White Paper

Coherent Technology for Point-to-Point Edge and Access Network Applications

Delivers the Performance, Scalability and Operational Efficiency Needed for Service Provider Networks Offering 5G Wireless X-haul, Broadband Access Aggregation and Enterprise Services

September 2020

Abstract

Applications such as gaming, telemedicine, and autonomous vehicles are driving the need for increased bandwidth towards the edges of the network that are closer to the end user. To meet these needs, there's an emerging requirement for service provider edge and access networks to evolve directly from legacy 10Gbps to 100Gbps optical links as the way to increase bandwidth. This paper examines the constraints that prohibit legacy Point-to-Point edge/access solutions from scaling to higher bandwidths, and discusses how coherent optical solutions can provide operational and scalability benefits in these networks when increasing bandwidth to 100Gbps and beyond.

Bandwidth demands in edge and access

Applications are clearly driving the need for increased bandwidth towards the edges of the network that are closer to the end user. For example, applications such as gaming, telemedicine, and autonomous vehicles need larger pipes from centralized cloud networks to connect to edge computing sites that are closer to the end user. In addition, data from these applications may also be transported via a wireless infrastructure which would require large wireline pipes to carry data from cell towers back to the core of the network. And for service providers offering high-capacity enterprise services via a private line fiber link to the customer premise, applications such as hybrid cloud services can drive increased bandwidth demands. Optical fiber deployments that do not require optical amplification or multiplexing using dense wavelength division multiplexing (DWDM) to reach the edge/access terminal equipment rely on economically optimized point-to-point (P2P) links where a dedicated fiber pair is used between the metro core and edge/access aggregation terminal equipment.

As bandwidth demand in these P2P network links increases, limitations are encountered because legacy optical transmission technology is not capable of supporting data rates beyond a certain speed for a given distance. For service provider edge and access networks, there is an emerging requirement to evolve directly from legacy 10Gbps to 100Gbps optical links as a preferred means to increase bandwidth. The alternative of utilizing multiple 10Gbps links (e.g., for enterprise access) may not be the most efficient from a cost-per-gigabit perspective as 100Gbps solutions become more ubiquitous. The challenge is that traditional technologies typically used in this portion of the network have distance limitations when scaling to 100Gbps and beyond.

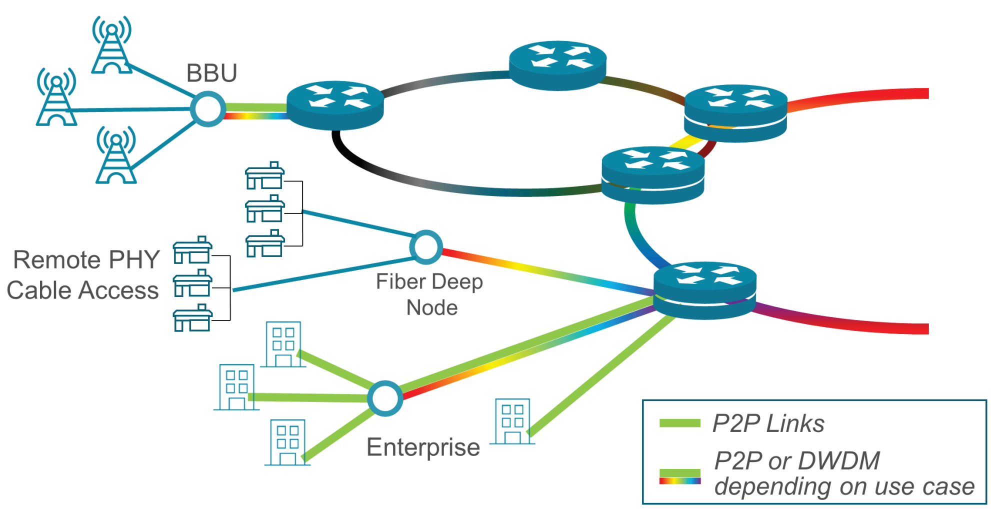

Figure 1. Examples of point-to-point links in the service provider edge/access portion of the network.

This paper examines the constraints that prohibit legacy P2P edge/access solutions from scaling to higher bandwidths, and discusses how coherent optical solutions can provide operational and scalability benefits in these networks when increasing bandwidth to 100Gbps and beyond.

Higher data rates pushing the limits of legacy P2P solutions

Traditional direct-detect optical transmission technology used in pluggable optical transceiver module solutions over single mode fiber have served the industry well in providing reliable P2P 10Gbps links over service provider edge/access networks. However, beyond 10Gbps, the ease of use becomes more challenging. Increasing the bandwidth of an optical P2P link from 10Gbps to 100Gbps using direct-detect relies on transmitting over multiple optical lanes at sub-multiples of 100Gbps (see *Direct-Detect and Coherent Comparison for 100Gbps Edge/Access* inset), such as four lanes at 25Gbps. The widely used 100GBASE-LR4 is an example of a direct-detect solution that supports 100Gbps links up to 10km using four transmitter lasers (operating in the 1310nm wavelength range) and receiver PIN detectors. Using the same technology to address edge/access reaches beyond 10km is challenging. To minimize impairments due to fiber chromatic dispersion, these four wavelengths need to remain in the 1310nm range. Extending to further reaches in this wavelength range requires additional power budget to overcome optical fiber loss. For example, extending to a longer reach of 80km would require an additional 28dB[1] power budget in comparison with 100GBASE-LR4. In addition to loss, the effects of optical transmission impairments such as chromatic dispersion slope and polarization mode dispersion (PMD) add to the loss penalty.

In an effort to stretch the achievable 100Gbps direct-detect reach beyond 10km towards 40km, 100GBASE-ER4 was introduced to address power budget by increasing both the transmitter power and receiver sensitivity. The challenge with this approach is that the maximum transmitter power is limited by laser eye-safety regulations, while improvements to receiver sensitivity are accomplished by using avalanche photo diode (APD) receivers or semiconductor optical amplifiers (SOAs). Even with these approaches, addressing the longer reaches (e.g. ≥80km) remain challenging.

Direct-Detect and Coherent Comparison for 100Gbps Edge/Access

Direct Detection/Intensity modulation: Optical signal intensity is modulated. Receiver detects whether light is on or off.

- Non-Return to Zero (NRZ) intensity modulation and direct-detection: Signal intensity varied by modulating the laser output between either fully on or fully off. As a result, the transmitter only sends one bit per symbol. The challenge is that the optical modulation rate is limited, with impairments encountered in the fiber transmission becoming a limiting factor to achievable reach at these speeds. Four lasers and four detectors each operating at ~25Gbps are required for 100Gbps edge/access.

Coherent: Optical signal is modulated in both phase and amplitude. The number of bits per symbol using a single laser is increased, reducing the need for multiple laser sources. Optical signal can be modulated with two orthogonally polarized beams, known as dual-polarization (DP), further doubling the amount of data transmitted. Receiver recovers data from preserved phase and amplitude information. DP-QPSK provides robust 100Gbps transmission over edge/access fiber links. Most recent solutions are DP and hence the "DP" is typically dropped as it is implied. On the receiver end, amplitude and phase components are extracted from the received signal using an optical reference source (a.k.a, local oscillator) and to provide gain. This information is then processed to decode the original transmission data.

- Quadrature phase-shift keying (QPSK): Optical signal split, with one part phase shifted relative to the other, and amplitude held constant. Recombining them generates an optical signal that encodes two bits of data for every state change of the laser. DP-QPSK doubles the amount of data transmitted.
- Quadrature-amplitude modulation (QAM): Modulates optical signals simultaneously in phase and amplitude. Bandwidth increase depends on levels of amplitude modulation. 16QAM uses four amplitude levels to encode four bits of data per symbol. DP-16QAM doubles the amount of data transmitted.

[1]Assuming 0.4 dB/km attenuation.

Unique requirements in the edge/access

In addition to the technological limitations of pluggable direct-detect solutions scaling to higher bandwidths and reaches, the landscape of the service provider edge/access network provides some unique challenges. Different fiber types with a range of loss and dispersion characteristics have been deployed over the years in various segments of the network to optimize transmission for different generations of transmission technology. The range of fiber types include ITU-T G.652A/B/C/D, G.653, G.654, G.655, G.656, and G.657. Because a large capital investment is required to install fiber, it does not make sense to rip out the fiber whenever a new technology advancement is made. Rather, accommodations on the terminal equipment optical transceivers/transponders may be required to operate on legacy non-optimized fiber.

It is not unusual to have multiple bulkhead patch-panel fiberoptic connectors and splice points along a fiber route within the edge/access network. The cumulative effect of multiple connectors and splice points is the accumulation of loss and back reflections (aggravated by unclean connectors), which can be detrimental to the optical transmission performance in a direct-detect link.

To account for numerous potential impairments depending on the fiber-plant condition (fiber types, connector reflections and losses), truck rolls may be required in order to characterize each fiber route — using an optical time-domain reflectometer (OTDR)— before certifying a link as operational to ensure an optical link can be closed if there is uncertainty about link margin.

In addition to fiber types and connector/splice induced impairments, consideration of environmental conditions of the service provider edge/access network must also be taken into account. Edge/access equipment terminals may be located in uncontrolled outdoor cabinets requiring optical modules to endure temperature ranges beyond what is typically found in an indoor temperature-controlled environment. Managing the performance of a multiple-laser direct-detect solution to meet overall transmission requirements, including longer reach links, may make outdoor temperature resilience a challenge.

Operational simplicity with coherent edge/access solutions

Coherent technology has existed in long-haul networks for approximately a decade and is also widely deployed in metro networks. Once requiring a full line-card of electronics and optics, coherent transmission technology can now be housed in a small compact pluggable module about the size of a pack of stick gum.

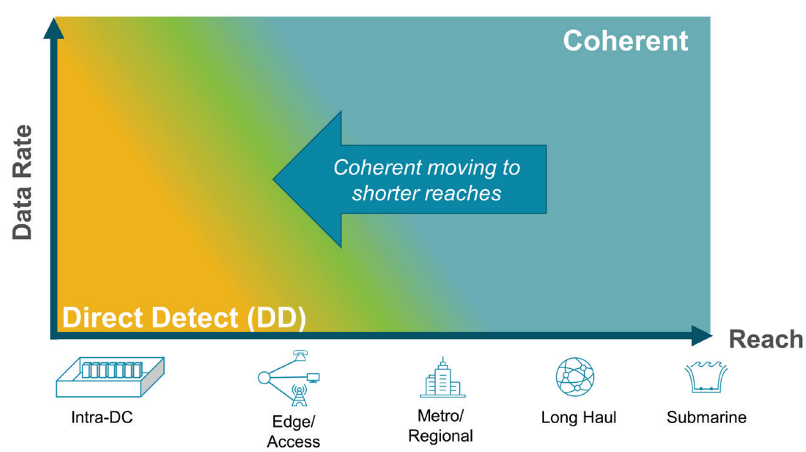

Figure 2. Coherent solutions are evolving towards shorter reaches.

This has been made possible through advancements in CMOS nodes with lower power consumption, opto-electronic integration, and silicon photonics technology. These continued innovations have positioned coherent solutions to advance into applications with shorter reaches (Figure 2) such as service provider edge and access networks.

While direct-detect solutions for service provider edge and access links are reaching bandwidth/distance limitations, coherent solutions on the other hand can easily bridge the gap to higher bandwidth and longer distances on any deployed fiber type. In addition to providing a path to higher bandwidth and longer distance capabilities, coherent also addresses the unique requirements of service provider edge/access applications while providing an operationally simple solution that leverages the many capabilities that made coherent a successful solution in longer reach environments. Coherent P2P solutions are user friendly in deployment and provisioning due to wide tolerance range, increased optical margin, loop-back capabilities, and rich monitoring and diagnostic features. Let's explore some of these advantages in more detail.

Coherent transmission tolerant to various service provider edge/access route impairments. A feature of coherent technology is its ability to electronically overcome both chromatic and PMD transmission impairments, which allows the transmission to adapt over different fiber types and conditions in a plug-and-play fashion. Figure 3 illustrates how 100Gbps coherent transmission can overcome multiple fiber transmission impairments over a fiber route.

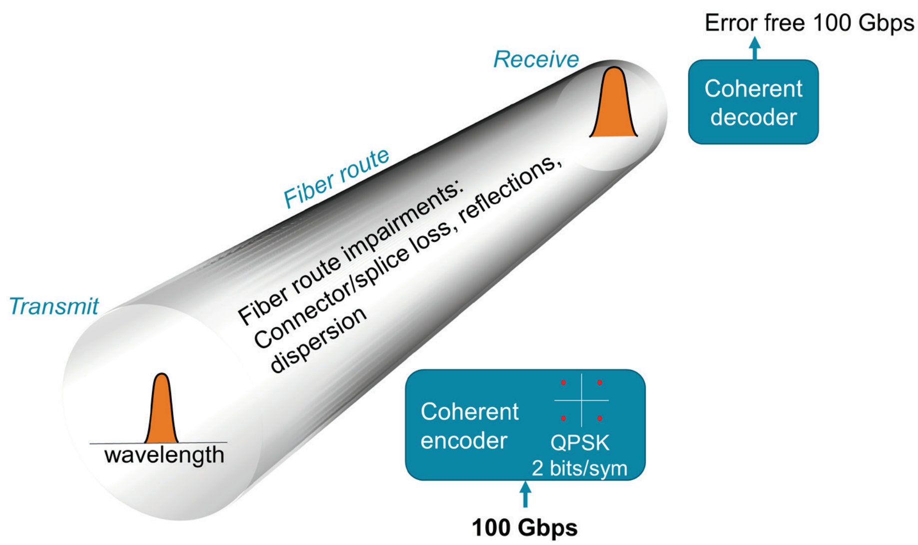

Figure 3. Error-free coherent transmission of 100Gbps using QPSK modulation tolerant to multiple impairments.

Coherent technology is also tolerant to the detrimental effects of loss and back reflections from multiple fiber connector/splice interfaces. Unlike in intensity-modulated direct-detect transmission where reflections encountered over the fiber route can create noise in the transmission link, coherent modulation formats such as QPSK are inherently much more tolerant to optical reflections. Due to the single-laser coherent transmitter operating in the lowest loss 1550nm window in single mode fiber, and the coherent receiver having extremely high sensitivity due to its coherent detection technology, coherent pluggable modules have ample power budgets to not only compensate for losses due to multiple fiber connectors/splices but also address long transmission links.

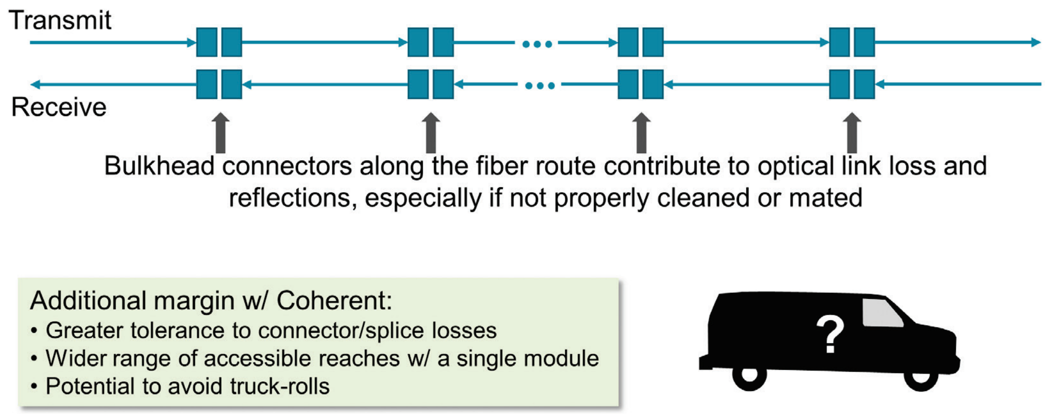

Figure 4. Coherent solutions provide additional margin resulting in operational flexibility in deployments from increasing the number of addressable reaches to potentially avoiding the need for truck rolls to "shoot fiber" (OTDR measurements), especially for routes deemed marginal using direct-detect transmission.

Figure 5 illustrates how the effects of dispersion and losses along a fiber route result in a reach limitation for 100Gbps direct-detect solutions. In contrast, the coherent solution with its higher tolerance to impairments provides improved performance in the form of additional margin and longer reach capabilities.

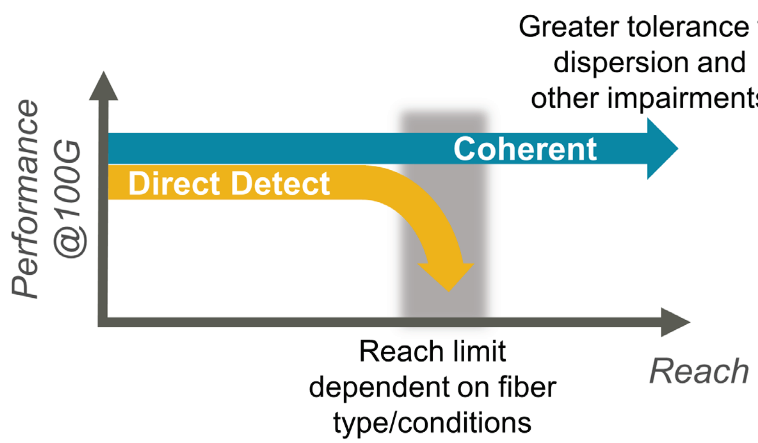

Figure 5. Direct-detect solutions hit a reach limit at a certain distance while the coherent solution will continue to operate beyond this reach limit.

Monitoring, Diagnostics and Troubleshooting. Built into pluggable coherent transceivers are monitoring and diagnostic capabilities to ensure robust data transmission. In addition, as previously stated, coherent 100Gbps P2P solutions have a very wide receiver dynamic range compared to an equivalent direct-detect P2P link, thus enabling a coherent link to accommodate optical loopback for troubleshooting. In comparison, direct-detect solutions include internal optical amplification at the receiver to close longer links, resulting in direct optical loopback troubleshooting not being possible due to receiver overload.

Reliability. As previously stated, a pluggable direct-detect 100Gbps solution relies on four transmitter lasers which may require operating at the higher end of their transmitter optical power range, especially for the longer reach links of an edge/access network. For these reaches, active optical amplification at the receiver end may also be required to close the link. Thus, a total of eight active elements must be taken into account when determining the reliability of these types of modules. In comparison, a pluggable coherent 100Gbps solution utilizes only one active optical element, the transmission laser, making it more reliable than the direct-detect solution.

In summary, coherent technology provides:

- Ample optical margin to potentially avoid truck rolls for fiber route characterization.
- High-tolerance plug-and-play implementation over a variety of fiber types and longer fiber links.
- The capability to perform optical loopback if necessary for troubleshooting.
- Monitoring of the transmission performance over these links.

This all leads to operational simplicity and shorter provisioning times, which can result in operational savings in the service provider edge/access network.

Scaling to higher data rates

Pluggable coherent solutions offer 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.

Acacia's Solution

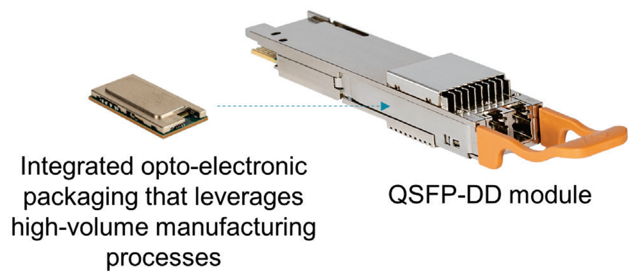

Figure 6. Integration in silicon enables a path to coherent transceivers for service provider edge/access in a compact QSFP-DD package.

Acacia's 100Gbps coherent pluggable solutions are specifically designed for optimization in service provider edge and access applications with unamplified links including 80km reaches and beyond. Offered in a quad small form-factor double density (QSFP-DD) that is widely used for client-optics, Acacia's new 100Gbps coherent P2P 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 some of the most challenging 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 100Gbps P2P QSFP-DD module. Figure 7 illustrates how advances in optical/electrical component consolidation has resulted in size reductions of coherent modules. 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.

By following the example of the electronics world and applying integration techniques such as 3D stacking, electronic circuits and a silicon photonic integrated circuit (PIC) can be co-packaged. This approach makes it possible to integrate crucial components into a compact package and reduces the number of electrical

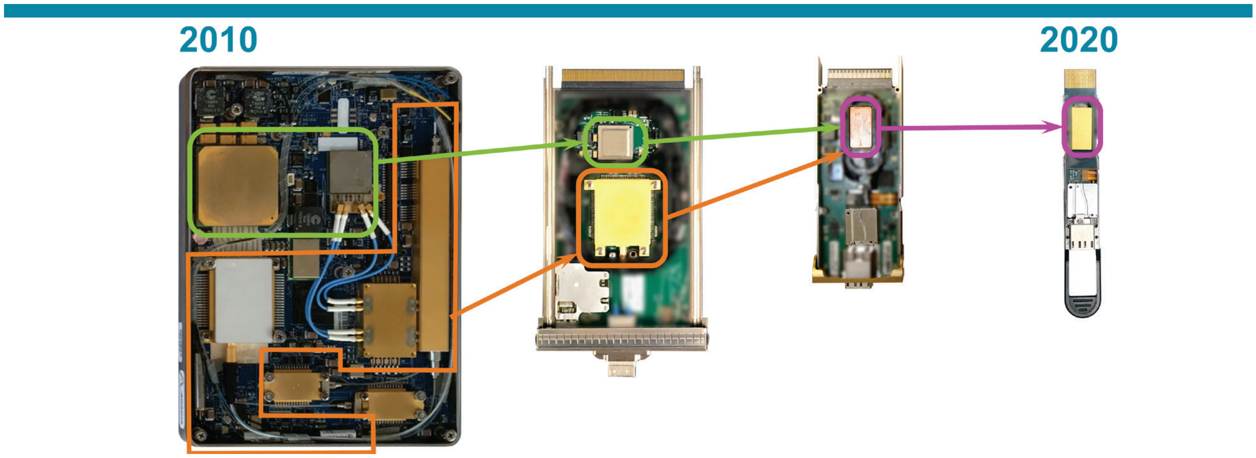

Figure 7. Evolution of coherent module size over time.

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

Bandwidth demand in P2P service provider edge and access networks is increasing at a rapid rate. This is placing enormous pressure on providers because legacy technology is not capable of supporting data rates beyond a certain speed for a given distance. This has driven a need for 100Gbps optical 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 the integration of multiple discrete optical components into a single package using Acacia’s mature and highly integrated silicon single-chip PICs that minimize both size and power consumption; as well as innovations in packaging/integration to achieve high densities. As a trusted partner for service providers and network equipment manufacturers (NEMs), Acacia is now leveraging its technology to develop 100Gbps and beyond small form-factor pluggable transceivers for the service provider edge/access market.

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.

ACACIA COMMUNICATIONS, INC.

3 Mill and Main Place, Suite 400
Maynard, MA 01754, USA
info@acacia-inc.com
978.938.4896
acacia-inc.com