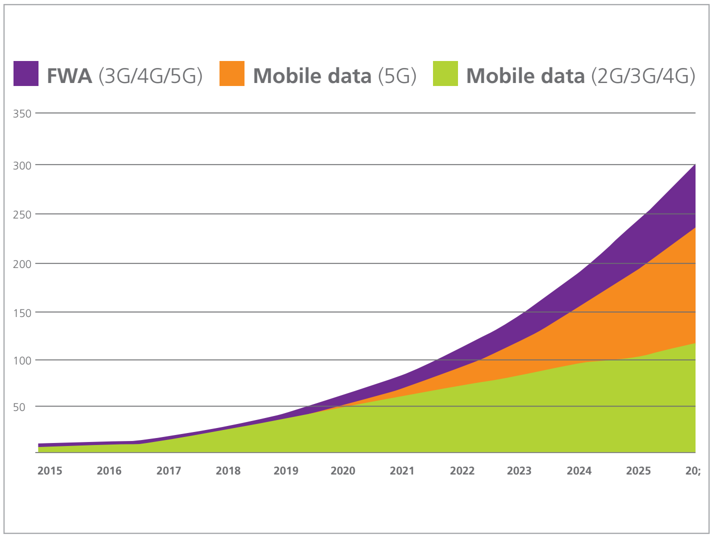


**Figure 1: Global mobile network data traffic (EB per month)**
Source: Ericsson Mobile Data Report, June 2021

The exceptions, as noted, were the largest MSOs that could afford to invest in wavelength division multiplexing (WDM) technology and have been doing so since the 1990s. Currently, WDM is a core strategic component within the OSPs of nearly all tier-1 MSOs in the U.S. and many of the largest cable providers globally.

Now, recent developments in WDM performance, form factor and OSP integration have made the technology commercially attractive across the board, from tier-2/tier-3 cable providers to wireless networks. This new generation of WDM solutions gives network operators a powerful tool that can be used either instead of, or in addition to, laying more fiber.

## About WDM and its evolution

WDM is a technique that allows network operators to multiplex several optical carrier signals onto a single optical fiber by using different optical wavelengths (i.e., colors) of laser light. Each wavelength carries an individual signal that does not interfere with the other wavelengths. WDM enables bidirectional communications over one strand of fiber, as well as multiplication of capacity. It has become the preferred option in telecommunications because it enables the network to increase the bit rate and increase the effective bandwidth without having to add more fiber.

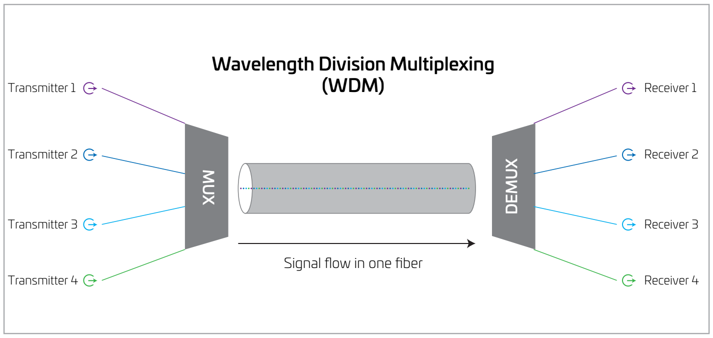


**Figure 2: At the transmitter site, 4 signals with different wavelengths are multiplexed and propagate along the same fiber to the receiver site where they are demultiplexed.**

Tier 1 cable operators first began to use WDM in their inside and outside plant networks in the 1990s. Since then, WDM solutions have become more compact and easier to install, more flexible in terms of their capabilities and, perhaps most importantly, significantly less expensive, and are gaining traction with many communications service providers. Furthermore, WDM can be integrated in coexistence elements to provide an alternative to combo cards. This enables operators to deliver multiple PON services with different requirements for upstream and downstream wavelengths and line rates over the same outside plant infrastructure.

For mobile networks, WDM technology has an important role to play in supporting the deployment of more cell sites to allow for cost-effective RAN architectures. In a recent market forecast, Allied Market Research explained:

> *"Long-haul networks, proliferation of cloud computing, deployment of WDM equipment in Metropolitan Area Network (MAN), and surge in investments on advanced networking infrastructure drive the WDM equipment market. Moreover, ongoing efforts of telecom companies to upgrade their network infrastructure with performance-enhancing network technologies and rise in investment on long-haul, metropolitan areas, and access network globally present numerous opportunities for market expansion."* [ii]

## Coarse WDM vs dense WDM

**Because DWDM can be overlaid over the same link where CWDM is used, network operators can easily upgrade from CWDM to DWDM without significantly impacting their existing fiber infrastructure.**

WDM is segmented into two main technologies, coarse wavelength division multiplexing (CWDM) and dense wavelength division multiplexing (DWDM). Each uses different wavelength patterns for different applications.

CWDM (Coarse Wavelength Division Multiplexing) typically supports 4-, 8-, 12- or 16-channel multiplexing, with each wavelength ranging from 1270 nm to 1610 nm and a 20 nm channel spacing. The great benefit of using CWDM is that it allows for using cheaper lasers, although amplification of the signal is not possible in the entire transmission band. This technology is ideal for short-range communications as it is compact and cost-effective.

Alternatively, DWDM (Dense Wavelength Division Multiplexing) typically can support up to 96 channels in the 1550 nm region (C-Band), with a channel spacing of only 0.8 nm (for 100 GHz). This narrow channel spacing requires temperature-controlled lasers (which are more expensive) but at the same time allows for the use of EDFAs (Erbium-doped Fiber Amplifier) to amplify the entire 1550-nm of C-Band spectrum commonly used in DWDM applications. As a result, DWDM allows a significant amount of data to travel along a single network link, making it ideal for long-haul transmission.

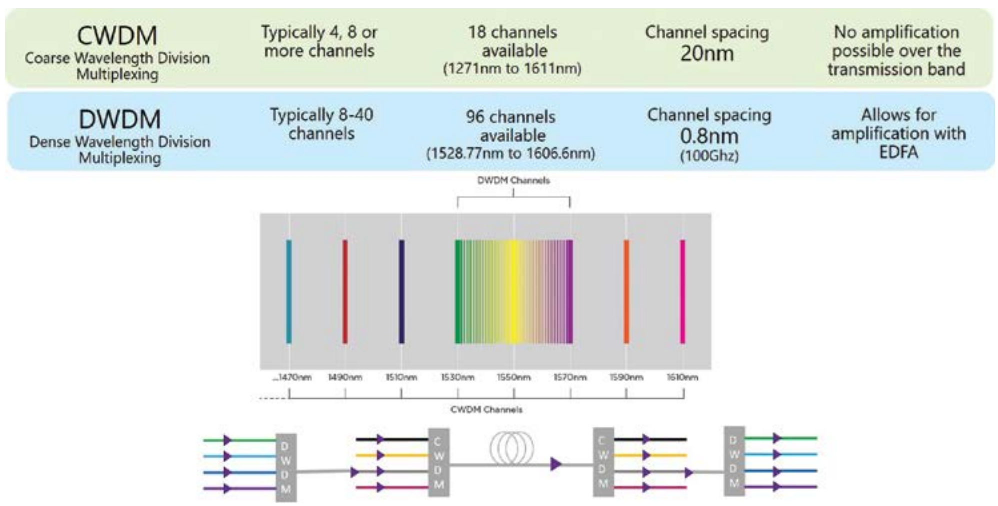


Figure 3: Number of channels and channel spacing for coarse and dense WDM

## Advances in WDM technologies provide more compact solutions

The industry has seen two major trends that will continue to drive the future solution requirements: more fiber is needed to keep up with bandwidth capacity expansion and to reduce the footprint for both inside plant and outside plant solutions. The need for smaller frames, panels, closures and terminals is driving development of more compact WDM devices or device assemblies that can be installed inside. So, while 3-port thin film filter (TFF) WDM, also known as FWDM, technology (discussed below) had been the preferred DWDM technology, newer designs including smaller free-space compact dense WDM (CDWDM) devices and athermal arrayed waveguide grating (AAWG) technology are quickly gaining traction. In addition to closures and terminals, these WDM devices can also be installed in optical distribution frames—providing operators the flexibility to cross over between different PON deployments.

The following is an overview of some of the most-promising WDM options with their pros and cons.

### 3-port TFF WDM (FDWM)

The 3-port FWDM is based on thin film filter (TFF) technology. It consists of a tubular device with one input and two outputs (one for the transmitted light and another for the reflected light). A TFF is sandwiched between a pair of collimating gradient index (GRIN) lenses, so that the light impinging the filter is collimated and transmitted or reflected by the TFF in an efficient way. The TFF wavelength in each tubular device will define the DWDM channel wavelengths.

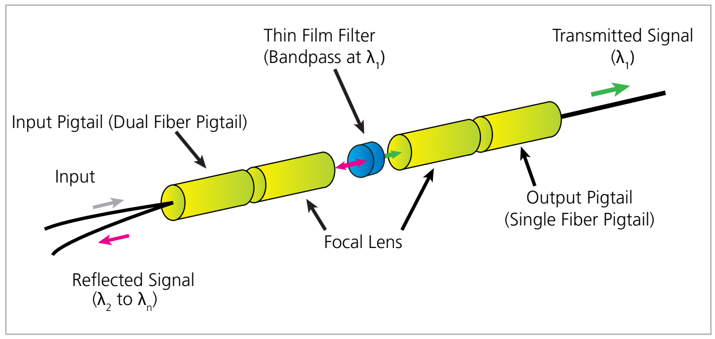


Figure 4: Layout of a 3-port filter WDM

A key benefit of the 3-port FWDM device is very low insertion loss, around 0.6 dB per filter. This makes the technology a good candidate for use in cascading devices. The CommScope NG-4 cassette in Figure 5, for example, incorporates twelve 3-port TFF devices supporting multiple channel DWDM capabilities.

Figure 5: FWDM cascade within the CommScope NG-4 cassette

In addition, FWDM is also characterized by a wide operating wavelength range and excellent channel isolation. An important application for the technology, therefore, has been the delivery of triple-play services in cable networks.

The main drawback of the FWDM technology is the arduous manual assembly it requires. A 12-channel DWDM device requires twelve 3-port tubular devices. Each must be correctly and sequentially cascaded via 11 successful fiber splices. The number of components in a cascaded device scales with the number of channels, which can be as high as 40 channels, and, consequently, insertion losses, footprint and costs scale as well.

### Free-space CDWDM

An alternative to the FWDM technology is the free-space compact dense WDM (CDWDM) technology. Free-space CDWDM uses free-space propagation of light before and after being filtered by a TFF. Incoming light from the input port propagates in free space until it finds a first TFF filter. After passing through the filter, the narrow-band signal is redirected to the output port corresponding to the first wavelength channel. The rest of the spectrum is reflected by the TFF filter and redirected to a second filter.

The optical losses of a free-space CDWDM device are typically less than 2.5 dB for a 12-channel device. Most importantly, the optical losses do not scale severely as the number of ports increases, giving an advantage over the fusion-spliced cascaded FWDM for some applications. The footprint also is extremely compact (about 5x3 cm), enabling it to be easily integrated into a small subassembly as shown in Figure 6.

The quality of the packaging of CDWDM devices has become outside plant robust and the assembly processes have improved to achieve high yields. Further improvement of the assembly procedures will favor lowering the cost and will allow it to become more cost-effective than state-of-the-art FWDM cascades.

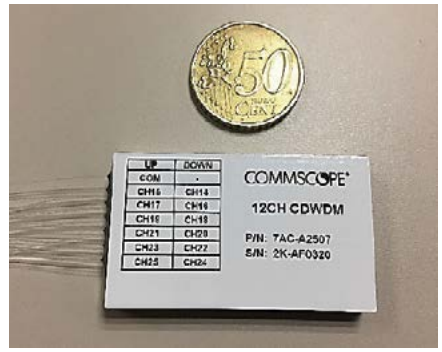


**Figure 6: 12-channel free-space CDWDM**

## AAWG

An arrayed waveguide grating (AWG) is an integrated interference-based device that consists of one input and several output ports, two regions of free-space propagation and a grating of waveguides with a constant incremental length (see Figure 7).

Light is coupled into the device via an optical fiber connected to the input port and propagates through an input waveguide until encountering a free-space region. The light diffracts and illuminates the grating of waveguides, which have different lengths. The length differences in the grating create a constant phase change within each wavelength until the light is diffracted to the second free-space propagation region. Here, constructive interference refocuses the light signal at the output waveguides.

Typically, interference-based devices are temperature dependent. Significant innovations in thermal design have led to development of an athermal AWG device (hence, AAWG) designs. Current AAWG technology is now available as wafer-scale integration while the assembly process is fully automated and scalable to very high volumes. The per-channel footprint is also extremely compact (≈ 7 x 12 cm for 48 channels) with up to 96 channels possible. Furthermore, insertion loss remains uniform, irrespective of the channel count.

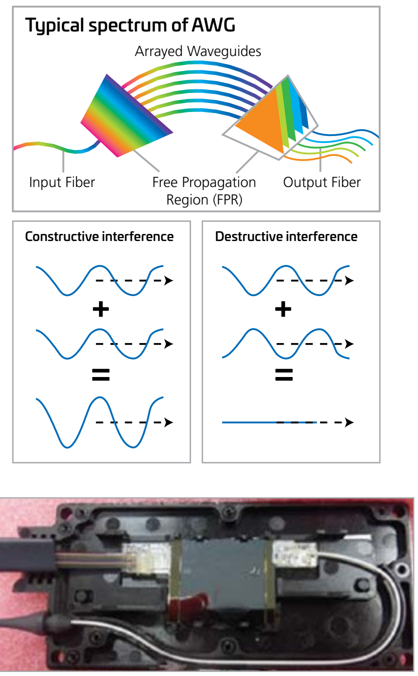


**Figure 7: Layout of an AWG multiplexer and picture of an AWG chip inside a device**

On the other hand, overall insertion loss performance (~5 dB for a 48-channel device) and isolation and polarization dependent loss is not yet on par with the FWDM or free-space CDWDM technologies. Despite the considerable strides made in the athermalization of these devices, packaging and long-term reliability are still being validated before they can be deployed in outside plant applications.

An appealing aspect of AWG device technology is that a properly designed cyclic filter can route a wavelength in different adjacent bands separated by a dedicated Free Spectral Range (FSR) (see Figure 8). The cyclic nature allows for smooth capacity upgrades or for specific universal filter designs capable of (de) multiplexing bands with a dedicated FSR.

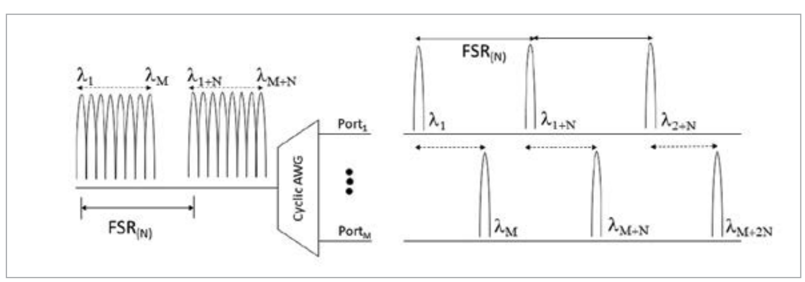


**Figure 8: Working principle of a cyclic AWG**

## Technology comparison

The following table gives a comparative overview of the technologies explained above:

| Feature | FWDM (Ref) | CDWDM | AAWG |
|---|---|---|---|
| Size vs. Port Count | Large footprint | Very compact packaging Butt-style advantage | Fully integrated chip and compact packaging |
| Port Count | 40-48 channels | 16-18 channels | 4-96 channels |
| Loss | Non-uniform and increasing with channel count | Uniform and low | Uniform and medium-low |
| Assembly Complexity | Complex fixed splicing schemes, fiber and component dense cassettes | Strict tolerances for the lens and filter positions, reflection angles | Automated assembly and packaging |
| Robustness | ISP and OSP | ISP and OSP | ISP and OSP |

Good
Better
Best

Table 1: Comparison of FWDM, free-space CDWDM and AAWG optical multiplexing technologies

# WDM Use Case Examples

## Coexistence of multiple PON standards: GPON, XGS-PON and NG-PON2

The higher bandwidth demands of 5G and other emerging technologies have led to the development of XGS-PON in addition to NG PON-2. XGS-PON operates at a downstream wavelength band of 1575-1580 nm and an upstream wavelength band of 1260-1280 nm compared to upstream traffic allocations in the band 1524-1544 nm and downstream in the band 1596-1602 nm for NG PON-2. WDM technology is a key enabler for operators who want to support simultaneous upstream and downstream traffic on a single fiber strand. Meanwhile, increased deployment of coexistence modules, which are essentially passive couplers, are enabling operators to support multiple services on a single fiber. Today, this includes delivering GPON, XGS-PON and NG-PON2 over the existing PON fiber infrastructure without changing the outside plant (see Figure 9).

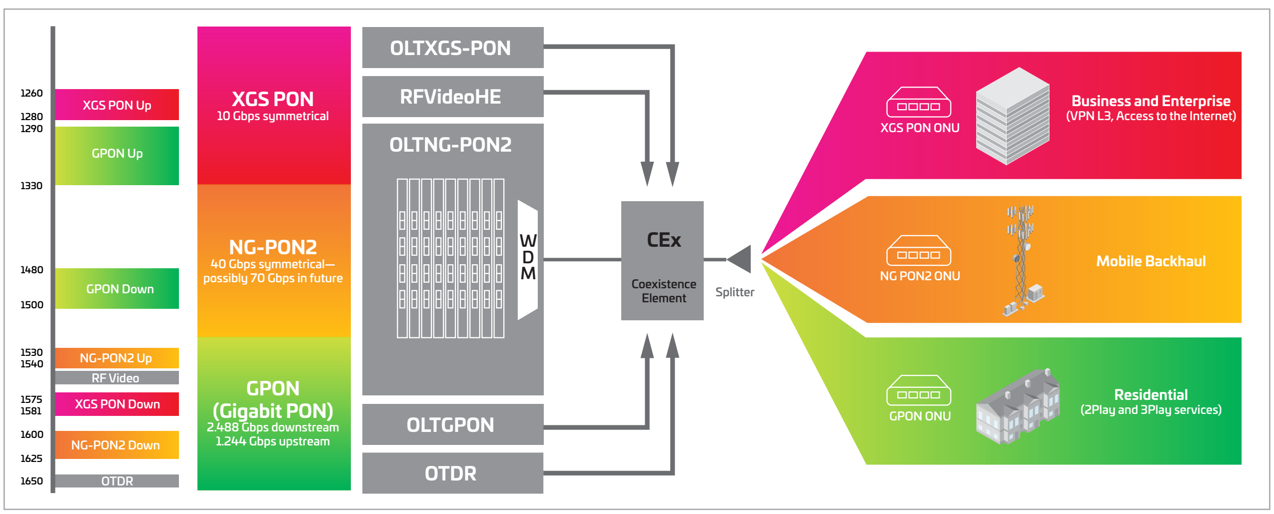


Figure 9: WDM implementation allowing for PON cross over scenarios

When added to subassembly components in optical distribution frames, WDM devices offer a passive, highly flexible solution for upgrading from one passive optical network scenario to another. It also provides another tool for supporting OTDR fault diagnostics. This enables operators to perform remote troubleshooting from the central office to identify network problems in the outside plant. Finally, the ability to turn specific capabilities and elements on and off with a mouse click gives network managers the agility to respond to traffic issues, capacity surges and faster turn-up of new services.

The benefits of WDM-enabled GPON, XGS-PON and NG-PON2 are well documented but hardly limited to these two specific PON standards. In the future, WDM will also allow for the coexistence of other new PON standards as they continue to evolve, helping to make the fiber network future-proof.

### Small cell support and a more efficient C-RAN

WDM technology is also poised to help mobile providers transition to C-RAN architectures and lay the foundation for more cost-effective and emerging broadband topologies driven by 5G (see Figure 10). As mobile operators continue to densify their networks with small cells, the fiber fronthaul—the link between a centrally located base band unit (BBU) and the radio at a remote cell site—becomes increasingly important. Because of the huge numbers of new small cells required, the centralized RAN serves as a critical hub within the front haul network. To handle the increased traffic, however, networks typically require 4-6 channels at each small cell location. Serving up those connections with dedicated fiber runs is cost-prohibitive, but it can be more efficiently accomplished by installing WDM-enabled field terminals and closures (see Figure 11).

### WDM use cases in the RAN

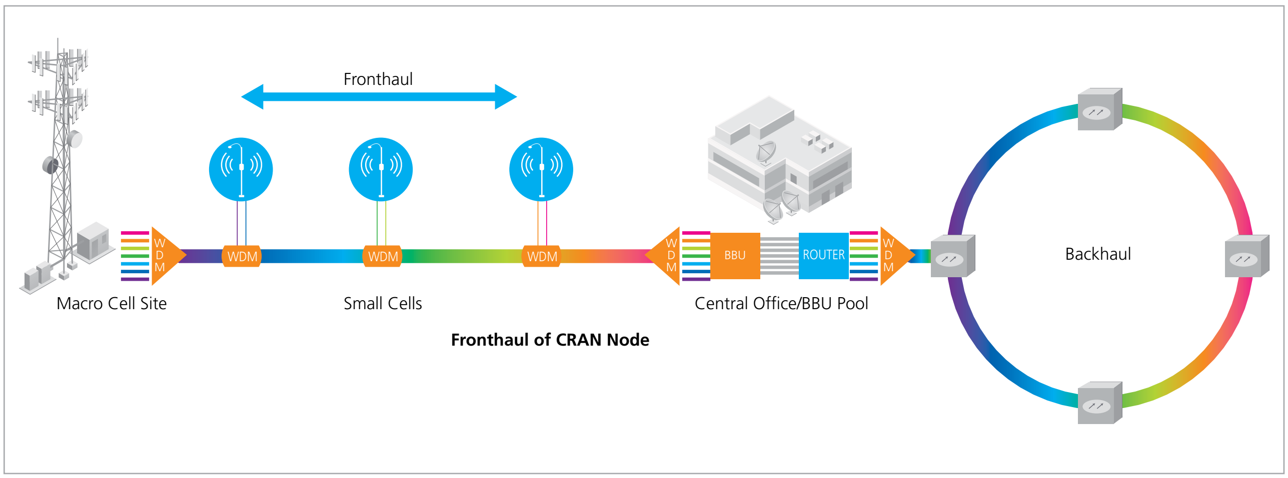


Figure 10: Fronthaul of CRAN Nodes

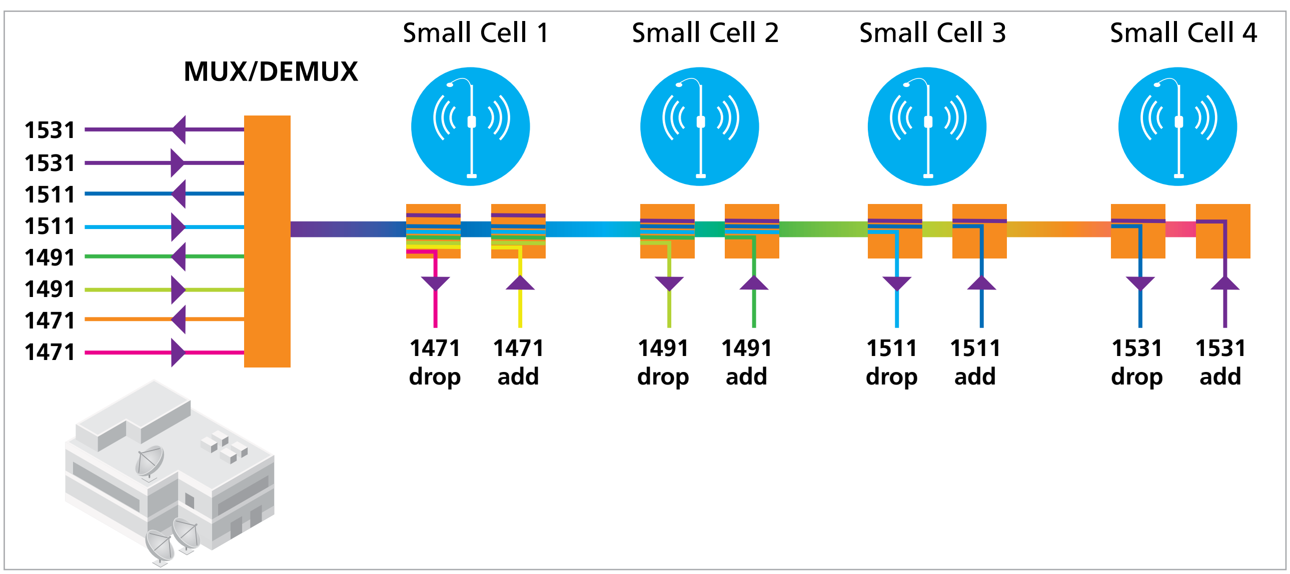


Figure 11: Cell site connectivity with optical add/drop modules

## Conclusion

WDM is not intended as a replacement for fiber, nor is it capable of doing so. The real benefit of WDM is its ability to add significant value and bandwidth potential to the existing fiber plant already installed.

In recent years, accelerating developments in multiplexing technologies have opened up new opportunities for operators to add capacity without necessarily having to lay more fiber. With compact DWDM and AWG technologies, next-generation passive optical devices offer more options to support all ISP and OSP environments and applications where high-density housing and low footprint are critical.

## About the authors

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[i] Digital Trends 2020; thenextweb.com

[ii] WDM Equipment Market: Global Forecast 2021-2028; Allied Market Research; November 2020

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