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100G coherent networking – more than just the line rate

THE VORACIOUS GLOBAL DEMAND for bandwidth continues to increase unabated in all regions of the world with TeleGeography forecasting it to grow at a compound annual growth rate of nearly 50% for the foreseeable future. Streaming high bandwidth video-centric content is responsible for the bulk of the bandwidth growth. An increasing number of subscribers connecting at increasing per subscriber access rates are exacerbating this voracious growth in bandwidth demand, even as the world economy is called into question.

This incredible bandwidth demand directly affects the global network, including terrestrial and submarine networks, as accessed content can be located anywhere on planet Earth - a situation that will only be compounded with the increasing popularity of cloud services whereby content is centralised in a few select geographic locations. This steady increase in bandwidth demand is also associated with global price erosion mandating service providers to scale their networks in a cost-effective way while introducing new revenue-generating streams. Agile 100G networking is one such way of scaling service providers' networks while reducing overall network operating costs.


Brian Lavallée, Director, Global Networks Marketing, Ciena

MERITS OF COHERENT OPTICAL NETWORKING

Coherent optical networking lays the foundation for increasing channel rates to 100G while enabling multi-terabit capacities on existing networks, both overland and undersea. This innovative optical networking technology facilitates new networking architectures such as gridless and colourless networking that increases spectral efficiency and improves network agility, respectively, by removing technology hurdles imposed by legacy network architectures.

Numerous technology advancements allow for improved spectral efficiency, increased noise tolerance, and increased agility enabled by an ecosystem of technologies that embed intelligence into the 100G optical network. The numerous advantages of coherent optical networking are significant and real, as evidenced by numerous undersea cable operators having already adopted and deployed this optical transmission technology around the globe. New technologies that open up new network architectures and associated capabilities that will accelerate coherent networking adoption are the focus of this particular article.

ECOSYSTEM OF INNOVATIVE NEW TECHNOLOGIES

Coherent detection greatly improves noise tolerance resulting in greatly increased optical transmission capacity and reach, especially when compared to traditional Intensity Modulated Direct Detection (IMDD) techniques that have served the optical networking industry so well for decades. Commercially available coherent offerings are relatively new but have actually been researched for almost three decades. The attractive promise of greatly improved receiver sensitivity coupled with the complexity of coherent methods resulted in coherent systems receiving a great deal of attention in research communities to world over. However, coherent research was for the most part supplanted with the introduction and rapid adoption of the optical amplifier, which provided an easier and far less expensive method for improving noise tolerance.

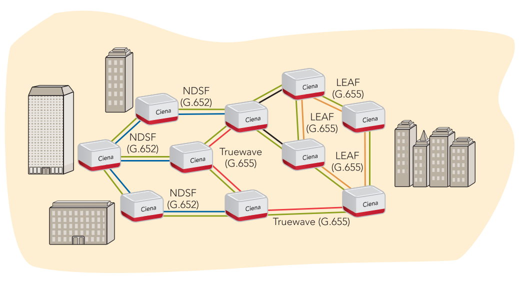
Coherent technology, as it pertains to optical networking, consumes a significant portion of research and commercial development today primarily due to the benefits afforded by its ability to cost-effectively address distortion compensation, polarisation de-multiplexing, and carrier extraction. All of these capabilities are enabled by one of the most important characteristics of coherent transmission, which is access to the optical electrical field facilitated by Digital Signal Processing (DSP) technology. DSP, working in conjunction with coherent optical detection, is the mathematical engine whereby complex algorithms are executed to recover received signals from impairments incurred during transmission, which although understood, were not electronically inaccessible, until recently.

Compensating for impairments such as chromatic dispersion and Polarization Mode Dispersion (PMD), among others, in the mathematical (electrical) domain is far more cost-effective than doing so in the far more expensive and complex optical domain. Being able to accurately compensate for incurred transmission impairments in the electrical domain requires an extremely fast and highly accurate Analog-to-Digital Converter (ADC) to properly convert a received signal from the optical domain to the electrical domain. Once the received signal is accurately translated into the electrical domain, complex mathematical algorithms can be applied to correct for noise and other impairments to accurately extract the desired transmitted information.

Chromatic dispersion refers to wavelength-dependent spreading of light as it propagates down optical fibres. Compensating for chromatic dispersion, which is a linear effect, has traditionally been implemented using fixed DCM (Dispersion Compensation Modules), which house spools of optical fibre with characteristics that counter the effects of chromatic dispersion. In other words, light pulses widen as they propagate down an optical fibre, and DCMs placed at prescribed intervals will "shorten" the pulses back together, as close as possible to their original shape.

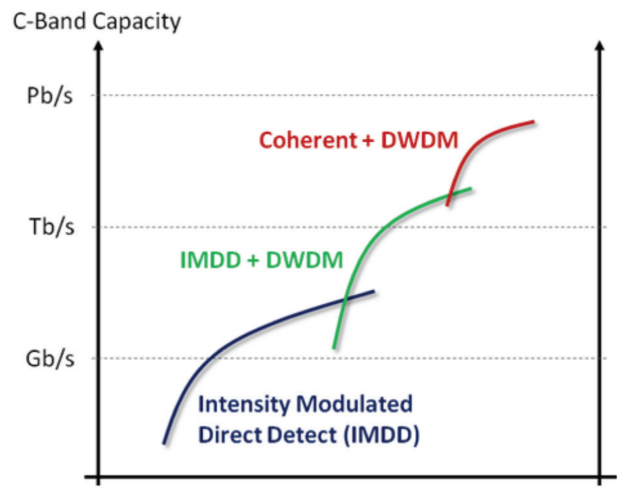
When using DCMs, fixed dispersion maps must be used forcing service providers to preplan the ultimate network length and topology, forecast where OADM sites will occur, select DCM values individually for each span, and reengineer after repairs or rerouting. Using DSP technology, electronic Dynamically Compensating Optics (eDCO) can be implemented, which allows for the complete removal of all DCMs from the network resulting in a significantly simpler network design and deployment task. eDCO allows service providers to design agile optical networks, regardless of mixed fibre types and lengths, using Reconfigurable Optical Add/Drop Multiplexers (ROADM) by essentially eliminating the distance/fibre dependencies related to chromatic dispersion. This then allows wavelengths to be dynamically routed around a network, over different distances and different fibre types and mixes as illustrated in Figure 1, since fixed dispersion compensation limitations are eliminated using DSP.

Figure 1: Typical network of mixed fibre types and lengths



Coherent networking also enables electrical compensation of Polarisation Mode Dispersion (PMD) dynamically in real-time as network characteristics change over time. Electrically compensating for PMD allows service providers to deploy 100G wavelengths over problematic older fibres deployed in the early days of optical fibre manufacturing when precise control over the shape of the optical core was not known to cause PMD-related issues. In fact, there are cases where 100G wavelengths are now running over fibre plants that in the past could only support 2.5G wavelengths using older non-coherent modems such as those based on IMDD technology. 100G coherent modems allow service providers to leverage older underused fibre plants that were not being monetized by breathing new life into significantly underused network assets.

Figure 2: IMDD vs. coherent detection optical network capacity comparison



Compensating in the cost-effective electrical domain also facilitates the incorporation of complementary technologies that further enhances coherent optical networking capabilities, such as the implementation of soft Forward Error Correction (FEC). Traditional transmission products use hard-decision FEC where the receiver determines if a received bit is a one or zero based solely on a decision threshold. Soft-decision FEC incorporates probabilities into its FEC decision algorithms allowing error correction decisions to be made with additional information, resulting in significant increases in system reach, capacity, and link budget margins. Embedding ADC and DSP functionality into a coherent receiver means that soft metrics are readily available to implement soft FEC.

Optical transmission systems must provide service providers with Bit Error Rates (BER) better than 10-15, which means complicated mathematical algorithms are required since multi-bit metrics for signals operating at 100G means greater than 100 billion information bits are received every second creating vast data flows and significant associated processing power. For heat efficiency alone, the processing task must be implemented within the same ASIC as the DSP, which is enabled with continued silicon integration, such as 32ηm CMOS ASIC fabrication, which allows for processing power in excess of 75 trillion operations per second, perfect for effective 100G processing tasks.

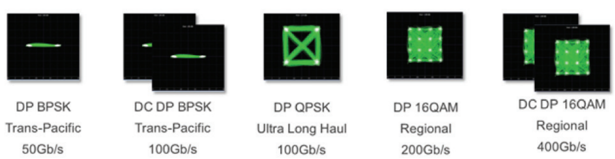
Integration of DSP in the transmitter is the latest industry advancement in coherent networking and delivers some very important flexibility and economic networking benefits with its spectral shaping and programmable modulation capabilities. Spectral shaping fits the traffic carrying signal in the minimal amount of optical spectrum, resulting in improved system margin in cascaded filter/OADM environments, as well as optimal spectral efficiency on a flexible wavelength grid. Moving forward, spectral shaping is also critical for ensuring spectrally efficient Terabit transmission super-channels.

High-speed DSP technology, and the processing power afforded by 32ηm CMOS fabrication, allows for the embedding of intelligence that is implemented through complex algorithms executed within the world of mathematics. ADC and Digital to Analog (DAC) devices enable continuous and real-time optimisation of the optical link between the transmitter and receiver, since both have embedded intelligence and are intimately tied together by a communications feedback loop. This allows the network to autonomously monitor link performance and perform any necessary adjustments in real-time at the transmitter and receiver. This ensures link optimisation is maintained as it ages and impairments change over time, for example. Detrimental issues inherent to coherent networks, such as cycle slips that lead to traffic hits or outages, can be effectively compensated for mathematically, with the correct techniques, without having to resort to reduced link capacity and reach.

AGILE OPTICAL NETWORKS

Programmable modulation enabled by transmitter DSP enables a very flexible transceiver that can be optimised for a variety of solutions, based on the desired network characteristics, as shown in Figure 3. This embedded transmitter flexibility also allows for a significant reduction in sparing, as a single circuit pack can now be deployed in a wide variety of different submarine and terrestrial network applications characterised by different reaches, capacities, and latencies.

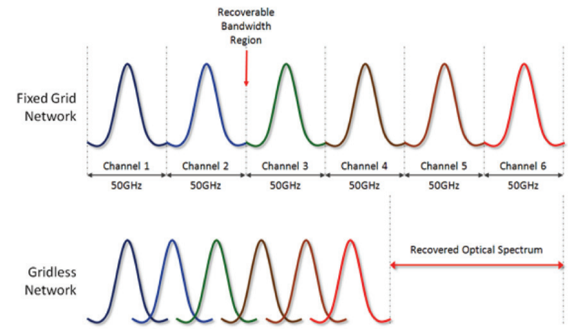
Figure 3: Software provisionable modulation flexibility and target applications



Coherent detection, along with complementary technologies such as ROADMs and colorless filters, facilitate colourless networking architectures whereby wavelengths can originate and terminate anywhere in the network, all under the control of software typically implemented via intelligent Layer 0 control planes. At the transmitter, programmable modulation allows for changing of signal constellation based on network requirements. At the receiver, numerous wavelengths are simultaneously received with the specific wavelength to be extracted performed by selective receiver tuning, analogous to tuning a radio to the desired station. Between the transmitter and receiver, colourless filters and agile ROADMs are deployed in favour of traditional optical filters that determine the network ingress and egress points of all wavelengths. In other words, if a transmitter or receiver is connected to a fixed port at 1530.72ηm, for example, only that wavelength can be used thereby hindering the capability of where a wavelength can enter or leave an optical network.

Colourless networking removes this hindrance allowing transmitters to tune to any wavelength while receivers can tune to one of multiple received wavelengths. The ability to precisely control spectral shaping at the transmitter allows for the traversing of more consecutive ROADMs, thus increasing the size and flexibility of agile network designs, a key design requirement of most network planners.

Figure 4: Fixed grid vs. gridless network comparison



100G – THE LINE RATE IS ONLY PART OF THE SOLUTION

The line rate itself is only a small part of the 100G network migration story. Numerous other technology advancements form a cohesive technology ecosystem that together not only allow for optical networks to be taken to previous unheard of capacities, but also reduces network costs to address global pricing declines experienced the world over.

The ecosystem of technologies discussed herein facilitates the evolution of optical network architectures from rigid fixed grids to increasingly flexible gridless and colourless architectures that enable new capabilities and associated revenue-generating streams. As optical networks shift into the next generation of architectures and enabled capabilities, 100G and its ecosystem of complementary technologies will be at the forefront of this technology shift.

The ecosystem of technologies that enable agile 100G networking today will be the same technology foundation that enables the path to 400G networks, and beyond.

Contact
Brian Lavallée is the Director responsible for Global Networks Marketing at Ciena and can be reached at: blavalle@ciena.com