Where Next for PON/FTTH?

The evolution of PON last-mile access networks can support high-capacity business services.

By Jon Baldry / *Infinera*

In a rapidly evolving, bandwidth-hungry, technology-driven world, demand continues to increase for ever-higher bandwidth in offices and homes. Forgetting how fast things can change is easy. Pause for a moment and think about how the bandwidth in your home has changed over the years.

What bandwidth speeds do you have today? What did you have 10 years ago? If you are old enough to remember, what did you have 20 or so years ago when broadband networks first appeared, and there was a shift away from dial-up internet access? Networks have evolved considerably, and there is no sign of bandwidth growth slowing down.

As capacity demands in homes outstrip the capabilities of older, copper-based, digital subscriber line (DSL) technology, fiber-to-the-home (FTTH)–based residential passive optical networks (PON) are rapidly becoming the access technology of choice around the globe.

Industry analysts from Omdia forecast that FTTH-based PON networks will hit 57 percent and 66 percent market penetration in Western and Eastern Europe, respectively, by 2027. In North America, where hybrid fiber-coax–based cable access remains strong and is forecast to maintain a 49 percent share in that time frame, market penetration of FTTH-based PON networks will grow to 35 percent.

CAPITALIZING ON PON INVESTMENTS

The growth in PON infrastructure is fueled by the billions of dollars being invested globally in FTTH PON infrastructure through government-led strategic national investment programs, such as the $42.5 billion Broadband Equity, Access, and Deployment (BEAD) Program in the U.S., and substantial private investment. Published analysis by network operators shows that up to 90 percent of the investment in a PON access network goes into single fiber working (SFW) infrastructure via civil works, ducts, cables and passive splitters. Only 10 percent goes into active PON hardware. Essentially, SFW infrastructure at the edge of an optical network driven by this surge in PON deployments is here to stay, and network operators need to be able to capitalize on this access infrastructure for all services – not just residential ones.

Because of the use of SFW within the PON access network, this domain is generally considered by the transport team within an operator as a separate access domain from the rest of the dense wavelength-division multiplexing (DWDM)–based optical transport network. The PON access domains are viewed similarly to a radio access network. The main task for the DWDM network is typically to provide backhaul capabilities to a PON optical line terminal (OLT). Similarly, the access team typically considers the SFW access domain as a separate optical distribution network (ODN) supporting PON technology only, with a backhaul handoff to the different DWDM transport domains.

This creates a real challenge for network operators, who can leverage their substantial investment in SFW infrastructure for residential and small/medium enterprise (SME) customers using the latest PON technology but may struggle to use this same resource for higher-capacity services such as 5G xHaul, high-capacity business services for larger enterprise customers or even backhaul of remote PON OLTs. These services can exceed the capacity PON technology offers and typically requires DWDM using coherent optics. Deploying a dedicated pair of fibers per service can make these higher-capacity services very slow, expensive to deploy, and costly for end customers. There is a better way!

CONVENTIONAL COHERENT OPTICS OVER PON CHALLENGES

Network operators' challenge is that the high-speed coherent DWDM optics needed to support high-capacity services typically can't be used over SFW networks. This is because coherent optics need a local oscillator in the receiver. Almost all modern designs use a tap from the transmitter laser to provide this, which locks the transmitter and receiver wavelengths to the same frequency. Lower-capacity 10G DWDM networks using direct-detect optics can use a different wavelength in each direction over SFW because the wideband receiver is able to receive any wavelength in the DWDM range.

But higher-speed DWDM optics above 10G rates need to be built using coherent optics and can't do the same two-wavelength technique because the receiver is locked to the same wavelength as the transmitter. 10G DWDM may provide a stopgap solution, but many service and backhaul rates already exceed 10G, and with bandwidth demands growing as fast as they are, operators need a solution that can scale beyond 10G.

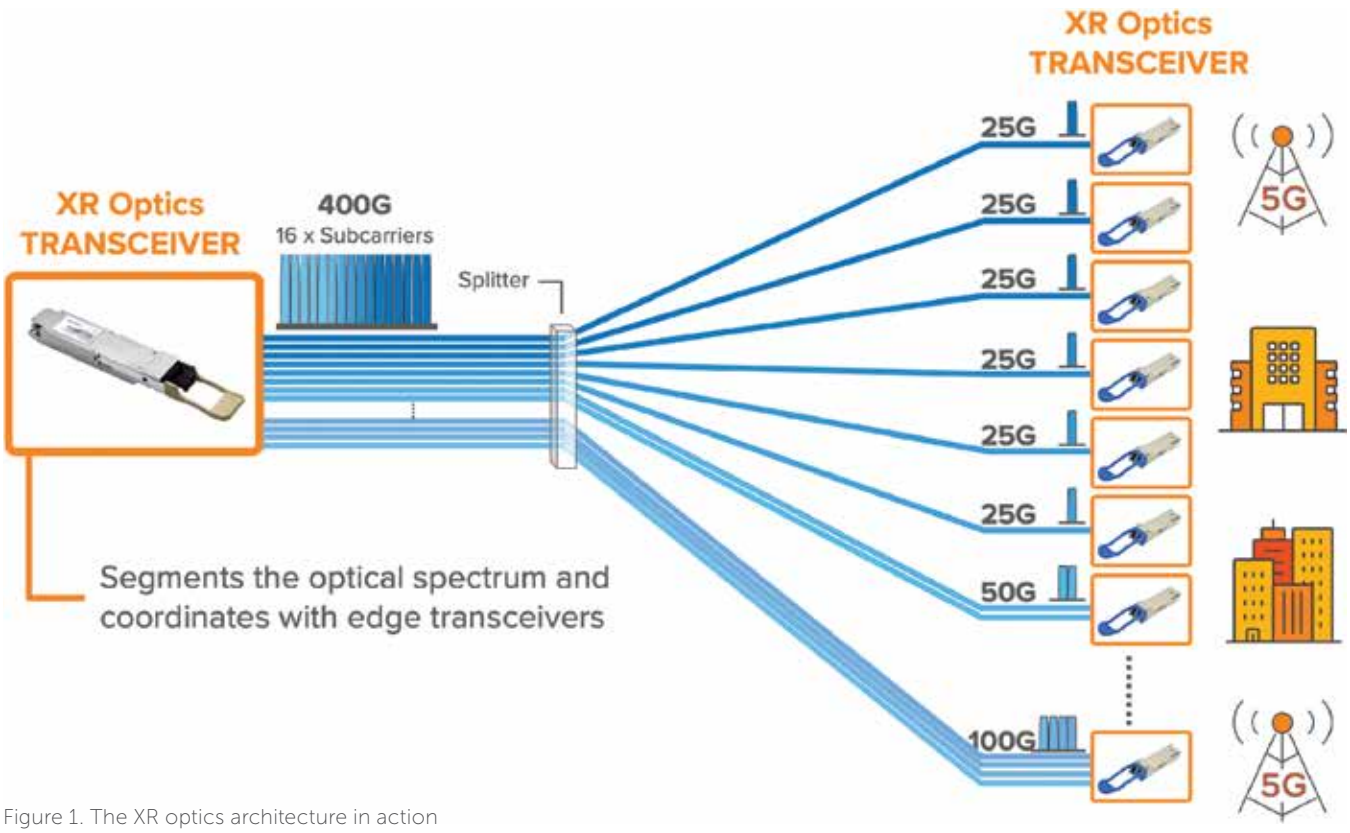

Figure 1. The XR optics architecture in action

There is light at the end of the tunnel, however. New subcarrier-based point-to-multipoint XR optics can solve this quandary, and the technology is gaining much interest from network operators. The new architecture offers support for high-capacity coherent optics over SFW PON infrastructure, enabling network operators to capitalize on their significant PON-based residential service investments for lucrative higher-capacity services for enterprise customers, mobile xHaul and backhaul of remote OLT devices.

The new point-to-multipoint XR optics use advanced signal processing in the digital signal processor (DSP) chip to modulate a single laser into many individual digital subcarriers. This capability enables a single higher-speed hub optic to communicate with multiple lower-speed leaf optics. For example, in a dual-fiber environment, a 400G hub optic would have a single

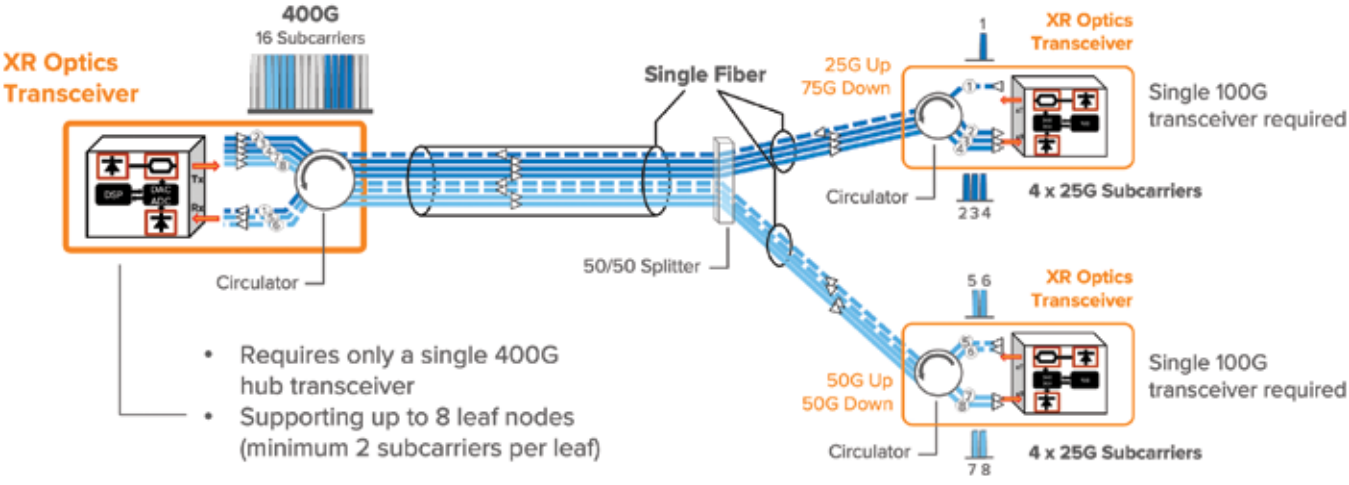

Figure 2. XR optics in single-fiber working environments

New point-to-multipoint XR optics use advanced signal processing in the digital signal processor chip to modulate a single laser into many individual subcarriers.

laser, but the DSP would modulate the signal into 16 individual 25G subcarriers. These subcarriers can then be routed to up to 16 different leaf nodes by the underlying fiber infrastructure. Lower-speed 100G optics can support one to four subcarriers supporting services from 25G to 100G, as shown in Figure 1.

In an SFW environment, it's possible to leverage these subcarriers and use them selectively in each direction to enable single-wavelength coherent optics to work over the single fiber, as shown in Figure 2. 10G DWDM optics use different wavelengths per direction, and the same is now done at the subcarrier level of granularity. This capability can then be overlaid with an existing SFW network to enable those high-capacity services parallel to the existing PON-based residential and SME customers.

Coherent technology comes at a different price than PON-based services, so this isn't a replacement technology for the PON network. The two technologies coexist on the same SFW infrastructure to broaden the range of services possible over an access network. Suppose high-capacity services that need coherent optics are required. In that case, overlaying these on the existing PON infrastructure by using subcarrier technology is substantially quicker and cheaper to deploy than the alternative of pulling a new dedicated fiber pair from the hub to the customer to support the dual-fiber requirement of standard coherent optics.

HIGH-CAPACITY PON OVERLAY IN PRACTICE

Deploying subcarrier-based XR optics over PON requires that the DWDM signals can be combined with the existing and planned PON technology running over the SFW ODN, typically via a coexistence element, as shown in Figure 3. Many ODNs either contain coexistence elements today or plan to in the future to enable the OND to support multiple generations of PON technology, such as GPON and XGS-PON.

Once the XR optics hub node is connected to the ODN via the coexistence element, high-capacity coherent services can be delivered to leaf nodes over the ODN using the coherent subcarriers. A single 400G hub optic will support up to eight leaf nodes with 25G per node for the maximum number of nodes or up to two leaf nodes with 100G per node for the

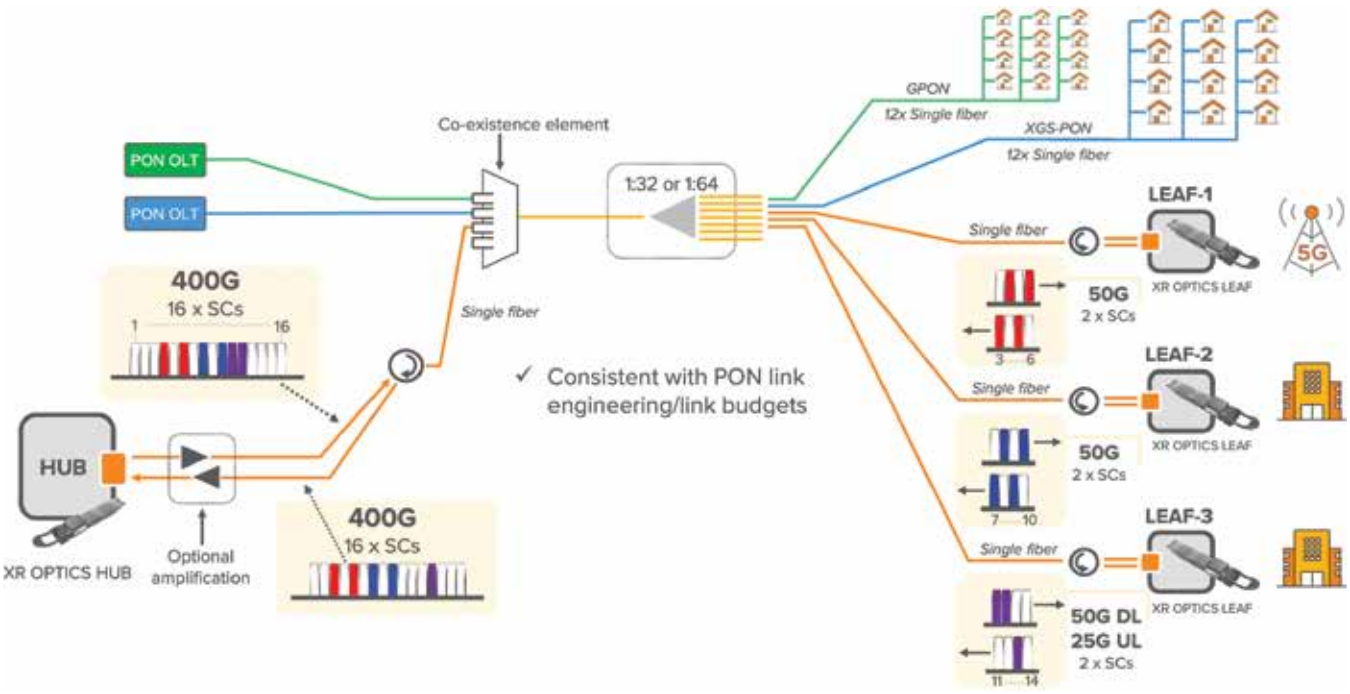

Figure 3. High-capacity services over a combined GPON/XGS-PON using subcarrier-based XR optics

Figure 4. PON and C-Band DWDM operating spectra.

highest capacity per node. As the ability to specify leaf nodes grows, additional subcarriers can be allocated via software up to 100G per leaf. Because the solution is based on DWDM technology, if total capacity or leaf nodes are required, adding additional hub optics using different DWDM wavelengths becomes necessary.

When this capability is validated in a test environment to the operator's satisfaction, the operator's sales teams can promote and sell the new high-capacity service capability. No initial hardware needs to be deployed until a service is sold, assuming the ODN connects to the customer. The hub, leaf optics, and host devices are installed where needed, and the connections are established to support the new service. The remaining SFW infrastructure is already in place from the residential/SME PON services.

ENSURING SMOOTH COEXISTENCE

DWDM optics operate over what is known as the conventional band, typically shortened to C-Band, which overlaps with the 1530-1540 nm NG-PON2 upstream spectrum and the 1550-1560 nm RF video spectrum, as shown in Figure 4. As XR optics are fully tunable across the whole C-Band, many existing coexistence elements can utilize these existing ports for new high-speed services. New coexistence elements can also be designed with specific XR optics ports that can further optimize a network's performance.

PUTTING THEORY INTO REALITY

What's the status of this new XR optics technology? It represents a unique architectural approach, and the first implementations of XR optics technology are coming to market now, with the first modules shipped to customers in Q1 2023. While the technology was being developed, network operators across the globe undertook numerous networking studies to understand the potential positive impact on their networks of point-to-multipoint XR optics, both in terms of the total cost of ownership savings and enabling new services that were not possible to deploy previously.

In parallel, many operators also undertook field trials to prove that the new point-to-multipoint technology worked as expected. These tests included lab and field trials in PON overlay applications, covering both existing GPON and XGS-PON networks, to prove that the technology worked and didn't impact existing PON services. Virgin Media and American Tower supported public announcements of their trials during this period. At the OFC 2023 event, Infinera also demonstrated the PON overlay application as part of the company's live point-to-multipoint demonstration. The demo showcased high-capacity services using point-to-multipoint XR optics in various applications, including operating over an SFW PON domain running GPON and XGS-PON supplied by DZS.

Within the range of network operator discussions the introduction of point-to-multipoint optics triggered, PON overlay for high-capacity services is proving to be a prevalent topic. The benefits are clear, and the approach offers a solution to a challenge that many network operators face. The solution solves the challenge: delivering high-capacity services over SFW without deploying a new dedicated pair of fibers from the hub to every high-capacity customer. Once the operator validates the capability, sales teams can promote and sell the service without any initial capital outlay or predeployment of equipment. The new service capabilities enable network operators to support a range of capabilities:

- Supporting their own 5G xHaul transport needs or offering this as a wholesale service to mobile operators
- Addressing large enterprises with high-capacity services
- Considering new PON architectures for next-generation residential PON in which the OLT is pushed out into the fiber plant closer to the customer with coherent backhaul over the SFW infrastructure.

Essentially this approach enables network operators to capitalize on their significant investment in SFW access infrastructure and seamlessly offer the full range of services over the fiber network – from residential/SME services using PON technology to the highest-capacity services using point-to-multipoint XR optics. The future looks bright for XR optics in PON overlay applications – this is a technology to watch.

Jon Baldry is the metro marketing director for Infinera.