White Paper

Coherent BiDi for Edge and Access Network Applications

Enabling Cable and 5G Network Providers to Easily Meet Rising Bandwidth Demands in Fiber-Limited Networks

October 2020

Abstract

In fiber constrained networks, network operators often have a single fiber route, with the ability to transmit and receive data in both directions. Historically, these networks have been served by 10Gbps bi-directional (BiDi) optical modules. With bandwidth demands growing, coherent bi-directional pluggable optical modules can provide these networks with an upgrade path to 100Gbps and beyond. This paper covers the ability to scale to higher bandwidths and address BiDi transmission, with operational and scalability benefits in these networks.

Demand growing for single-fiber BiDi communications

Gaining right-of-way access and digging up streets to install fiber optic cables are major hurdles in deploying service provider edge and access optical infrastructure to address the continuing growth in bandwidth demand. This predicament leads to constrained fiber situations in a variety of environments such as urban, suburban, rural, and metropolitan. It is not unusual for a service provider to rely on a *single* strand of fiber optic cable in order to deliver services over this infrastructure, especially if the service provider is sharing a cable bundle or duct space with others. In these single-fiber routes, optical transmission is bi-directional (BiDi)--transmitted and received signals co-exist on the same fiber, as opposed to different fibers in a more typical duplex fiber route.

Today's applications such as uploading 4K-resolution videos into the cloud for social-network sharing and the increased use of two-way video chats and file sharing tied to work-from-home requirements are examples of applications beyond existing streaming entertainment that are driving the need for bandwidth increases, especially when traffic from a large number of end users is aggregated. In addition to demand growth from these applications, the traffic patterns are evolving. Legacy access networks have typically dedicated larger bandwidth to downstream traffic. The aforementioned applications have driven the need for higher bandwidth capabilities to upstream traffic. Network infrastructure being deployed to support 5G wireless and enterprise business customers is also driving bandwidths higher than legacy infrastructure can support based on traditional optical transmission technology. 5G networks are expected to have traffic from a higher number of endpoints to aggregate, compared to legacy 4G LTE. All of these bandwidth growth drivers are creating a challenge for legacy optical service provider edge and access infrastructure to support this traffic. For example, cable network operators (aka, multiple system operators, MSOs) currently utilizing 10Gbps optical links are seeking to upgrade to 100Gbps links that operate over edge and access fiber routes. A compounding challenge is how to perform these upgrades over a single-fiber route.

Rather than digging up the streets, an alternative method to increasing bandwidth over service provider edge/access single-fiber routes is to upgrade the transmission technology used at the terminal equipment endpoints. The challenge is that legacy optical direct-detection technology is not capable of keeping up with increasing data rates in supporting BiDi transmission.

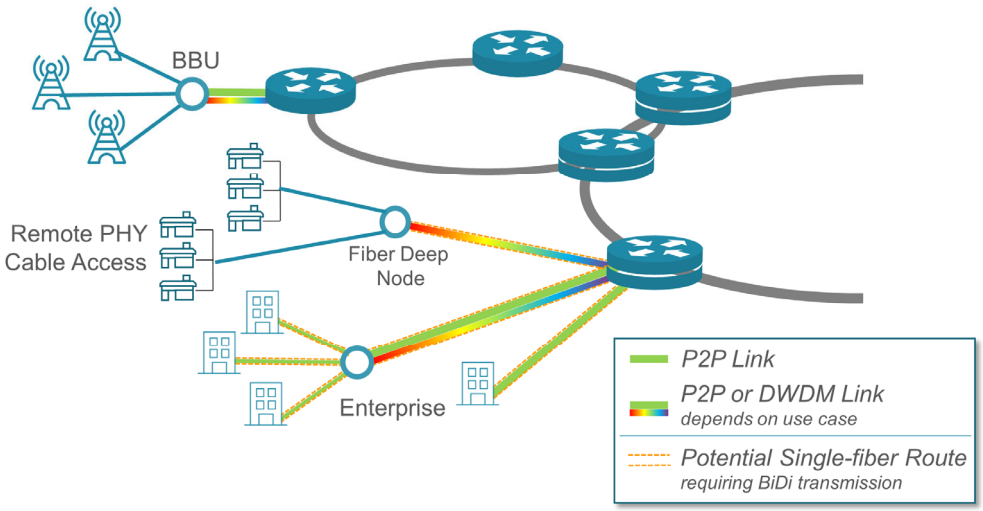


Figure 1. Examples of different connectivity solutions in the service provider edge/access portion of the network.

This paper examines how coherent BiDi pluggable edge/access solutions address both the ability to scale to higher bandwidths and address BiDi transmission, with operational and scalability benefits in these networks when increasing bandwidth to 100Gbps and beyond.

Limitations of legacy BiDi edge/access solutions

Traditional 10Gbps direct-detect optical transmission technology used in pluggable optical transceiver module solutions over single mode fiber has provided reliable 10Gbps BiDi links over service provider edge/access networks. Implementing direct-detect solutions at higher data rates is more challenging due to the need to utilize parallel optical lanes at lower data rates, e.g. 4 x 25G. Coherent transmission technology can be used to transmit serial 100Gbps with support for BiDi architectures. Thus, coherent provides a more effective path to migrate today's BiDi routes to 100Gbps.

Figures 2 and 3 illustrate examples of BiDi deployments compared to traditional duplex fiber deployments. Figure 2a illustrates a typical duplex fiber route in which transmission from "A-to-Z" and transmission from "Z-to-A" utilize the same wavelength. However, in fiber constrained environments there may be only a single-fiber path available in which the A-to-Z transmission and Z-to-A transmission travel bi-directionally along the same fiber route over different wavelengths, as shown in Figure 2b.

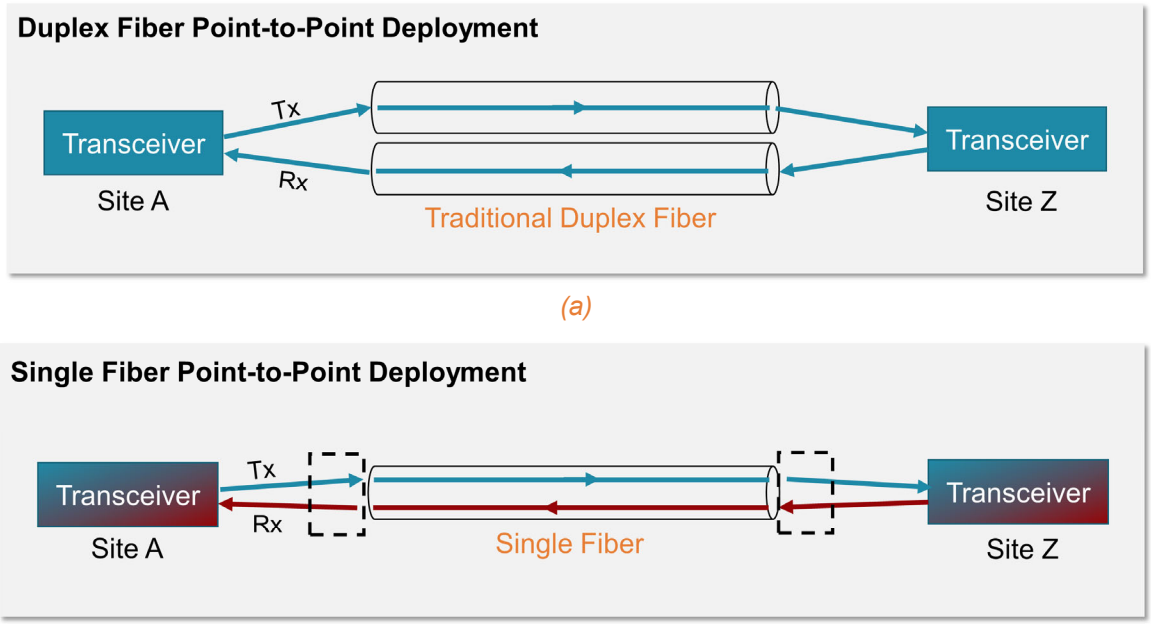


Figure 2. Optical transmission in a service provider edge/access network over (a) duplex optical fiber; and (b) a single fiber BiDi link in which transmit wavelength is different from receive wavelength and combined onto the same fiber.

Using dense wavelength division multiplexing (DWDM), the number of links can be increased in both duplex and single-fiber deployments, as shown in Figure 3.

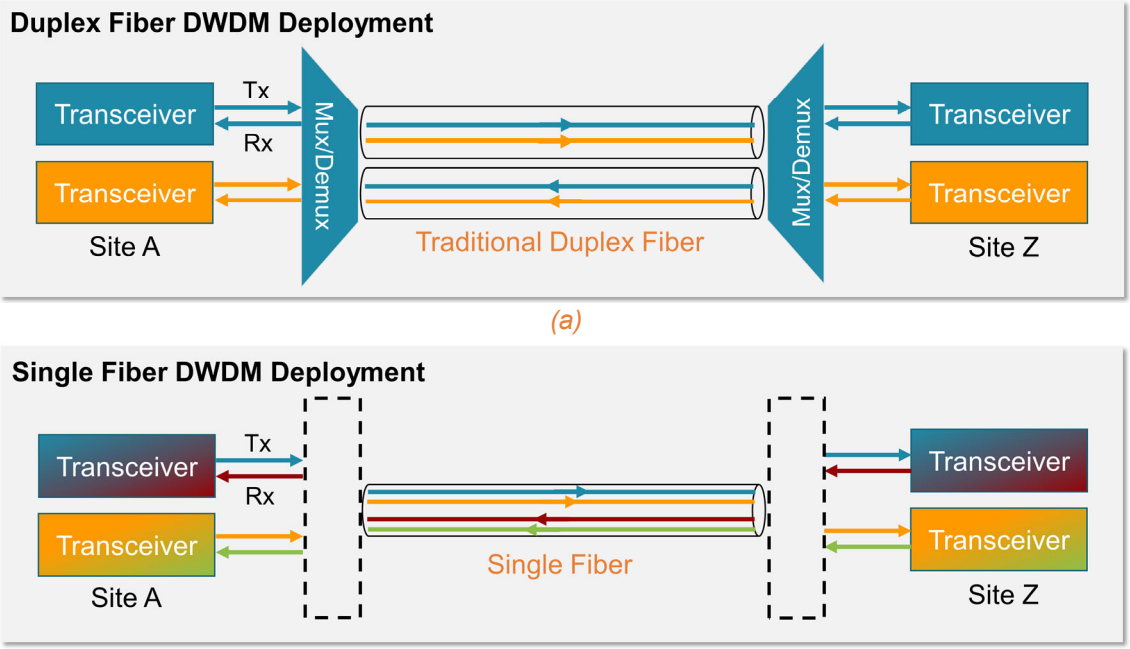


Figure 3. Illustrations showing wavelength-multiplexed transmission over (a) duplex optical fiber; and (b) a single-fiber BiDi link in which transmit wavelength is different from receive wavelength—the optical implementation to combine signals into a single fiber depends on the link requirements.

As Figures 2 and 3 illustrate, the optical transceiver modules used for single-fiber BiDi deployments must have the ability to transmit and receive on *independent* wavelengths, a capability dependent on the module design. This will be covered in more detail in a later section of this white paper.

Operational simplicity with coherent BiDi edge/access solutions

Optical coherent technology has come a long way since its early days when a full line-card of electronics and optics was required. Today, this technology can be housed in a small, compact pluggable module[1], made possible through advancements in silicon photonics, opto-electronic integration, and CMOS nodes with lower power consumption. These continued innovations have positioned coherent solutions to advance into applications with shorter reaches (Figure 4) such as service provider edge and access networks.

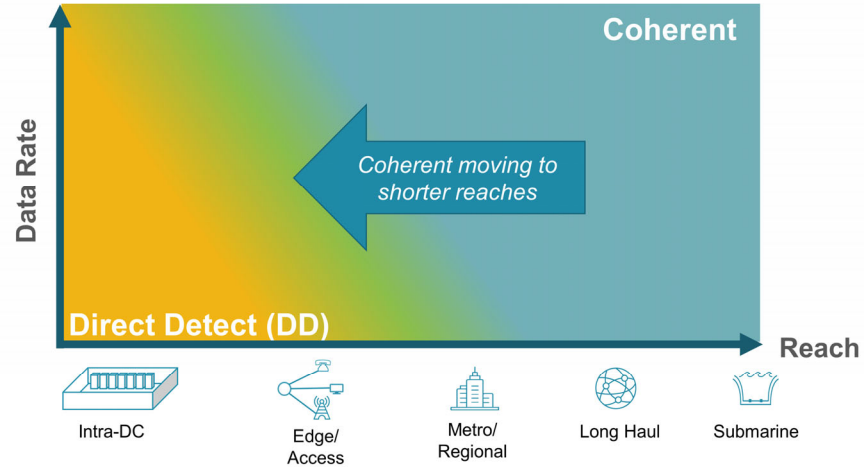


Figure 4. Coherent solutions are evolving towards shorter reaches.

As previously stated, direct-detect solutions for service provider edge and access links are reaching bandwidth/distance limitations, compared to coherent solutions that can easily bridge the gap to higher bandwidth and longer distances on any deployed fiber type. Coherent also addresses the unique requirements of service provider BiDi edge/access applications (to be discussed in a later section), while providing an operationally simple solution that leverages the many capabilities that make coherent a successful solution in longer-reach environments. Coherent solutions are user friendly in deployment and provisioning due to wide tolerance range, increased optical margin, and rich monitoring and diagnostic features.

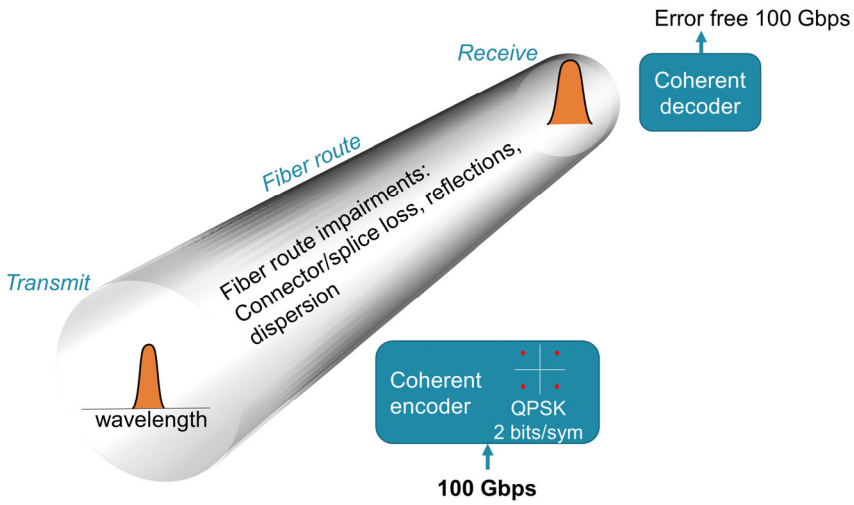


Figure 5. Error-free coherent transmission of 100Gbps QPSK modulation example, tolerant to multiple impairments (only one transmission direction shown).

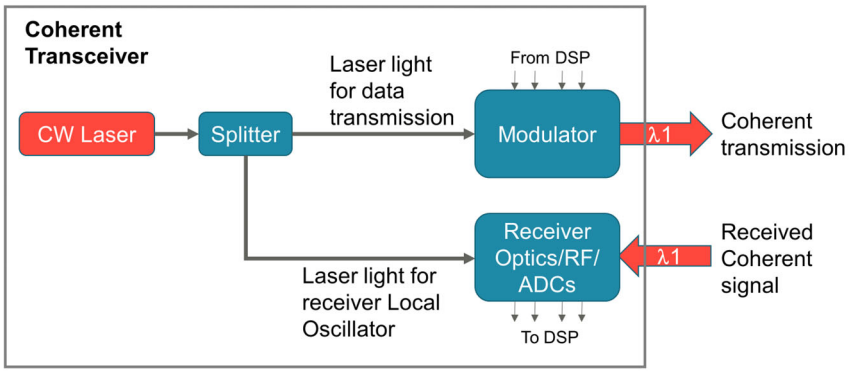
Coherent solutions have the ability to electronically overcome both chromatic and PMD transmission impairments, which allows the transmission to adapt over different edge/access fiber types and conditions in a plug-and-play fashion. It is also tolerant to the detrimental effects from loss and back reflections from multiple fiber connector/splice interfaces. All these capabilities result in coherent solutions providing additional margin compared to direct-detect solutions.

Pluggable coherent solutions enable the capability to achieve higher data rates in the future over the same, or greater, distances. Compared to today's access data rates, higher rate coherent options are already available in small form factor pluggable modules, providing a ready-made path to meeting the demands of service provider edge/access bandwidth growth. Coherent transmission solutions beyond 100Gbps are quite mature, and thus, there is no fundamental near-term impediment in coherent technology for scaling service provider edge and access to higher bandwidths.

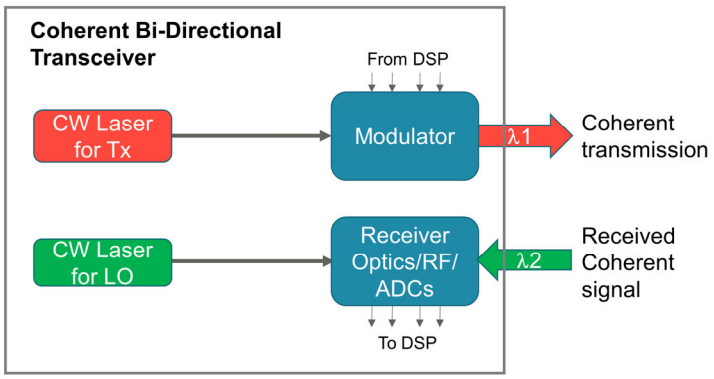
Coherent solutions are user friendly in deployment and provisioning due to wide tolerance range over a variety of fiber types and long fiber links, increased optical margin, plug-and-play implementation, and rich monitoring and diagnostic features. Coherent solutions also provide a roadmap to addressing higher data rates and longer reaches over the same edge/access infrastructure. This all leads to operational simplicity and shorter provisioning times, which can result in savings in the service provider edge/access network.

Design optimization for coherent BiDi

A required element of any coherent optical transmission implementation is the local oscillator (LO), a stable continuous wave (CW) laser used as a clean reference source to optically mix with the received optical signal. It is typical for the transmitter and receiver wavelength in a coherent link to be the same, which allows for the sharing of the same CW laser source for transmission as well as the receiver LO (Figure 6a). However, for BiDi applications in which the transmit and received wavelengths are different, the LO should not be derived from the transmission laser. A separate second laser is required as the LO. Thus, a **coherent BiDi** module contains dual lasers, one used to transmit the data, while the other is used as the LO. This allows the transmit wavelength to be independent from the receive wavelength.



(a)



(b)

*Figure 6. (a) High-level block diagram of optical coherent module transmission in which the received wavelength is the same as the transmitted wavelength; CW laser is shared as the optical modulator source and the LO source. (b) A **coherent bi-directional** module in which the received signal is a different wavelength than the transmitted wavelength, and the LO source cannot be shared with the transmitter laser source.*

This coherent BiDi module is designed to support service provider edge and access optical network links with single-fiber routes, as illustrated in Figures 2b and 3b. Wavelengths propagating in opposite directions have to be different in order to avoid in-band crosstalk due to back reflections. In addition, having the Tx laser and receiving module's LO laser be fully tunable enables the management of a single product code rather than managing an inventory of multiple fixed-wavelength pluggable module product codes, thus simplifying network deployment.

Acacia's Solution

Acacia's coherent BiDi pluggable solutions are designed for service provider edge and access applications that require independent transmit/receive wavelengths. Acacia's coherent BiDi module is housed in a CFP2 form-factor module and delivers an operationally efficient and cost-effective way for network operators to increase capacity to 100Gbps and beyond over both single-fiber as well as diverse transmit/receive network architectures.

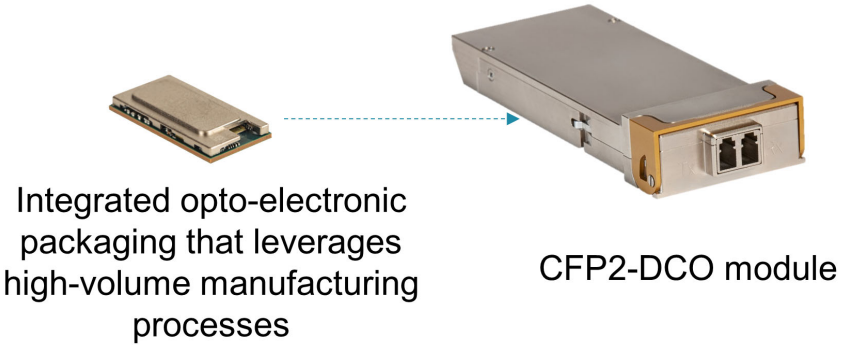


Figure 8: Integration in silicon enables a path to coherent transceivers for service provider edge/access in a compact pluggable CFP2 module.

For single-fiber BiDi transmission, there are various implementation options to convert from a dual-port configuration to a single-port configuration such as passive optical mux/demuxes, splitter/combiners, or circulators, depending on the application and link requirements. The module supports both Ethernet and OTN client protocols. Acacia's new coherent BiDi service provider edge and access solutions were designed to provide network operators the ability to scale to higher data rates to meet growing bandwidth demands over challenging BiDi optical links, while also providing operational simplicity that may lead to overall network savings.

Acacia's 3D Siliconization approach, which utilizes high-volume manufacturing processes and benefits from the maturity of Acacia's silicon photonics technology, is used in the coherent BiDi CFP2 module. The use of silicon photonics to take discrete bulky optical components and integrate their functions into a CMOS-based silicon chip has been a key factor in module footprint reduction.

3D Siliconization follows the example of the electronics world and applies integration techniques such as 3D stacking to electronics and silicon photonic integrated circuit (PIC) co-packaging. This approach makes it possible to integrate crucial components into a compact package and reduce the number of electrical inter-connects while preserving robust signal integrity. Integration involving silicon photonics follows progress already made in the semiconductor fabrication process suitable for volume production and high yields.

Conclusion

Constrained fiber environments in service provider edge and access networks pose challenges to address increasing bandwidth demand, especially over single-fiber routes. Legacy technology is not capable of supporting data rates at 100Gbps in BiDi applications in these networks. This has driven a need for optical links at 100Gbps and beyond that can address network architectures such as BiDi links that are operationally simple to deploy, along with a path to easily and cost-effectively scale to higher speeds in the future.

Acacia has a proven history of bringing coherent technology to new markets, delivering the low power, performance, operational simplicity, and scalability customers have come to rely on. Since 2011, Acacia has leveraged the benefits of integration to evolve from 100Gbps in a 5”x7” form factor to pluggable form factors such as CFP2 and QSFP-DD supporting up to 400Gbps. This has been enabled by Acacia’s mature and highly integrated silicon photonics designs. As a trusted partner for service providers and network equipment manufacturers (NEMs), Acacia is now leveraging its technology to develop coherent BiDi 100Gbps and beyond transceivers for the service provider edge/access market.

References

[1]Acacia Communications (2020), “Coherent Technology for Point-to-Point Edge and Access Network Applications,” Retrieved from: https://acacia-inc.com/acacia-resources/coherent-technology-for-point-to-point-edge-and-access-network-applications/

About Acacia

Acacia’s innovative silicon-based high-speed optical interconnect products accelerate network scalability through advancements in performance, capacity, and cost. Our silicon photonic PICs, DSP ASICs, and coherent modules inside a variety of network equipment products empower cloud and service providers to meet the fast-growing consumer demand for data.

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