Book Chapter Review-Evolution from Wavelength-Switched to Flex-Grid Optical Networks

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Agenda

- Objective
- Identifying the Problem
- Solution: Flex-Grid Network
- Fixed-grid DWDM Architecture
- WSS Technology: Fix and Flex-grid
- ROADM Architecture
- Migration to Flex-grid: Is it a necessity?
- Migration to Flex-grid

Paper Review

Lord, Andrew, et al. "Evolution from Wavelength-Switched to Flex-Grid Optical Networks." *Elastic Optical Networks*. Springer International Publishing, 2016. 7-30.

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Objective

- ❖Basics of Dense Wavelength Division Multiplexing (DWDM) and shows how this will be superseded by a more flexible use of optical fiber spectrum, together with more flexible transponders offering multiple bit rates from same device.

- ❖Explains benefits of this new approach and examines the optical filter technology that enables it.

- ❖Finally, how networks will migrate towards this new network operating paradigm.

Identifying the Problem:

- Until recently, the large available spectrum provided by optical fiber has been significantly more than required.
- Adding more data to a fiber was a simple matter of adding additional wavelengths, making use of the fact that at low enough power levels, multiple waves can be supported on the same fibre without interaction.
- Recently, continued internet-based exponential traffic growth has resulted in this spectrum to start to fill
- This has focused attention on two related areas—how to more effectively manage the spectrum and how to fill the spectrum up as much as possible with light signals.

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Solution: Flex-Grid Network

- ITU-T proposed a finer grid associating a variable frequency slot to an optical connection, called flexible frequency grid, or more commonly flex-grid.
- Flex-grid allows the allocation of a variable number (n) of fixed-sized slots to an optical channel as per demand. A slot measures 12.5 GHz, allowing the transmission of 100 Gb/s channels in 37.5 GHz ($n = 3$), rather than 50 GHz in the fixed grid case.

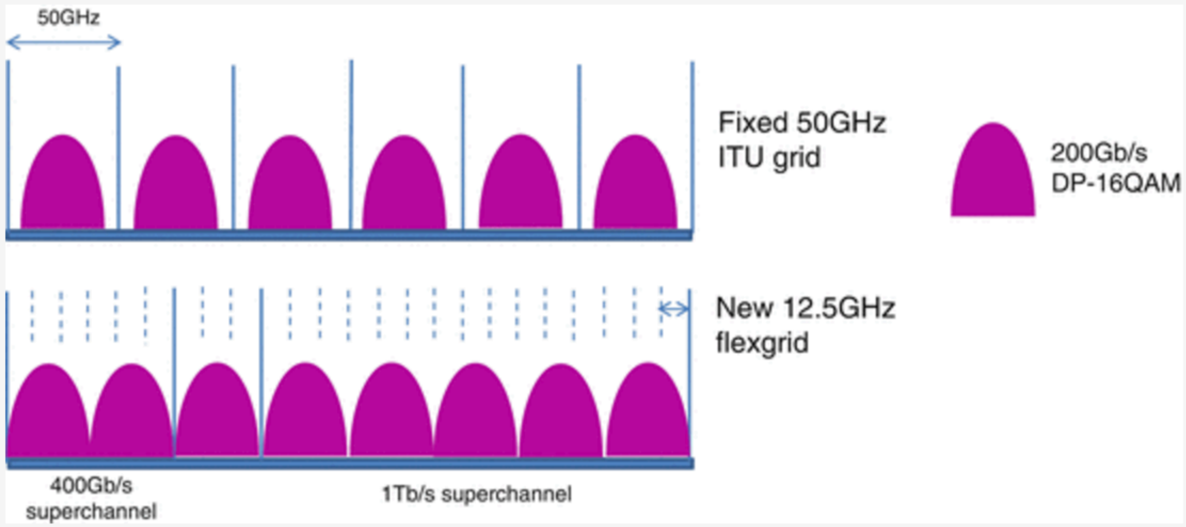

Fig. 2.1
12.5 GHz resolution for flex-grid allows closer packing of channels. Concatenation allows creation of a 400 Gb/s and 1 Tb/s super-channel

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Fixed-grid DWDM Architecture

- Multiple wavelength channels are generated in optical transmitters, each being modulated by a data signal and then combined by a WDM multiplexer.
- Composite DWDM signal is then transmitted over an optical fibre link with optical amplifiers to boost signal before transmission, to compensate fibre loss and to improve receiver sensitivity.
- The in-line amplifiers are usually two stage amplifiers as shown in the inset in Fig. 2.2, where the Dispersion Compensation Module (DCM) is used in each span to compensate fibre chromatic dispersion

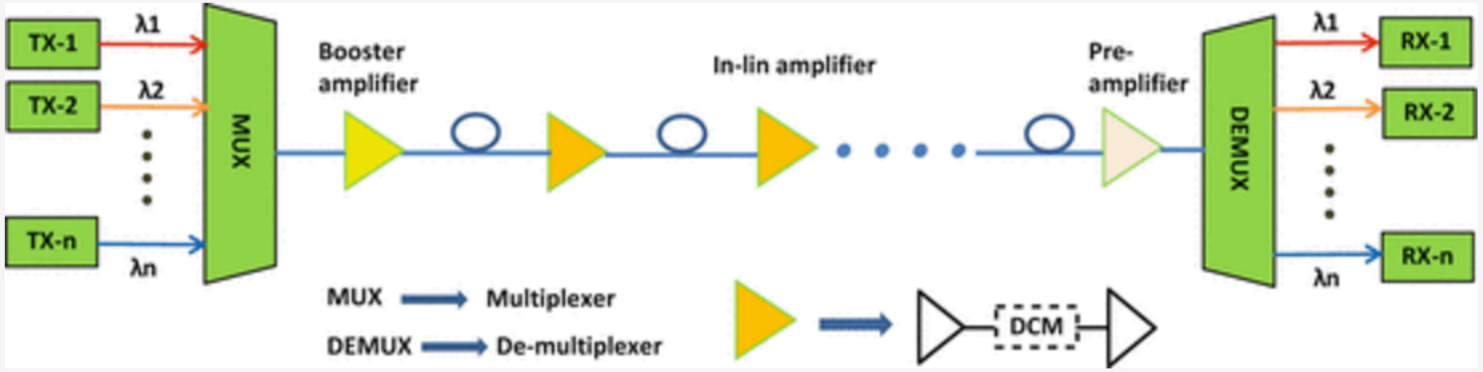

Fig. 2.2

Schematic of a point-to-point DWDM system

Fixed-grid DWDM Architecture

- When using coherent technology, the fibre dispersion can be compensated in the coherent receivers instead. Hence the new DWDM networks are designed to be DCM-less.
- At the receiving end, a DWDM de-multiplexer is used to separate the DWDM signal into individual channels and data signals are recovered in the optical receivers.
- DWDM technology provides an efficient way of increasing network capacity. As traffic demand increases, network capacity can grow by adding extra transponders (i.e. transmitters and receivers) at the terminating points of the traffic.

Fixed-grid DWDM Architecture

- DWDM technology has also evolved from point-to-point DWDM systems to DWDM networking with wavelength switching, e.g. fixed wavelength Optical Add and Drop Multiplexers (OADM), Reconfigurable OADM (ROADM).
- As bandwidth continues to increase and becomes more dynamic, ROADM-based WDM networks provide network operators more flexibility in adding new wavelengths or re-directing wavelengths, as well as restoration of traffic when a failure occurs.

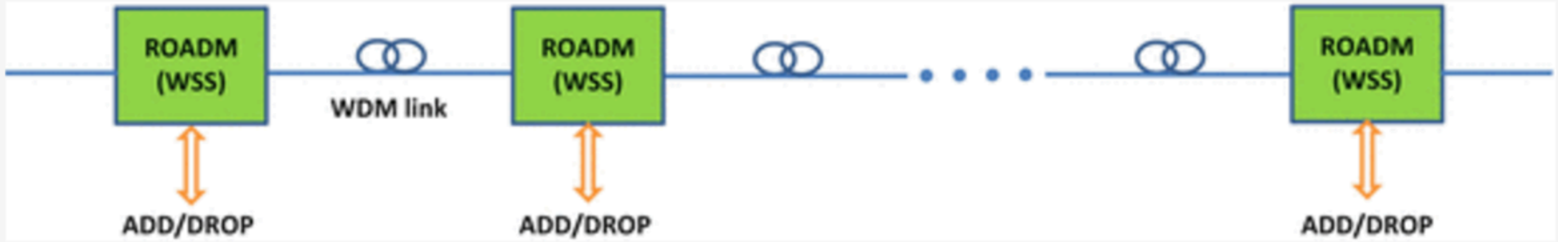

Fig. 2.3
Schematic of a ROADM-based WDM network

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WSS Technology: Fix and Flex-grid

- A key technology on emergence of flex-grid architectures is the Wavelength Selective Switch (WSS), with its wavelength (λ) switching and routing functionalities.
- This component has a single fibre input that contains many wavelength signals. Its job is to direct these wavelengths to any of a number of fibre outputs without any restrictions or blocking; any combination of the input wavelengths can be redirected to any of the fibre outputs
- However, flex-grid requires additional flexibility of variable passband, much finer spectral resolution, bandwidth control, and filtering.

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WSS Technology: Fix & Flex

- WDM technologies, e.g. Arrayed-Waveguide Gratings (AWGs) and Micro-Electromechanical System (MEMS) devices, do not allow the possibility for variable passband widths. Rather, AWGs and MEMS devices are inherently fixed-grid WDM devices, with their fixed channel granularity (e.g. 50 GHz, 25 GHz, etc.) set at the time of their manufacture.
- In contrast, liquid crystal-based technologies have matured in recent years, and using the holographic principle can offer flexible passband filtering in conjunction with the wavelength switching and routing functionalities required for a flex-grid WSS
- In this case, the key component within the WSS is a Liquid-Crystal-On-Silicon (LCoS) device, to enable active switching and beam steering of light.

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WSS Technology: Fix & Flex

The specific functionalities that a flex-grid WSS based on the holographic LCoS principle include:

- Multiple wavelength routing and switching
- Power equalization of different wavelength channels
- Dispersion compensation/mitigation
- Variable channel bandwidths
- Polarization-independent operation
- Compactness
- Millisecond reconfiguration times.

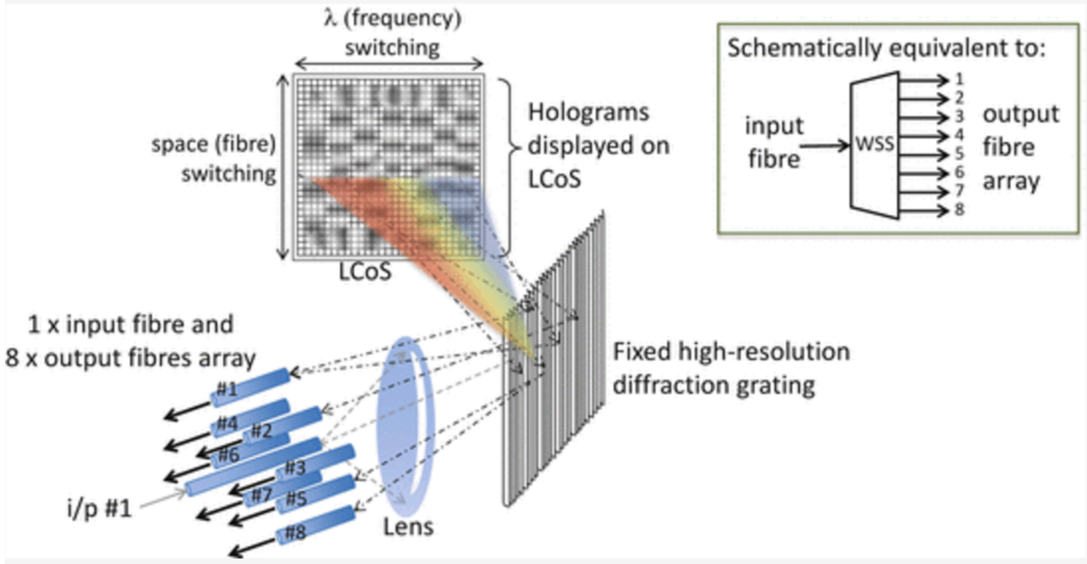

Fig. 2.4
Schematic of Wavelength Selective Switch

ROADM Architecture

- A ROADM is a network element that allows for dynamically adding or dropping of wavelengths at a network node
- ROADM architectures are also able to switch DWDM wavelengths between the different express fibres. In the past, DWDM wavelengths were transmitted on a fixed 50 or 100 GHz bandwidth ITU grid. Flex-grid ROADMs have the additional advantage of being able to add and drop wavelengths with both fixed and variable channel optical bandwidths.
- The two paths for traffic through a ROADM are shown in Fig. 2.5. 1st is the express path for traffic that traverses the node and 2nd is the add/drop path for traffic that terminates or originates at the node.

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ROADM Architecture

Some of the widely used components used today in both fixed and flex-grid ROADMs are:

1. Wavelength Selective Switches (WSS)
2. 1 × N and M × N All-Optical Switches (OXC)
3. N × M Multicast Switches
4. Optical Amplifiers (OA)
5. Fixed and Tunable Filters
6. Wave Blockers (WB)
7. AWG Multiplexers
8. Optical Splitters

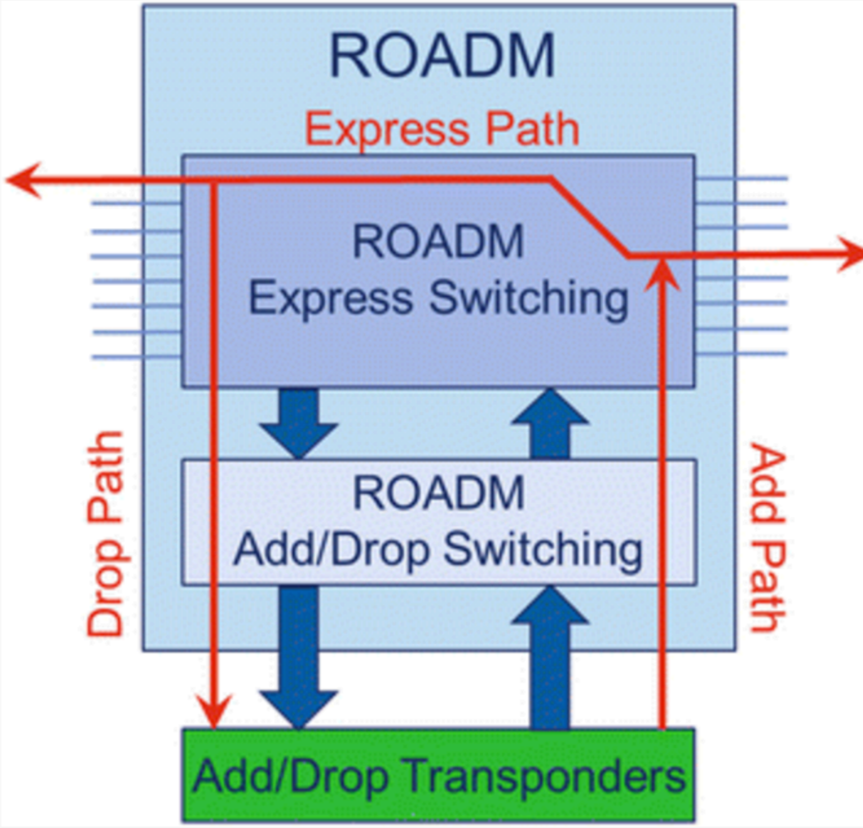

Fig. 2.5

Express and add/drop functions of a ROADM

Migration to Flex-grid: Is it a necessity?

- Expected traffic volumes for short and medium term (few Tb/s of total traffic) are not enough to justify immediate flex-grid deployment across entire network.
- Some links grow more quickly than others and become congested, acting as bottle necks to future network growth.
- It is in those links where flex-grid can be first deployed to extend network lifetime.

Migration to Flex-grid is needed !

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Migration to Flex-grid: Is it a necessity?

Capacity exhaustion is not the only motivation behind migration.

- In short term (2014–2016), the use of higher bit rates and advanced modulation formats for specific connections will allow cost-effective 400 Gb/s (and beyond) signals.
- In medium term (2017–2019), Sliceable Bit Rate Variable Transponders (SBVT) will be helpful to increase the reach of flex-grid areas to those parts where, although spectrum will not be exhausted yet, the capability of splitting multiple flows will be beneficial.
- In the long term (>2020), capacity exhaustion as a result of dealing with expected traffic volumes of hundreds Tb/s or even some Pb/s will require deploying flex-grid. Legacy fixed-grid equipment would then be completely upgraded to flexgrid in the core.

Migration to Flex-grid

- Migrating fixed-grid OXCs equipped with LCoS-based WSSs can be done, in general, by upgrading its software, resulting in a low cost migration.
- Older OXCs however, are equipped with MEMS-based WSSs. Many of those OXCs can be easily migrated to flex-grid by replacing WSSs

Migration to Inter-operability

- While connection A is transported transparently through the flex-grid island using a 50 GHz media channel, the filter of connection B is shrunk to 37.5 GHz thus adjusting to the signal bandwidth. This allows connection C to use a portion of the fixed media channel allocated for connection B, which is possible since C will be dropped inside the flex-grid island.

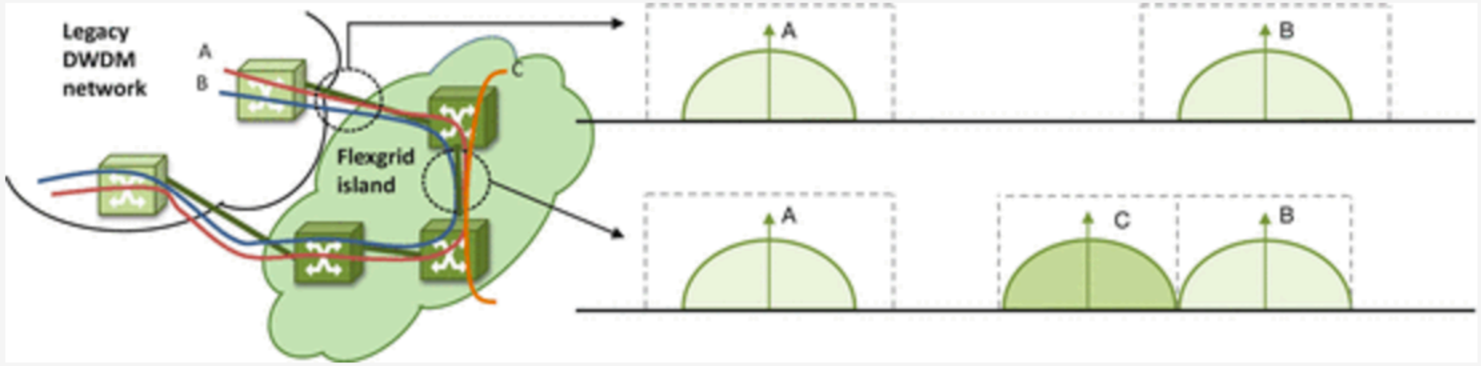

Fig. 2.6

Fixed and flexgrid inter-operability