Optical Switching and Networking 19 (2016) 155–164

Contents lists available at ScienceDirect

Optical Switching and Networking

journal homepage: www.elsevier.com/locate/osn

Reconfigurable DP-16QAM/QPSK transponders for the transmission of coherent 200 Gb/s carriers in a flexgrid super-channel arrangement

Claudio Colombo

Alcatel-Lucent, Italy

ARTICLE INFO

Article history:
Received 31 October 2014
Received in revised form
1 September 2015
Accepted 2 September 2015
Available online 14 September 2015

Keywords:
Flexgrid
Super-channel
Coherent detection
DWDM
Spectral efficiency

ABSTRACT

The next generation of Dense Wavelength Division Multiplexing (DWDM) networks are likely to use Flexgrid arrangement, providing operators with additional flexibility when assigning spectrum compared to traditional DWDM networks using the 50 GHz ITU grid. Flexgrid breaks the spectrum up into small (typically 12.5 GHz) slots, but its key feature is that contiguous slots can be joined together to form arbitrary sized blocks of spectrum. This additional flexibility will allow faster transponders that utilize high spectral efficiency modulation techniques, like multi-level m-QAM schemes. From the use of these new spectrum efficient modulation formats and finer control over spectrum allocations, a key benefit that Flexgrid offers to the network operators is that their DWDM networks can carry more traffic with optimized spectral efficiency. High speed technology became essential for realizing greater network capacity and enabling network operators to meet the increasing bandwidth challenges from new generation superfast devices, services and applications. Coherent technologies beyond 100G are now focusing on higher level modulation formats and multiple sub-carriers/channels, using super-channels to achieve Terabit transmission.

1. Introduction

Service providers around the world are moving quickly to accelerate their networks, making the jump from transport speeds of 10G and 40G to barrier breaking 100G and beyond. With the introduction of the first commercial 400G electro-optical chips, the recent technological evolution is already opening the way for future high-speed optical networks, allowing the optimal tradeoff between spectral density and optical reach per deployed line system. Moreover the benefits of Flexgrid arrangement become readily evident when coupled with next-generation DSP, supporting for higher baud-rate transmission. Improving flexibility while increasing capacity of the photonics line allows giving service providers faster access to the latest advances in optical and silicon technologies on their switched optical networks, and the potential evolution for the optical platforms it supports.

From the beginning of 2013 many experimental trials have been proposed to demonstrate an evident technological advantage in high capacity optical transmission by different manufacturers, through the networks of the main International Global operators. Some of the more interesting results will be presented and discussed in the paper, especially concerning the linear properties of transmission.

2. Key innovation technology

The push for 400G consolidates when 100G transport is an increasing industry success story. Hundreds of commercially deployed 100G systems across the globe and continued bandwidth growth pressures motivate the

http://dx.doi.org/10.1016/j.osn.2015.09.001
1573-4277/

industry increased focus on 400G and 1 Tb next generation of higher transmission systems to drive down cost of transported bit.

Steady advance in optical and electronic transceiver technology supporting advanced modulation and spectral shaping techniques motivate the rate increasing. 400G data rate is a natural next step gives the current evolution of datacom and telecom transport interface speeds and implementation complexity. 400G and beyond R&D activities occurring now in order to build the technology innovations and sustainable ecosystem for a commercial future.

Various ways to realize 400G transmission rate have been proposed:

- increasing the symbol rate,
- increasing the number of bonded channels,
- increasing the modulation levels, or their combination

For long haul distances, bonding a number of established PM-QPSK channels via WDM techniques can result in high spectrum efficiency and lower bandwidth requirements.

For metro distances, higher-level QAM formats can be used to achieve spectral efficiency that is greater than that of PM-QPSK. Dual-Carrier PM-16QAM coding on 75–100 GHz grid is an attractive solution to realize 400G line rates while at the same time relaxing the high speed bandwidth requirements of the electronic circuits and optoelectronic components.

The coherent 200G/16QAM optical solution can provide many customer benefits: avoid saturating photonic lines and costly overlays, propagate with 10G NRZ, 40G DP-BPSK and 100G DP-QPSK, propagate over other vendor's photonic line (Fig. 1).

Compared to today's 100G chips, the new 400G Photonic Service Engine (PSE) designed by Alcatel-Lucent and tested in the described trial links delivers: 4 times the line rate; more than 2.6 times the spectral efficiency; more than 4 times the density; 33% lower power consumption and 25% better tolerance to fiber impairments. As a result, the device reaches the current technological limits of the market's silicon for integrated digital signal processing in high-speed telecom applications (Fig. 2).

According to the key enable technologies to reach the high-speed fiber optics performances

- DWDM solution to reach multiterabit/s capacity, with a super-channel configuration in an optical multi carriers arrangement
- Reconfigurable Nodes and Flexible-grid operation
- Modulation format, advanced DSP, soft-decoding FEC and Coherent detection,

the main functionalities achieved during all the field-trial activities have been focused on:

- High-speed 400G transmission over two aggregated sub-carriers 16QAM modulation scheme.
- Integrated wave-shaping, pre-compensation and enhanced optical signal to noise ratio (OSNR) performance, enabling very high tolerance to fiber non-linearities.
- Advanced algorithms enabling SW-programmable adaptive modulation format and bit-rate reconfiguration on the same optical channel including PDM-BSPK, PDM-QPSK and PDM-16QAM to optimize reach and capacity.
- Spectral efficiency improvement, demonstrating the benefits of "Flexible-grid Optical Networks" combining the best relation between distance and speed, according to the ITU-T Rec. G.694-1 [1].
- Support for 50 GHz spacing at 400G for full compatibility with reconfigurable optical add-drop multiplexer (ROADM) networks.

With the optical technology available today, service providers must choose a specific modulation format for each signal speed. The 400G PSE forms the basis for software-defined flexible bit-rate and adaptive modulation line interfaces. A transponder based on this ASIC generation can generate a number of spectrally engineered modulation formats. This gives service providers the flexibility to choose the optimal modulation format for their distance and spectral efficiency requirements.

3. Capacity and bandwidth efficiency

Bandwidth efficiency and increased role of digital signal processing in the optical layer have been the key elements to allow the multi-terabit transmission over the traditional channel planning and the flex-grid arrangement, recognized as the revolutionary technique for high capacity future systems.

Considering, at the beginning, the limit for a linear channel with an additional Gaussian white noise distribution, the maximum capacity C_{max} (maximum spectral efficiency) can be expressed as a function of channel width CW by the relation:

$$C_{max} = CW * \log_2(1 + SNR)$$

In Fig. 3 the theoretical trend of the channel capacity as a function of OSNR

$$OSNR = \left[CW/12.5\right] * SNR$$

is described, for different channel widths equal to the DWDM grid channel spacing.

The theoretical OSNR degradation can be evaluated for a channel width of 37.5 GHz respect to the fixed 50 GHz WDM grid: 1 dB for a channel capacity of 100G, 2.5 dB for a capacity of 200G, 7 dB for a capacity of 400G.

Software re-configurable QPSK/16QAM transponders guarantee excellent optical performances for both the adaptive rate (100 Gb/s and 200 Gb/s) in terms of OSNR and *Q*-factor. Figs. 4 and 5 show some significant measurements performed with standard production transponders.

At the relative SD-FEC thresholds [BER=2.1×10^{-2}], the deviations of measured OSNR respect to the theoretical