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WHITE PAPER

Flexible Spectrum Networks

Are Not All That Flexible

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Flexible spectrum networks (FSNs), also called flexible grid, gridless or elastic networks, are being touted by some as the technology for the next generation of transmission line rates and the optical network. FSNs are designed to allow the center frequency and/or bandwidth of optical channels to be dynamically adjusted. The purpose of the elastic networks is to open up more flexibility in the transceivers and switches for spectral networks operating at 100 Gb/s and beyond data rates.

FSNs require the use of flexible spectrum wavelength selective switches (WSSs) within reconfigurable optical add-drop multiplexer (ROADM) nodes. Such flexible WSSs operate similar to a conventional 100 GHz or 50 GHz WSS, but with finer channelization granularity, such as 25 GHz or 12.5 GHz.

FSNs allow adjustment of the channel bandwidth to match the needs of a particular modulation format. Proponents of such functionality argue that it can future-proof a network to support bit rates above 100 Gb/s, or allow for better spectral utilization in systems that use advanced modulation formats with an adjustable spectral occupancy, set to match a given reach and bit rate. Although this is an intriguing proposition from a conceptual standpoint, the practical viability and actual need for FSNs is questionable, as explained in this paper.

Supporting 100 Gb/s Wavelengths and Beyond

FSNs are not needed to support 100 Gb/s DWDM signals because networks with a fixed 100 GHz or 50 GHz ITU grid have sufficient bandwidth to support a 100 Gb/s PDM-QPSK signal; the de facto technology for serial transmission at 100 Gb/s.

Interfaces for DWDM transmission above 100 Gb/s, such as 200 Gb/s, 400 Gb/s or 1 Tb/s, are in the exploratory phase. When they are eventually commercialized, they will likely involve multi-level modulation, such as PDM-16QAM, lane bonding using multiple DWDM wavelengths, and/or increasing the baud rate to match, say, a 100 GHz ITU grid. Although one could deviate from the standard ITU grid when defining these new interfaces, it is certainly not necessary. For example, four 100 Gb/s PDM-QPSK signals could be bonded to provide a 400 Gb/s signal using four DWDM wavelengths; or, five 200 Gb/s PDM-QPSK or PDM 16QAM signals could be bonded to provide a 1 Tb/s signal using five wavelengths on a 100 GHz or 50 GHz grid, respectively.

Another consideration is spectral efficiency, or, in the context of DWDM transmission, the product of distance and spectral efficiency. One view is that the dead band between channels in a conventional network is wasted spectrum that could be recaptured using an FSN. Another view is that a guard band between channels is generally a good thing, because it provides the isolation needed to mitigate interference for non-Nyquist transmission. Although it may be true that the spectral-efficiency-distance-product could be improved “a bit” using closer spaced carriers and more complex multi-carrier signal processing, it is reasonable to assume that such complex transmission formats are likely to be adopted in point-to-point applications, such as transoceanic, where the full transmission spectrum is naturally available, and an increased cost in terminal equipment can be easily justified. For terrestrial mesh applications, however, the use of FSNs to accommodate such signals is a questionable value proposition, as explained in the following section.

Supporting Commodity 10 Gb/s and 40 Gb/s DWDM Wavelengths

Commodity 10 Gb/s DWDM transceivers, such as XFPs, require the residual dispersion to be no greater than ~1200 ps/nm at the receiver. This is achieved using bulk compensation within the line system to compensate all DWDM wavelengths together. Although 40 Gb/s transceivers based on, say, DPSK or DQPSK modulation, use a tunable dispersion compensator at each receiver, the tuning range is generally limited to the residual dispersion typical of a bulk-compensated 10 Gb/s system, implying bulk compensation must still be present in the line system. Hence, to support commodity 10 Gb/s and 40 Gb/s wavelength services, the system must employ bulk line compensation.

Although there are 10 Gb/s and 40 Gb/s transceivers that do not require bulk line compensation, due to their use of coherent detection and/or advanced digital signal processing (DSP), they are the exception and not the rule. Not only do such transceivers raise the question of cost, but most network planners are simply not willing to adopt a DWDM infrastructure that is incompatible with commodity transceivers. Employing these transceivers confines operators to a specific vendor’s DWDM interfaces and connecting equipment. Instead, they are more likely to adopt a DWDM infrastructure that is compatible with commoditized interfaces available from multiple vendors, providing the security of multi-vendor sourcing and the inherent cost reductions that come from multi-vendor competition. If the DWDM network needs to be compatible with essentially any connecting networking equipment from any vendor, support for commoditized 10 Gb/s and 40 Gb/s line interfaces is essential, which means bulk line compensation is essential.

Dispersion Management

Legacy DWDM networks have generally been deployed using bulk dispersion compensation modules (DCMs) based on dispersion compensating fiber (DCF). However, PDM QPSK signals with coherent reception do not require optical dispersion compensation, because all compensation can be achieved in the electrical domain at the receiver. In fact, PDM QPSK signals with coherent reception perform better when there is no in-line DCF, due to the reduced impact of nonlinear interference effects. From this standpoint, PDM QPSK signals are arguably incompatible with systems employing bulk dispersion compensation. Over the past few years, however, DCMs using periodic fiber Bragg gratings (FBGs) have become the technology of choice, due to their low insertion loss, tolerance to high input power levels, negligible latency, small form factor, and lower cost.

Periodic FBG DCMs are channelized devices by their nature. They realize group delay variation across each channel passband, needed to compensate dispersion for the respective channel, while adding negligible group delay variation between channels. In other words, bulk compensation using such DCMs provides optical dispersion compensation for each wavelength, while allowing the system to look like an uncompensated system with respect to inter-channel, nonlinear interactions.

As the launch power is increased into each span, the impact of intra-channel nonlinearities can become a dominant impairment for a PDM QPSK signal, which can again be mitigated if bulk line compensation is avoided. However, even for a system with no in-line compensation, there is an optimal span launch power, typically around 0 dBm, that maximizes the achievable BER for common transmission fiber types. At such power levels, the nonlinear-induced OSNR penalty for including bulk line compensation is, at most, a few tenths of a dB. Hence, from a practical standpoint, the slight reduction in OSNR sensitivity for a PDM QPSK signal, to make the network compatible with commodity 10 Gb/s and 40 Gb/s transceivers, is clearly a sensible and desirable tradeoff. Hence, unlike a network using legacy DCF, a network using periodic FBG DCMs is compatible with both commodity 10 Gb/s and 40 Gb/s transceivers, as well as next-generation 100 Gb/s coherent technology and beyond.

Another potential advantage to using bulk FBG compensation with coherent technology is that DSP complexity can be reduced, because the residual dispersion window that must be accommodated is much narrower than with no line compensation. A reduced DSP complexity provides an opportunity for lower-cost, lower-power coherent transceivers, and ultimately, a lower cost network.

Planning and Operational Concerns

There are significant planning and operational concerns with FSNs, including bandwidth management and service planning, control plane operation and complexity, multi-vendor equipment inter-operability, and optical power management. Characterizing, understanding and managing the performance of dynamic mixed-signal transmission in a FSN would certainly be a major challenge, to say the least. These concerns alone represent a significant barrier to the practical application of FSNs, and may make theme unviable for most networking scenarios.

Another consideration is the use of channelized multiplexers and de-multiplexers for wavelengths added or dropped at a given node in colored ROADM applications. High access port density is typically achieved using array waveguide gratings (AWGs), which are channelized devices that are not compatible with a FSN concept. Hence, a FSN would mandate the use of colorless access ports, implying a more expensive ROADM architecture where it may otherwise not be required.

The Just-in-Case Argument

Flexible spectrum ROADMs are currently a solution looking for a problem, not the other way round. Still, even though there is no use for flexible spectrum ROADMs in networks today, some will argue that they should be deployed anyway "just-in-case" they are needed in the future. Of course, that argument can be made for any technology, no matter how ridiculous. The fact is, future ROADM technologies will likely see fundamental changes in design, and adopt new technologies and further levels of integration that allow them to achieve full colorless, directionless and contentionless (CDC) functionality at a much reduced cost. Providing full CDC functionality economically would then likely mandate the use of such new technologies throughout a network. Similarly, increasing transmission capacity well beyond what is possible today will likely involve new fiber types, such as multi-core or few-mode, and new technologies to interface with these, none of which are likely to be compatible with today's flexible spectrum ROADM architectures. Moreover, limiting a network solution to a flexible spectrum architecture implies a proprietary design, with fewer potential vendors and a resulting higher cost. Such a limitation, solely based on a "just-in-case" argument, that itself is hard to substantiate, makes little sense.

Another consideration is that some conventional 100 GHz and 50 GHz ROADMs provide a continuous passband when energizing two or more adjacent channels. As such, they are already "flexible grid," just with more coarse channelization granularity, and they are able to support a high bit-rate superchannel with any intra-carrier spacing and spectral efficiency.

A Real Flexible Network Requires a Standardized Fixed Grid

If a flexible DWDM network is defined as one that can accommodate both colored and colorless access structures, and that is compatible with both legacy 10 Gb/s and 40 Gb/s wavelengths using commoditized interfaces, as well as 100 Gb/s and higher wavelengths using next-generation coherent technology, then such a network can be realized today using channelized FBG DCMs and AWG multiplexers. In this case, there is no value or need for FSN ROADMs. If instead you define a flexible network as one that cannot support legacy 10 Gb/s and 40 Gb/s wavelengths and/or colored access structures, but that is potentially compatible with interfaces that do not yet exist, and may never exist, then FSN ROADMs can play a role in such a network. In other words, depending on how you define "flexibility," it may actually imply the use of a fixed, channelized grid.

Author Biography

Sheldon Walklin (sheldon.walklin@optelian.com) is Chief Technology Officer at Optelian. He received a BSc with distinction and a PhD in Electrical and Computer Engineering from the University of Alberta in 1992 and 1997, respectively. In the mid '90s he pioneered research at TRLabs on advanced modulation formats for high-speed optical transmission. He has been a Radio System Designer at Nortel, Senior Designer at RIM, Optical System Designer at Innovance, Control System Designer and Manager of Hardware and Software at Metconnex, Systems Architect and Director of Systems Architecture at Optelian, and was appointed as Optelian's CTO in 2010. He is a member of the IEEE Communications Society, Photonics Society and CREATE Program Committee for Next Generation Optical Networks.

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