Flexible Light Orchestration of Wavelengths

A new control plane supporting flex spectrum networks

The service provider challenge

Introduction

In an environment where bandwidth requirements continue to grow as revenues decline, service providers are looking for cost-effective ways to maximize their network infrastructure. When applications were fairly static, service providers simply overprovisioned the network to meet bandwidth requirements. However, today’s traffic patterns and applications have proven to be increasingly dynamic, and simply expanding the scale of the network doesn’t solve the problem. And as networks have grown larger, so has the scale of network management complexity. For the optical network to be an efficient transport platform for today’s device and application traffic, the network must be flexible, using the entire spectrum, enabling application traffic to go where it is needed, when it is needed.

In the past, network growth and transitions were delivered with new generations of hardware technology. Today, some of the hardest transitions are operational and driven by network software enhancements. But new opportunities are now emerging. By using a new, flexible control plane, the software-driven network lets providers adjust their bandwidth automatically and take a proactive approach to the typical tradeoffs that exist between capacity and distance in the optical network.
Although optical fiber bandwidth has increased significantly in long haul and metro areas, it is not enough. Many service provider networks are simply not ready to handle 4K video, interactive gaming, and in addition to higher broadband connectivity. 4G and 5G networks, with the increasing number of mobile phones, tablets and laptops, personal activity devices, and the Internet of Things sensors, present additional challenges when that traffic is aggregated onto a optical network. Applications that rely on real-time information—for example, autonomous cars—add to the complexity of the problem. Requiring faster transmission speeds to operate, they must avoid real-time congestion in the network to provide value and assurance.

Maximizing the optical network

With more devices and more applications running on the network with dynamic traffic patterns, how can service providers maximize their existing optical network while building enough bandwidth overhead to survive the massive increase in data? One approach is to build optical networks with the flexibility to use the full fiber spectrum.

Although the spectrum can be increased in different ways, such as expanding from the C-band into the L-band and S-band, some paths to expansion can be costly because of the limited availability of extended band components. Software can provide another path to use the full fiber spectrum. The latest Cisco® software release supports the flexible control plane on the Networked Convergence System (NCS) 2000 platform - which can utilize the flexible and reconfigurable grid to support the required Nyquist spacing. By using the flexible control plane, providers can adjust their bandwidth automatically to take advantage of the physical tradeoffs that exist in all optical networks.

Wavelength-switched optical networks and Flexible Light Orchestration of Wavelengths

Wavelength-Switched Optical Networks (WSON) follow the standard ITU-T grid specification, which defines up to 50 GHz channel spacing. To ensure flexibility in the spectrum and assignment beyond 50 GHz, the ITU-T defines an extended granularity (G.694.1) in the channel spacing and introduces the spectrum concept instead of single lambda. Now, an optical circuit can be associated with a specific spectrum containing one or multiple carriers instead of a single lambda. The spectrum can have multiple 12.5 GHz width slices positioned at 6.25 GHz to enable service providers to use the entire spectrum.

There are some consequences that come with this approach; it increases the complexity of running the network, by putting more requirements onto the optical control plane. Optimizing the transmission layer to cope with distance and capacity tradeoffs and introducing multiple modulation formats and multiple baud rates also add to the complexity.
Optimizing and defragmenting the provisioned channels, while preserving the overall spectrum, can present issues as well. But these can be solved by Cisco Flexible Light Orchestration of Wavelengths (FLOW).

Existing optical networks typically use channel spacing of 50 GHz, where the pipe size is always defined and remains the same at 100 Gbps wavelengths. However, new networks need faster speeds such as 200 Gbps, 400 Gbps, and even 1 Tbps for single and multiple carriers. The 50 GHz grid is not adequate for these larger bit rates because the carriers are inefficiently packed. And while 50 GHz was the best technology at the time, it isn’t any more. Now we have flex spectrum with new lasers that can do much more, but up until now, we didn’t have the software to take advantage of it.

FLOW is a new software control plane that supports flex spectrum by extending the Generalized Multiprotocol Label Switching (GMPLS) control plane. It is compliant with the Spectrum Switched Optical Networks (SSON) standard and allows operators to provision, protect, and restore new bandwidth by simply dismounting the fixed grid network. FLOW incorporates enhanced optical calculation algorithms to manage the new higher bit rate wavelengths. FLOW is flexible because it is software configurable. By using software to alter your channel spacing for bandwidth needs, future-proofing is also possible. And with the availability of enhanced algorithms integrated into a software-configurable solution, bandwidth congestion can be easily adjusted on a dynamic basis. This is an important new benefit for optical networking.

**Flex spectrum**

Flex spectrum enables Reconfigurable Optical Add-Drop Multiplexer (ROADM) devices to manage portions of the optical spectrum by delineating a range of frequencies. This does not prohibit 50 GHz grid support. Figure 1 compares a slice of 50 GHz with four slices to a flex spectrum with assignable dimensions that can be switched inside of the ROADM.

**Figure 1. Delineating start and stop frequencies**
The signal is condensed in the spectrum, and multiple carriers can be inserted to be optimized within the space.

To manage the flex spectrum, we need the FLOW control plane. Because the signals are closer together, a small percentage of overhead penalty must be applied. Based on testing, the penalties increase as higher Quadrature Amplitude Modulations (QAMs) are utilized. Extensive testing and modeling have been done to provide a clear indication of Optical Signal-to-Noise Ratio (OSNR) penalties compared to carrier spacing with Nyquist shaping. Therefore, with flex spectrum, a certain amount of overhead will need to be factored in as the modulation increases and is associated with each carrier.

Figure 2. Flex spectrum use

Baud rate

Implementing flex spectrum also requires a change to the baud rate. As you can see in Figure 2, 64 GBaud doubles the bit rate for each modulation format. However, 64 GBaud will not fit into the 50 GHz network spacing. Therefore, different spacing and a different portion of the spectrum are required to support the 64 GBaud signal. It is important to note that when the modulation format is changed, there is a trade-off between capacity and distance. As the modulation format increases, the distance or reach will be limited to hundreds of kilometers as compared to other modulation formats.

Table 1. Baud rate comparison

<table>
<thead>
<tr>
<th>Today: 32 GBaud</th>
<th>Future 64 GBaud</th>
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</thead>
<tbody>
<tr>
<td>Quadrature Phase Shift Keying (QPSK): 100 Gbps</td>
<td>QPSK: 200 Gbps</td>
</tr>
<tr>
<td>8-QAM: 150 Gbps</td>
<td>8-QAM: 300 Gbps</td>
</tr>
<tr>
<td>16-QAM: 200 Gbps</td>
<td>16-QAM: 400 Gbps</td>
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<tr>
<td></td>
<td>32-QAM: 500 Gbps</td>
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<tr>
<td></td>
<td>64-QAM: 600 Gbps</td>
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</tbody>
</table>

What is FLOW?

FLOW is a new control plane that supports flex spectrum networks by extending the GMPLS control plane. It is compliant with the SSON standard and allows an operator to provision, protect, and restore bandwidth by the simple dismounting of the fixed grid network. FLOW contains enhanced optical calculation algorithms to manage the new physical higher bit rate wavelengths being deployed.

Implementing FLOW

Use case: 30 to 50 percent fiber capacity increase

A 50 Ghz ITU-T grid maximum capacity calls for 96 channels across the C-band. Using shaping of the transmission of the coherent interface and the flex spectrum capability of the ROADM, we can boost the capacity from 96 wavelengths up to 150 wavelengths and possibly more. For practical applications, a realistic number is around 130 wavelengths, which is at least a 30 percent improvement on the existing fiber.

Use case: a “fat pipe” that doesn’t fit standard 50GHz ITU-T grid

The NCS 1000 series is the first to support DWDM slices of 250G, and in a standard ROADM network, that would require a new 62.5 GHz grid to be transported. Future 2 x 150G 8-QAM carriers and future double- baud rate signals will not fit in a 50 Ghz grid. All of those require a FLOW control plane.
A new generation of optical transponders

A new generation of optical transponders will be able to use the higher modulation scheme up to 64-QAM to reach a per wavelength capacity of 600 Gbps. However, because the density of the symbol at 64-QAM/64 Gbaud is much higher, the OSNR requirement is also higher to discriminate between the different symbols. With preliminary testing, we have found that 64-QAM for 600G requires a specific Nyquist spacing and a minimum grid spacing. At 64-QAM for 400G, the baud rate is much lower, and Nyquist spacing is lower, thus increasing the potential number of channels on the grid. The Cisco Digital Signal Processor (DSP) supports 8-QAM, 16-QAM, 32-QAM, and 64-QAM modulation formats and thus is very flexible in supporting any wavelength an operator prefers.

The media channel

The FLOW control plane includes a new optical signal hierarchy called a media channel to support the flex spectrum capability. The media channel acts as the continuous spectrum portion from the initial source to the final destination, which brings a single or many carriers. The set of carriers inside the media channel is called a “superchannel.” The media channel includes information about the allocated optical bandwidth as well as the path within the network.

In the past, a carrier was a single wavelength within a Dense Wavelength-Division Multiplexing (DWDM) system. The general rule was one transponder, one wavelength, one carrier. A superchannel is a set of one or more homogeneous (same type) optical carriers, for example, 2 x 150G 8-QAM signals. The superchannel has information about the carriers and all the optical data required. It is a single logical entity of two homogeneous carriers with the same modulation rate and format.

One carrier equals one wavelength. It is defined by the optical interface and transponder. Additional parameters are the signal bit rate plus the Forward Error Correction (FEC) type, possible encoding, the modulation format, the modulation guard band (one per side), the filtering guard band, and the termination group (where they are terminated in the add/drop stage). All of these parameters define the carrier.

Those are the entities defined to construct the infrastructure of FLOW. The rule is that there is always one superchannel mapped within a media channel. The superchannel can also be a single carrier. To maximize spectral efficiency, several media channels can be aggregated to form a media channel group that will have the same source and destination path and will be managed and routed as a single entity. The entities can be seen in Figure 3.
**The carrier superchannel**

There is also a new concept of carrier superchannel. In the past, the carriers were known as individual single wavelengths inside a DWDM system. The general rule was one transponder, one wavelength, one carrier. The superchannel is a set of one or more homogeneous (same type) optical carriers. An example of a superchannel is 2 x 150G 8-QAM signals. The superchannel has information about the channels contained and all the optical data required. It is a single logical entity of two homogeneous carriers with the same modulation rates.

**Network future-proofing with FLOW**

FLOW is a flexible solution because it is software configurable. Network future-proofing is possible when you can alter your channel spacing for bandwidth needs by software.

Cisco FLOW delivers:

- Increased spectral efficiency up to 50 percent
- State-of-the-art technology
- An advanced control plane
- An existing Single Module ROADM- Flex Spectrum (SMR-FS) may be software enabled to support FLOW
- Support for mixed coexistence between the WSON network and FLOW
- Optimized support for 100G, 200G, and 250G wavelengths and future 300G, 400G, and 600G wavelengths with FLOW

When the carriers are in a superchannel, they are a single logical entity and share the same payload. If one carrier fails, the superchannel fails. The FLOW control plane will take into account the difference and the requirements to handle the superchannels accordingly. Likely the most common superchannel type will be that each carrier has its own termination point or port. In this case, filtering is required, and the ability to squeeze them tightly is not possible because of the port filtering band.

With the media channel, which is the continuous spectrum section allocated from source to destination to support a single superchannel, the parameters required are source and destination, the path of the media channel, the central frequency of the media channel and its bandwidth, the superchannel included, and carrier frequency inside the superchannel.

**Figure 3. Media channels and media channel groups**

**Media channel groups**

It is possible to aggregate several media channels into a Media Channel Group (MCG). The primary use case is where multiple or many 100G wavelengths have already been deployed in a network. These can now be grouped together, but if one fails, the other waves are not affected. The FLOW control plane is alerted that these wavelengths have been put into a media channel group. The FLOW control plane will also use this information to squeeze the media channels into the smallest portion of spectrum. The media channel group is also defined by the source to destination of the path. The media channel group is a collection of media channels that need to be transported without interruption. You can also predefine a media channel group to reserve optical bandwidth and populate it with media channels later.
In addition, the bandwidth of an existent media channel group can also be extended (increasing the number of slices) to allow the transport of more media channels. This can be automated or done manually by the user. You can also shrink the bandwidth of a media channel group that already exists to release some optical bandwidth. This can only be done manually by the user.

Advantages of FLOW

Existing optical networks can benefit substantially from the new Cisco FLOW control plane. Fiber carrying capacity is increased on the existing infrastructure, along with support for next-generation data rates such as 600G, 1 Terabit, and higher. With FLOW, the bits per port are increased, which in turn decreases the cost per bit by leveraging the advances in silicon. In addition, advances in automation and simplification (using software) will reduce operational costs and provide more flexibility.

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FLOW is a flexible solution because it is software configurable. Network future-proofing is possible when you can alter your channel spacing for bandwidth needs by software. With the agility of a configurable solution, bandwidth congestion can be easily adjusted on a dynamic and automated basis. The capital and operational advantages of FLOW and massive spectral efficiency are obvious: bandwidth on existing platforms can be increased by up to 50 percent while optimizing larger wavelengths within the same spectrum, resulting in significant CapEx and OpEx savings for all network operators.