Challenges and key technologies for coherent metro 100G transceivers

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Service providers are currently adopting coherent transceivers for their 100G DWDM backbone applications to achieve the higher capacity and longer fiber reach that coherent technology offers. Coherent transceivers also provide cost-effective electronic equalization of fiber impairments – such as chromatic dispersion and polarization-mode dispersion – as well as extensive performance monitoring capabilities that enable easy installation and network management. These benefits help service providers meet bandwidth demand growth while reducing the total cost of ownership.

With their superior optical performance and ease of use, coherent transceivers are also very attractive for the emerging 100G metro market. The metro-market segment typically develops two to three years after the long-haul market but is two to three times larger in size. Following this timeline, the 100G metro market is expected to take off in 2014 and attracting significant attention from equipment manufacturers and transceiver suppliers.

The size, power dissipation, and cost structure of today's coherent transceivers, which were developed for long-haul applications, limit these modules' application in the more cost-sensitive metro networks where space comes at a high premium, making line-card density very important. Consequently, a path to a lower-cost coherent module in a smaller footprint has become increasingly important.

DWDM metro-network requirements

There is no universal definition of a metro network, but the segment is generally divided into three subcategories: metro regional, metro core, and metro access (Figure 1).

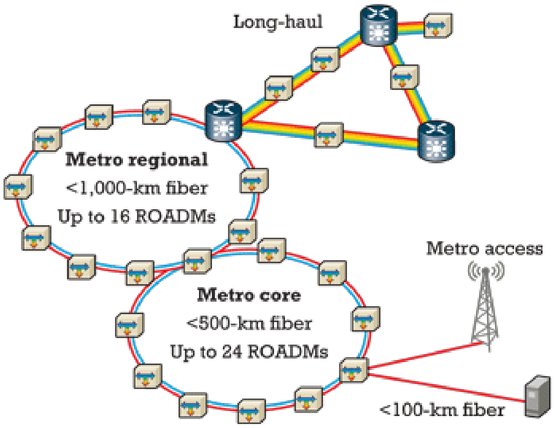
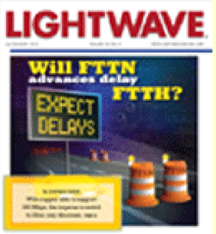


FIGURE 1. A typical optical transport network, with the three types of metro networks.

The metro regional and metro core cover distances of 500–1,000 km and 100–500 km, respectively, and typically include a large number of reconfigurable-optical-add/drop-multiplexer (ROADM) nodes. Although these distances are shorter than long-haul links, the transmission requirements can be quite challenging with a large number of ROADMs and the fact that metro fiber is often older and can consist of many interconnected segments that cause higher loss. Additionally, the 100G metro wavelengths likely will have to coexist with existing 10G wavelengths, requiring the support of links with and without in-line dispersion compensation, i.e., both brownfield and greenfield deployments. Efficient use of the available fiber bandwidth is often very important, since installation of new fiber is generally cost prohibitive in a metro environment. Therefore, single-wavelength 100G implementations are highly desirable for both metro regional and metro core applications.



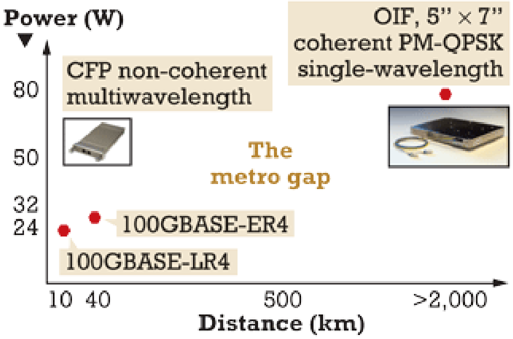


FIGURE 2. Today's 100G transceiver landscape.

Metro access links are generally point-to-point connections shorter than 100 km. This factor makes the metro access segment particularly cost-sensitive, since lower-performing competing approaches can cover this distance, including the non-coherent multiwavelength implementations defined by IEEE (e.g., 100GBASE-ER4 can cover up to 40 km).

Today's 100G transceiver landscape – the metro gap

Until recently, equipment manufacturers implemented coherent transceivers via discrete components on a line card. Multisource-agreement (MSA) modules, based on Optical Internetworking Forum (OIF) recommendations, have emerged over the past 12 months, providing equipment manufacturers with a low-risk path to a multisourced, high-volume transceiver that enables their internal R&D resources to be allocated to address next generation challenges, e.g., 400G.

The evolution from discrete components to integrated modules has been proven repeatedly in the past, and the OIF has eased the 100G transition by defining Implementation Agreements on the coherent MSA module as well as specifying the key optical components inside the module. For example, the OIF defined the module size to be 5×7 inches, power consumption to be less than 80 W, and the modulation format to be polarization-multiplexed (PM)-quadrature phase-shift keying (QPSK).

Although the OIF does not define the optical performance, the intention of the 100G MSA module is to support long-haul applications beyond 2,000 km. For shorter-reach singlemode-fiber applications, the IEEE has standardized multi-lane 100G transceivers that use four wavelengths; 100GBASE-LR4 covers up to 10 km and the 100GBASE-ER4 covers up to 40 km. Both implementations support the C form-factor pluggable (CFP) transceiver with a maximum power consumption of 32 W. The OIF and IEEE defined transceivers, and their key characteristics are illustrated in Figure 2. As evident from Figure 2, there is a large gap between the long-haul and short-reach segments not presently addressed by any transceiver. This gap represents the metro-market segment.

Coherent transceiver challenges and key technologies

The size and power consumption of today's coherent long-haul transceivers are not suitable for metro networks where port density is important. As shown in Figure 3, coherent transceivers require advanced optical transmitters and receivers with many building blocks that represent a significant footprint if implemented as discrete blocks.

Additionally, coherent transceivers include an ASIC that performs the extensive digital-signal processing necessary for demodulation and link equalization of the received optical signal. The ASIC contains high-speed analog-to-digital converters (ADCs), digital-to-analog converters (DACs), and often very powerful soft decision forward error correction (SD-FEC). The power consumption of the ASIC typically constitutes a significant part of the overall power consumption of the transceiver, which causes associated challenges with heat dissipation when looking to limit the minimum size of the transceiver.

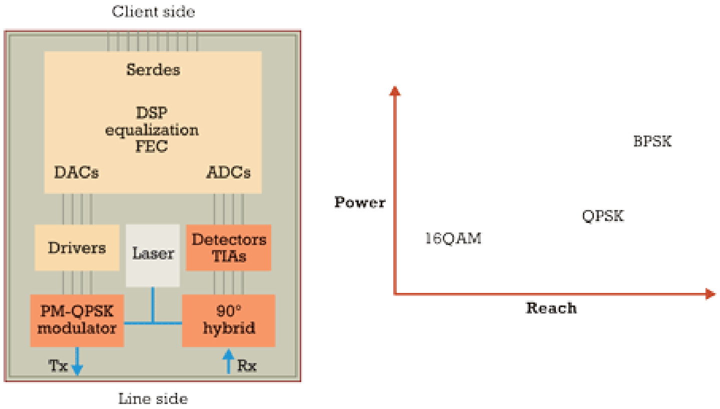


FIGURE 3. Schematic of a typical coherent transceiver and key building blocks and accompanying graph showing the tradeoff between power and reach for different modulation formats at a fixed data rate.

To reduce the power consumption and thereby meet the size requirements for metro applications, development of an ultra low-power ASIC is essential. In particular, development of an ASIC with specifications optimized for metro applications – rather than using a watered down version of a long-haul ASIC – is imperative.

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Naturally, the shorter transmission reach requires less link equalization, i.e., fewer filter taps and less processing are needed in the digital-signal processor (DSP). A reduction in signal-to-noise-ratio (SNR) performance is acceptable for shorter-reach metro applications, which allows for a lower sampling rate of ADCs/DACs and fewer bits to be carried through the DSP. These factors lead to lower power consumption. Lastly, implementing the ASIC in the latest CMOS process is important since a power reduction of 20–25% is expected with each reduction in node size. Today, 40-nm CMOS represents the state-of-the-art for mixed-signal ASICs. However, more advanced CMOS processes will be introduced soon and likely will become the preferred feature size for first generation metro ASICs.

The choice of modulation format has implications for power consumption issues. In general, power consumption escalates with increasing baud rate because the ADCs/DACs have to work at a higher sampling rate and more filter taps are required for a given link equalization. Therefore, higher-level modulation formats have the lowest power consumption since they work at a lower baud rate for a fixed data rate.

Conversely, the supported transmission distance decreases with higher-level modulation formats because of a reduced SNR and lower tolerance to fiber nonlinearities. As shown in Figure 3, binary phase-shift keying (BPSK) supports the longest reach, whereas 16 quadrature amplitude modulation (16QAM) supports very limited transmission distances. The 16QAM format is particularly sensitive to fiber nonlinearities induced by potential 10G neighbor wavelengths.

As indicated in Figure 3, QPSK provides a reasonable compromise between power and reach, supporting very long reach with power consumption only marginally higher than 16QAM. While an ASIC can be designed to support multiple formats, it's difficult to optimize each modulation format for the lowest power since each format requires a different number of bits carried through the DSP pipeline.

The optical components and associated electronics also have a large impact on the size, power, and cost of coherent transceivers. To meet the challenging size requirements of metro transceivers, miniaturization of the optics by integrating the many optical building blocks into a single chip or package will be critical. Photonic integration is expected to provide substantial cost and size savings by reducing the number of interfaces and packages.

On the receive side, integration of the 90o hybrid, detectors, and polarization beam splitters is conceivable. On the transmit side, integration and co-packaging of modulators, polarization combiners, and drivers is attractive. Integration of the laser with the modulators has limited advantages, since a single laser is likely to be shared as the transmit laser and local oscillator to reduce the cost and power of a metro transceiver. Also, a laser generally requires cooling, and a modulator and its drivers are expensive to cool.

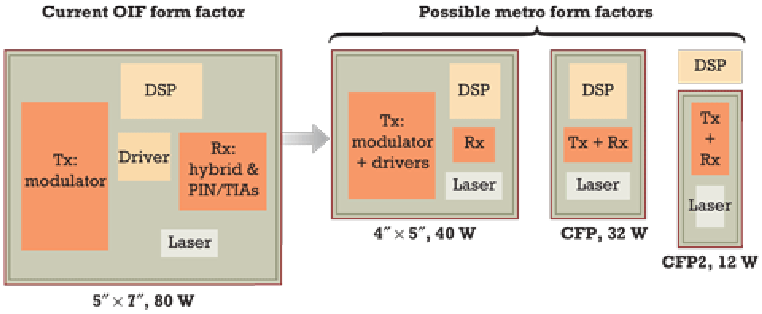

FIGURE 4. Possible options for smaller-form-factor coherent 100G transceiver modules.

A truly cost- and size-optimized design is likely to consist of an integrated receiver and transmitter in a single package. Several integration platforms are available, including indium phosphide (InP), silicon photonics, and a hybrid of the two. Each approach has its own merits and limitations. InP enables implementation of lasers, although the smaller wafer size and yields can be a concern. Silicon photonics takes advantage of CMOS foundries with large wafers and high yield, has a much tighter allowable bend radius, and does not require hermetic packaging. But it doesn't support implementation of optical gain for amplifiers and lasers.

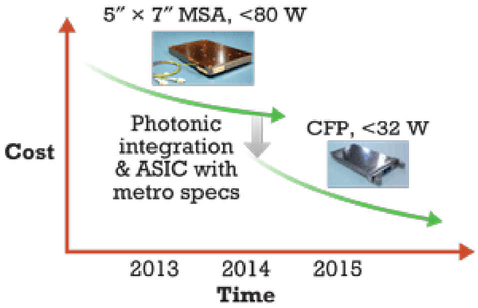

FIGURE 5. Cost evolution of 100G coherent transceivers with photonic integration and purpose-built ASICs for metro specifications.

It's important to note that the sophisticated DSP can compensate for many of the imperfections in the transmitter and receiver optics that are initially expected with extensive optical integration. A concurrent development of highly integrated optical components and the DSP is likely to provide a performance-, size-, and cost-optimized coherent 100G metro transceiver.

Metro form factors for 100G coherent transceivers

Service providers, equipment manufacturers, and module suppliers are today considering several options for a smaller-form-factor 100G coherent metro transceiver. Each option requires a different level of photonic integration. As shown in Figure 4, one choice is a nonpluggable 4×5-inch MSA module currently gaining traction in the OIF. Other choices include the pluggable CFP and CFP2 modules that support “pay as you grow” abilities and permit a single line card to support transceivers with different performance and cost points. A CFP module with the common CAUI-10 electrical interface would enable “mix and match” of line and client modules in the same slots.

Implementing a 100G coherent transceiver in a CFP module is more challenging than the 4×5-inch MSA module since considerably less space and heat dissipation are available in the CFP. Therefore, the CFP implementation would require a higher degree of optical integration and more power-optimized ASIC design. With careful engineering of today’s technology, it’s conceivable to implement a 100G coherent transceiver in a CFP module within the next year or two.

The CFP2 module is very attractive for applications where very high module density is required, e.g., on routers. A current challenge with the CFP2 module is fitting the ASIC and optics within the CFP2 power constraints of 12 W. Moving the ASIC out of the CFP2 module and placing it on the host card is a consideration for such applications. This strategy, however, can produce a very challenging high-speed and pluggable analog interface between the CFP2 and host card.

Again, concurrent developments of highly integrated optical components and DSP ASICs are likely to enable optimized CFP2 modules. Also important to note is that the CFP2 approach requires a level of integration that would be difficult to standardize, since a common footprint is likely suboptimal for any technology with a very high degree of integration. Modules smaller than CFP2, e.g., CFP4, have been discussed and would require even higher levels of integration.

The way forward

Coherent transceivers are expected to be very important building blocks for the emerging 100G DWDM metro market. But the industry needs to develop lower-cost and smaller-form-factor transceivers than are deployed in today’s long-haul networks. As shown in Figure 5, photonic integration and ASICs purpose-built for metro applications are keys to a successful execution of this goal.

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