Optimization of Spectral Band Utilization in Gridless WDM Optical Network

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Abstract

In this paper the effects of gridless spectrum allocation in Wavelength Division Multiplexed (WDM) optical networks is examined. The signal advanced modulation formats and multi-rate transmissions, which are key parameters in the optical system project, are taken into account. The consumed spectrum, as well as the impact of linear and nonlinear impairments on the signal transmission, are compared to WDM network adopting standard ITU grid and gridless. To analyze the influence of these physical effects, some key network design parameters are monitored and evaluated, such as the guard band size, signal occupied bandwidth, laser power and the quality of channels. The applied signal modulation formats were On/Off Keying (OOK), Quadrature Phase Shift keying (QPSK), and Dual Polarization State Phase Modulation (DP-QPSK), whereas the transmission rate per wavelength was varied from up 10 Gb/s to 100Ghz. The guard band, signal band, and laser power were swept and the resulted Bit Error Rate (BER) was estimated from the eye-diagram. Analytical calculations and simulations are conducted to evaluate the impact of the gridless spectrum allocation on both the spectral consumption and the signal quality of transmission (QoT). Results reveal that gridless transmission system reduces the spectral consumption while offering an acceptable QoT. This work was carried out with both analytical modeling and numerical calculation using the Optisystem as well as Matlab.

Keywords: Gridless, Optical Networks, Spectrum Allocation, Guard Band, Signal Band, Laser Power, BER.

1. Introduction

The increase of online data services such as peer-to-peer, high-definition audiovisual services (VOD, HDTV, 3D-HDTV) and social networks, as well as the development of broadband access through optical wireline or 4G mobile, has resulted in an exponential growth of traffic creating several challenges for the developers and managers of the network systems.

In the optical Network, several of these challenges involve aspects of physical layer and transport layer relating issues of physical impairments, signal processing aimed at minimizing the impact of high transmission rate, the development of routing protocol and control plane more smart and other, being that the set of these solutions will search to enable the network operations in higher performance and to achieve the maximum potential utilization of the technology infrastructure existing [1]-[3].

In the last 30 years, the main technological innovations in optical systems are related with issues mentioned in the last paragraph. Among them can be mentioned the evolution of advance signal modulations, optical amplification technology combined with wavelength division multiplexing (WDM) technology and digital coherent detection technology which is currently undergoing research and development. Another researches also have been realized looking for the development of equipment allowing a dynamic of transmission more flexible, reconfigurable, smart, capable to indeed to adapt the data rate according with the capacity demand and amount of impairments for each type of transmitted signal.

The dynamic of fiber signal transmission and its transport is governed by the combined action that involves effects of attenuation, group velocity dispersion and nonlinearities, being that the signal power and bandwidth allocation are considered the main sources of signal degradation and through of control of these parameters co-relating to type of modulations that will be defined by the quality of transmission (QoT) [1][4][5]. However is essential to analyze the behavior among channels working in different rates, modulations, intensity of power lasers and other parameters that are connected directly with minimal spectral band allocation.

Recently the question about signal spectral band allocation has gained increasingly attention. The traffic transmitted over optical networks has a quite heterogeneous characteristic, mainly in terms of volumes in order to call attention to the particular spectrum allocation for each type of transmitted and transported signal [6]-[11].

Classically optical network systems are allocated into the defined frequency grids according to ITU-T (International Telecommunication Union, Telecommunication Standardization Sector) standard. The proposal to offer a WDM network architecture allocating the spectrum as the size of the signal band is a background that has been widely discussed [6][8]-[11]. With the increasing transmission rates in 10Gb/s, 40Gb/s, 100Gb/s and beyond and with the evolution of the types of advanced optical signal modulation and multiplexing schemes became possible to reduce and improving the channel spacing being fixed in accordance with ITU that propose channel slots of 100, 50, 25GHz. Evidently the technical gridless allocation brings benefit as the optimization of consumed spectral but the quality of signal transmission (QoT) can have several limitations and penalties, thus analyzes to know the influence of these physical effects, are essential to validate the proposal. In this work to validate our study some keys network design parameters are monitored and evaluated, such as the guard band size, signal occupied bandwidth, laser power, transmission rate. The applied signal modulation formats were On/Off Keying (OOK), Quadrature Phase Shift keying (QPSK), and Dual Polarization State Phase Modulation (DP-QPSK), whereas the transmission rate per wavelength was varied from 10 Gb/s to 100 Gb/s. The Bit Error Rate (BER) result was estimated.

The work is organized as follows. Section 2 is described some basic concepts about gridless optical network and it is realized a perspective estimative about consumed spectrum, adopting the ITU standard and the gridless model. In the Section 3 is showed the set-up of the simulation model with its configurations and some considerations. And to sum up, the section 4 presents the results, comments, conclusions and perspective of future works.

2. Perspectives for Gridless Optical Network

In general WDM systems operate within spectral windows that are divided into spectral band grids, which are established by ITU-T. Actually there are 3 ways to improve the spectrum utilization that are: reduction of guard band among WDM channels, the improving of technical modulation aggregating more bits per symbol, and recently have been discussed the model of gridless network that proposes the concept of spectral allocation considering a dynamic and flexible environment, whereas networks enable to operate in different rates and signal modulations [2][3][6].

The proposal to offer a WDM network architecture that allocates the spectrum without considering a fixed band grid, has come with the increasing of data transmission rate and the need to allocate a huge amount of bits within of established by ITU-T (100, 50 or 25GHz)[6]-[11] .

The general concept of gridless spectrum allocation is to use the same signal bandwidth added with a minimal guard band (see in Figure 1) to allocate the signal, for example, a modulated signal in On Off Key (OOK), transmitted in 10Gbit/s, will be allocated in a spectral band of 20GHz adding a minimal guard band that means enough to its transmission [6].

This section is focused on investigating through mathematical calculations, the impact that the type of spectral grids (fixed or gridless) with the type of modulation and transmission rate can result in the optimization of spectral consumption. In these calculations were not computed the influence of linear and non-linear effects in the transmission of signal. In this step is considered the space necessary to transmit a signal according to the modulation and rate. The effects related to the acceptance the signal transmission will be analyzed in the future sections.

The occupied spectrum band without considering the physical impairments and considering only the signal bandwidth is calculated dividing the transmission rate by the number of bits per symbols, specific of each type of signal modulation, multiplied by two, since the band allocated is twice the signal bandwidth (Nyquist rate) plus the guard band, (e.g. a transmitted signal in 40Gb/s and modulated in DP-QPSK (4bits per symbol) equals 10Gbaud, then the allocated signal bandwidth equals 10GHz plus guard band). The spectral efficiency is defined as the ratio of data rate and occupied spectral band, and it is quantified in unit of bits per second per Hertz (b / s / Hz). However the spectral efficiency is also related to the type of adopted grid, i.e. a modulated signal in QPSK and allocated in fixe grid of 50GHz will have a spectral efficiency equal 1.6 bits / s / Hz (40 Gb/s / 50 GHz), but if the same signal uses gridless allocation, it will have a spectral efficiency of 1,33 bits / s / Hz being that in this case it is considered a guard band equal 10GHz (40 Gbs / (20 GHz +10 GHz).

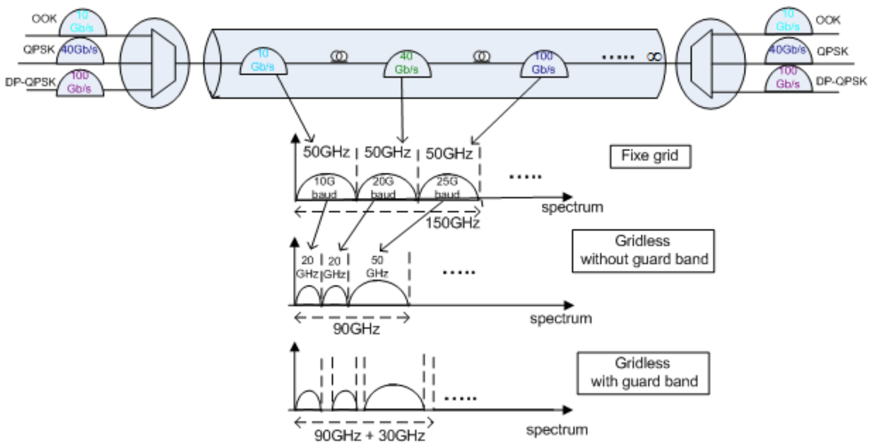
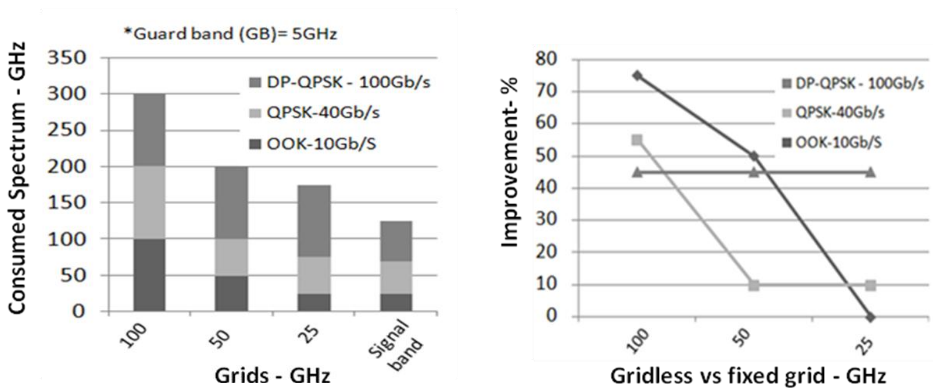


Fig.1: Allocation with fixed grid and gridless

As it was mentioned previously, the signal modulation formats considered in this work were On/Off Keying (OOK), Quadrature Phase Shift keying (QPSK), and Dual Polarization State Phase Modulation (DP-QPSK), being the transmission rate per wavelength of10 Gb/s, 40GHz and 100GHz respectively.



(a) (b)

Fig. 2: (a) Spectrum Consumption and (b) Improvement offered by Gridless

The results presented in the Fig.2a refer to the spectrum consumption for the grids of 100, 50, 25GHz and signal bandwidth adding a guard band and the Fig. 2b is quantified the improvement in percent (%) between gridless and fixed grid models. Through these results can be seen that considering only the spend of bandwidth to insert the bits in the spectrum without considering the bandwidth necessary to satisfy the linear and non-linear effects of fiber transmission, the grids ITU offer much more bandwidth that the signal requires to be allocated. It can also be observed that the most sophisticated modulation formats (e.g. QPSK and DP-QPSK), that means to aggregate higher amount of bits per symbol, save more bandwidth spectrum. Obviously that the ideal scenario to spectrum consumption is with type of gridless allocation, but as it was mentioned previously, it presents some issues influencing the QoT of signal, however these issues shall be analyzed and controlled for the validation of signal transmission.

In the next section will be presented the analytic model applied in each signal to achieve the spectral band optimizing.

3. Analytic model of spectral band optimizing

The adopted analytic model for implementing the set-up of simulations assumes that the occupied signal bandwidth (Δf_s) is related to its transmission rate (TR) and to the type of modulation as it is given in equation 1,

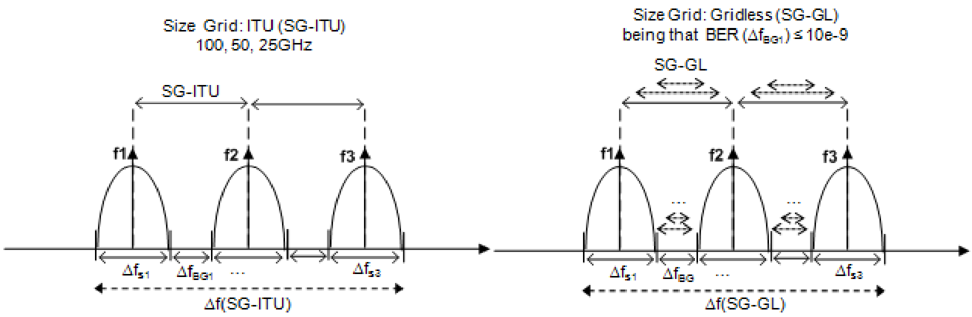
$$\Delta f_s = \frac{1}{Log_2 M} * TR \qquad (1)$$

where *M* means number of symbols, characteristic for each modulation format.

To allocate a signal inside spectrum grid is required a guard band that varies according to signal and transmission impairments, thus the total signal spectrum band is given by equation (2),

$$\Delta f_s = \frac{1}{Log_2 M} * TR + \Delta f_{BG} \qquad (2)$$

and minimum range of Δf_{BG} should satisfy BER $\leq 10e^{-9}$. For QPSK and DP-QPSK modulation is common to apply a digital signal process (DSP) with Forward-Error-Correction (FEC). In this case the set up can aim at a certain BER = $10e^{-2}$ or $10e^{-3}$ and with the application of DSP with a FEC, resulting in a reduction of BER for $10e^{-9}$.



(a) (b)

Fig.3: Band consumption: (a) with guard band, (b) reduction guard band

The strategic of band consumption optimization is based in the model that the signal band allocation is done according to the use of the gridless schemes. In Fig. 2a can be seen that in fixed grid allocation (SG-ITU) the range among each channel is fixed in 100, 50 and 25GHzas ITU-T standard being that as the signal band as band guard are contained within this spectrum range. To the gridless model (SG-GL) Fig 2b this range is not fixed, it can be changed according to the size of signal band and guard band in order to offer QoT.

Notice that for enabled system with channels in differents rates and modulation format the calculation of the total allocated spectrum (Δf_{st}) shall be done separately for each channel in order, and it is realized by the sum involving all signals in the equation (3)

$$\Delta f_{st} = \sum_{i=1}^{N} \frac{1}{Log_2 M_i} * TR_i + \Delta f_{BG} \qquad (3)$$

being that i means the specific channel and N equal the total number of channels. As this work, it is enable to operate in different rates and modulation, however it is necessary to calculate the consumption spectrum individually, e.g a channel enables to transmit signal in On Off Key at 10Gb/s has a different spectrum consumption that another enables in QPSK at 40Gb/s.

4. Simulations Model

This section describes the physical network set-up that is used in the step of simulations to obtain the main results. The physical layer is configured with 3 WDM channels, being that each one was enabled in different modulation formats (as in Fig.1). The signal modulation formats applied are OOK, QPSK, and DP-QPSK, whereas the transmission rate per wavelength of 10 Gb/s, 40Gb/s and 100Gb/s. The Erbium Doped Fiber amplifier (EDFA) and dispersion compensate fiber (DCF) are considered by compensation of the attenuation and dispersion of the signal. The fiber link span length is of 50 km with fiber type standard single mode fiber (SSMF). The considered attenuation coefficient is of 0.2dB/Km and to dispersion compensation fiber has the attenuation of 0.5dB/Km. The dispersion considered is of 17ps. The laser power was swept in 0.1 to 8mW and ITU-T grids, signal band GHz, were considered. In this conditionals the Bit Error Rate (BER) results are estimated. The transmitters and receivers used to each channel are standard and available by simulation software These simulations were carried using the Optisystem. The Fig. 4 presents a general diagram of the dynamic simulation.

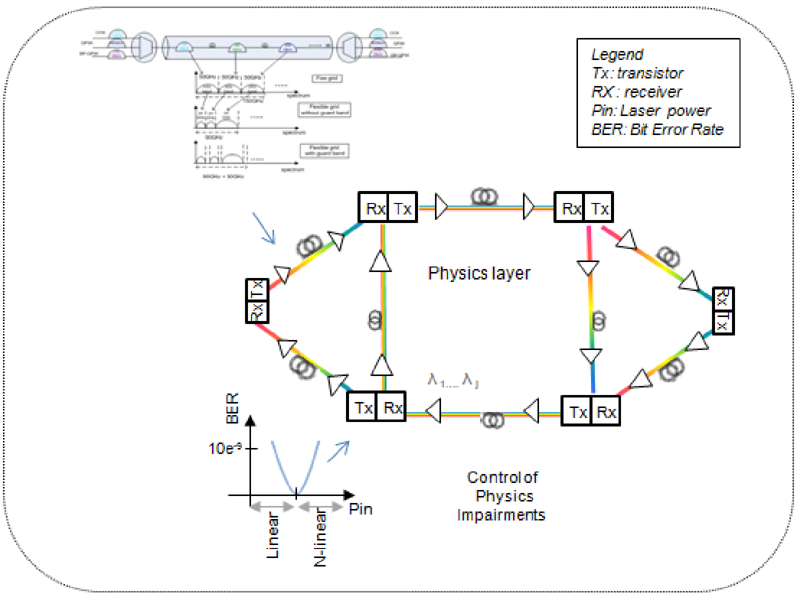


Fig.4: Simulation dynamic

5. RESULTS AND DISCUSSION

The results of this section focus in to analyze the influence of laser power load, as well as the impact of spectrum allocation in the transmission quality of signals. The parameter used for this evaluation was the BER. To obtain the results were built three different set ups considering three channels, enabled to operate in 10, 40, 100Gb/s and in signal modulation format different such as QPSK, OOK, and DP-QPSK being that the central channel was monitored to obtain the BER. To better acknowledgment, the used frequencies for each type of spectral allocation is shown inside of the graph.

The results of the first set up (Fig.5), the applied modulation signals have the following sequence of the channels (ch), ch1:QPSK-40Gb/s, ch2:OOK-10Gb/s, and ch3:DP-QPSK-100Gb/s calling to attention that the central channel was enabled to transmission OOK signal in 10Gb/s. In these results, it is seen that the BER values were satisfactory in all laser power load and for all types of adopted spectrum allocation. It is clear that the impact is higher for gridless allocation scheme, but the reduction of consumed spectrum is achieved.

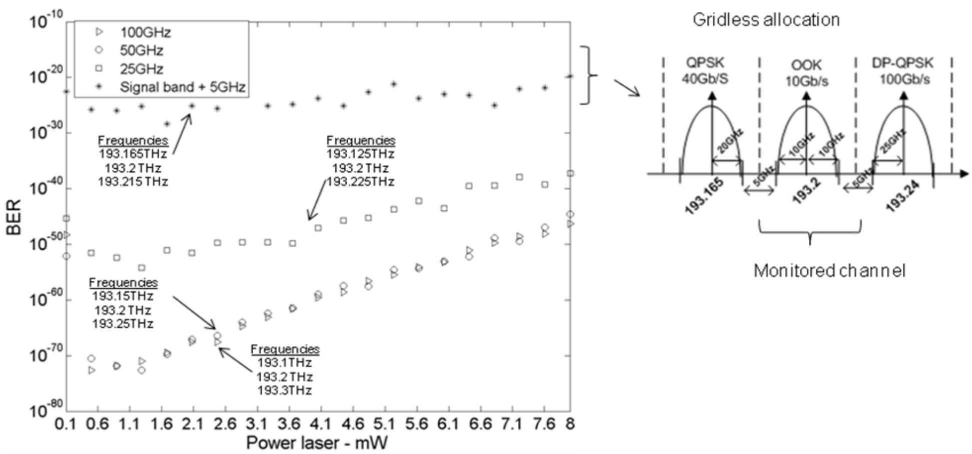


Fig. 5: OOK, 10Gbs, spans of 50Km

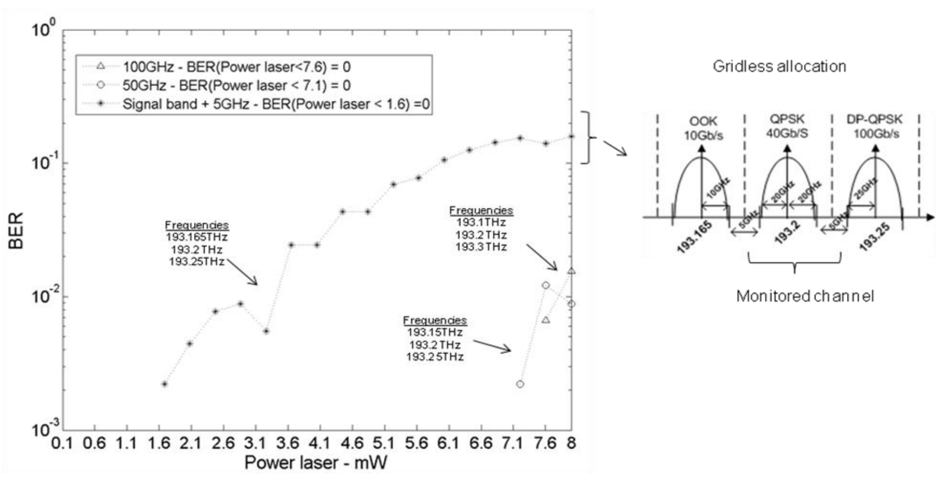


Fig. 6: QPSK, 40Gbs, spans of 50Km

For the second set up were implemented channels configured in Ch1:OOK, Ch2:QPSK and Ch3:DP-QPSK respectively. In the results presented in Fig.6, it is seem that the transmission has success only for some values of laser power (to see legend) and the range these valuers increase when it is applied gridless alocation. In this set up were not considered grid of 25GHz because the minimal grid size, enough to allocate the signal of central channel configurated with modulation QPSK in 40Gb/s is of 40GHz, then should be considered grid sizes upper than 50GHz.

The last set up Fig.7 were implemented channels Ch1:OOK, Ch:DP-QPSK, Ch:QPSK respectively. The BER values for the central channel DP-QPSK transmitted in 100Gb/s will satisfy the QoT if the DSP and the FEC are applied in the signal reception. Note in Fig. 7 that the values of BER for all laser power and all spectral allocation are not lower than 10e-3.

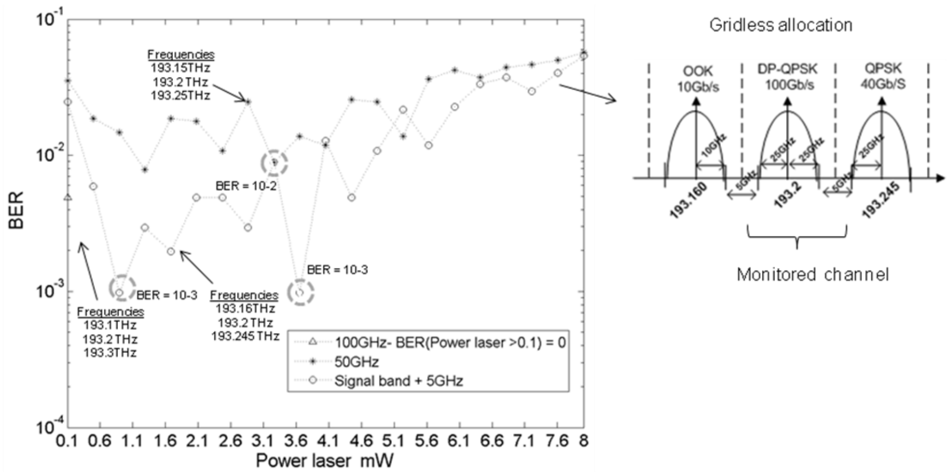


Fig. 7:DP-QPSK, 100Gbs, spans of 50Km

In all set ups analyzed the gridless allocation scheme can be applied offering better spectral consumption with QoT.

6. Conclusion

The dynamic of gridless signal allocation for an optical network system enabled to operate in different rates and modulation format has been proposed and analyzed. The validation of transmitted signal through of BER parameter was given considering all the physical impairments such as linear and non-linear effects of a optical fiber channel. Through of these simulations results also was verified that the gridless spectrum allocation is possible but a band guard is necessary, independent of modulation format and transmission rate. Attaching that for the DP-QPSK transmitting in 100Gb/s, the application of DSP and FEC is essential to obtain QoT for the signal.

In the next work will be verified the maximal distance possible for each one of the set ups and evaluate more accurately the guard band size necessary for each signal modulation.

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