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Impact of Number of Channels on Signal Transmission in Elastic Optical Networks

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ABSTRACT

In this paper, the impact of the number of channels on the performance of elastic optical networks (EONs) is examined considering a multilevel modulation format and coherent transmission. Network design parameters such as spectral bandwidth and channel symbol error rate (SER), are analysed. We simulated the transmission of quadrature phase shift-keying (QPSK) signals, modulated at 56 and 100 Gbps, to evaluate a proposed flexible spectral allocation method in order to evaluate the effect of number of channels and the required total spectral bandwidth.

Keywords: optical channels, flexible spectrum allocation, signal band, symbol error rate, Elastic optical networks

1. INTRODUCTION

THE ongoing increase of services and applications such as online video, VoIP, online game, Digital TV, and emergent major applications such as social networks, Internet of things as well as the convergence of wireless and optical wireline has resulted in an exponential growth of Internet data traffic, which has distinct bandwidth demands. According to research conducted by a major supplier [1], by 2020 the global Internet traffic should reach 2.3 ZB (zettabytes = one billion gigabytes); that is, IP traffic will then have increased almost 100 times between 2005 and 2020. This scenario presents challenges for network design engineers both now and in the future, having to face ever-increasing capacity demands, with additional constraints on reliability, flexibility, cost, and low energy consumption

Nowadays optical networks interconnect worldwide multiple locations with variable capacities and transmission rates using Wavelength Division Multiplexing (WDM) systems [2] with up to a hundred channels, each carrying data rates from 10 to 400 Gbps, leading to impressive Tb/s aggregates [3].

Traditionally, signal spectra in WDM optical network are allocated as frequency fixed-grid according to ITU-T (International Telecommunication Union, Telecommunication Standardization Sector) standard [4]. The proposal of an Elastic Optical Network architecture supports bandwidth-variable signals (which can have large or small bandwidths), has been identified as a good solution to save spectral band and allows the possibility of transmission rates above 400 Gbps, compared with the traditional wavelength division multiplexing (WDM) allocation model established by ITU-T (100, 50, 25 or 12.5 GHz)[3], [5-7]. Evidently, the use of EON brings the benefit of the reduction of spectral consumption; however, the quality of signal transmission (QoT) should be investigated, due to several limitations and penalties of the physical layer [8].

The main goal in this work is to analyze some key network design parameters regarding the signal SER and signal band allocation. Thus is examined the impact of the number of channels on the elastic optical networks

(EONs) considering the multilevel modulation format and coherent transmission. Analytic calculations and simulations were realized to evaluate the impact that the amount of channels in EON causes on the spectral consumption and on the signal QoT. The first step of results is based in calculations that account the reduction of spectrum consumed comparing with WDM network that adopt grid standard defined for ITU. In the second step, we evaluate through simulation the spectral allocation method in EONs seeking to analyze the effect of the number of channels and required spectral bandwidth. In order to analyze the influence of the physic effects, the spectral bandwidth was analyzed to monitor for the channel symbol error rate (SER). Simulation of the physical layer was configured with variable number of channels between 1 and 31, signals modulated using QPSK, the transmission rates per channel were 56 and 100 Gbps, Erbium Fiber amplifiers (EDFA) and dispersion compensating fiber (DCF) were considered to compensate attenuation and dispersion. Fiber spans were configured to 100 km using standard single mode fiber (SMF). Some non-linear effects were also considered in the simulation set up. Analytic modeling and computer simulations were carried out using VPI® Transmission System, and Matlab®.

2. BASIC CONCEPTS OF SPECTRUM ALLOCATION

In this section, some basic concepts and calculations about spectral allocation as a function of the modulation format and transmission rate are followed [9] and presented here.

For the spectrum allocation, the occupied signal bandwidth (Δf_s) must related to its transmission rate (TR) and the type of modulation. To allocate a signal inside a spectral grid (fix or elastic), a guard band (Δf_{GB}) must be considered, thus the total signal spectral band is given by equation (1):

$$\Delta f_s = \frac{1}{\text{Log}_2 M} * TR + \Delta f_{GB} \quad (1)$$

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

To multichannel systems, the calculation of the total spectrum allocation shall be done separately for each channel independently, and in order it is obtained by the sum involving all signals as:

$$\Delta f_{st} = \sum_{i=1}^N \frac{1}{\text{Log}_2 M_i} * TR_i + \Delta f_{GB} \quad (2)$$

where index i represents a specific channel and N is equal to the total number of channels in the system.

The spectrum consumption optimization can be achieved with the signal allocation in finer spectrum slots, thus to obtain the required slots (RS) is:

$$RS = \frac{\sum_{i=1}^N \frac{1}{\text{Log}_2 M_i} * TR_i + \Delta f_{GB}}{GS} \quad (3)$$

where GS is a given grid size.

In other words, the *allocated bandwidth* should always be larger than the *signal bandwidth*, including guard bands to compensate physical impairments and to avoid eventual crosstalk. The minimum allocated bandwidth can be calculated by dividing the transmission bit rate by the number of bits per symbol specific of each signal modulation, and then multiplied by two, since this minimum allocated band has to be twice the signal bandwidth [10]. To illustrate what will be used in Table 1, a transmitted signal of 56 Gb/s and modulated in quadrature phase shift keying (QPSK) holds 2 bits per symbol and equals 28 Gbaud (56/2), then the minimum allocated signal bandwidth equals 56 GHz (without guard-band). The *spectral efficiency* is another parameter related to the spectrum utilization and is defined as the ratio of data rate and occupied spectral band, and quantified in units of bits per second per Hertz (b/s/Hz). It means how much the allowed grid space is effectively being used (e.g., 56 Gb/s QPSK, allocated in a fixed grid of 75 (3x25) GHz, will have a spectral efficiency of 0.7 bits /s/ Hz, which is rather low).

Table 1 presents the theoretical values of bandwidth requirement and allocation considering grids of 100, 50, 25 GHz (ITU standard) and slots of 12.5 GHz (Flex Grid) [3,4], transmission rate of 56 and 100 Gbps and modulation format QPSK, 2 bits by symbol. Through this analysis it can be observed that the (fixed) WDM ITU

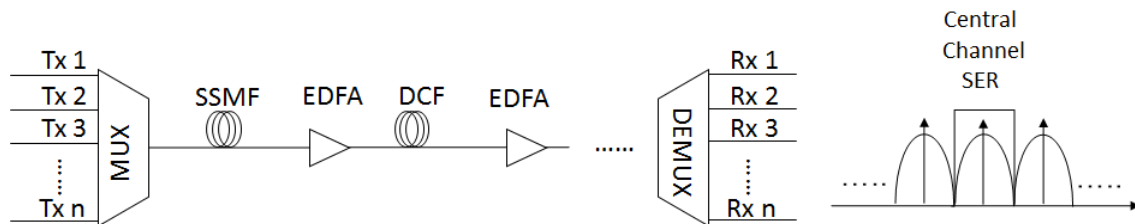
grid slots waste much more bandwidth than the required for the signal to be allocated, because it is $n \times (slot)$, where n is the number of slots. The parameter wasted band (Wb1; Wb2, Wb3, Wb4) denotes the wasted bandwidth in the fixed grids and Flex. It is interesting to note that for 56 Gb/s signal much is gained in this procedure, but for 100 Gb/s (which is exactly 4×25 and 2×50) the procedure is not necessary. Furthermore, we point out that these results consider only the amount of bandwidth necessary to insert the signal band in the spectrum band, without considering eventual linear and propagation effects in the optical fiber.

TR (Gbps)	No. Channels	Δf_{st} (GHz)							
		ITU Grid						Flex Grid	
		$n_1 \times 25$	Wb1	$n_2 \times 50$	Wb2	$n_3 \times 100$	Wb3	$n_4 \times 12,5$	Wb4
56	1	$3 \times 25 = 75$	19	$2 \times 50 = 100$	44	$1 \times 100 = 100$	44	$5 \times 12,5 = 62,5$	6,5
	3	$7 \times 25 = 175$	7	$4 \times 50 = 200$	32	$2 \times 100 = 200$	32	$14 \times 12,5 = 175$	7,0
	9	$21 \times 25 = 525$	21	$11 \times 50 = 550$	46	$6 \times 100 = 600$	96	$41 \times 12,5 = 512,5$	8,5
	15	$34 \times 25 = 850$	10	$17 \times 50 = 850$	10	$9 \times 100 = 900$	60	$68 \times 12,5 = 850$	10
	31	$70 \times 25 = 1750$	14	$35 \times 25 = 1750$	14	$18 \times 100 = 1800$	64	$139 \times 12,5 = 1737,5$	1,5
100	1	$4 \times 25 = 100$	0	$2 \times 50 = 100$	0	$1 \times 100 = 100$	0	$8 \times 12,5 = 100$	0
	3	$12 \times 25 = 300$	0	$6 \times 50 = 300$	0	$3 \times 100 = 300$	0	$24 \times 12,5 = 300$	0
	9	$36 \times 25 = 900$	0	$18 \times 50 = 900$	0	$9 \times 100 = 900$	0	$72 \times 12,5 = 900$	0
	15	$60 \times 25 = 1500$	0	$30 \times 50 = 1500$	0	$15 \times 100 = 1500$	0	$120 \times 12,5 = 1500$	0
	31	$124 \times 25 = 3100$	0	$62 \times 50 = 3100$	0	$31 \times 100 = 3100$	0	$248 \times 12,5 = 3100$	0

Table 1 – Bandwidth requirement and allocation (theoretical values).

3. SIMULATION MODEL

This section describes the network simulation set-up. Simulation of the physical layer is configured with 1, 3, 15, and 31 and channels using QPSK modulation format (see Fig.2). The transmission rates per channel are 56 and 100 Gbps. Erbium Doped Fiber amplifiers (EDFA) and dispersion compensating fiber (DCF) are considered. Spans of 100 km using standard single mode fiber (SSMF), with attenuation coefficient of 0.2 dB/km and dispersion of 16 ps/km/nm. To DCF has considered an attenuation of 0.5dB/km and dispersion of -90 ps/km/nm, as it is presented in the parameters table in Fig.2. All no-linear effects were considered in the simulation. The SER was evaluated on the central channel.



Parameters	Fiber (SMF)	DCF
D (ps/nm/km) @1550 nm,	16	-90
Loss, dB/km	0.2	0.5
Fiber link length -km	100	20
D. Slope, ps/nm ² /km	0.08	-0.45
Effective area, μm^2	80	50
Group Refractive Index	1.47	

Fig. 1: Schematic diagram of the system simulations and system fiber parameters.

4. RESULTS AND DISCUSSION

Results show the impact of spectrum allocation as a function of the signal SER and distance. The system uses single channels and multi-channels with the same transmission rate, performance of the central channel are the one presented.

Results in the Fig. 2 show the SER against channel spectral width on the system transmitter (back-to-back transmission) for 56 and 100 Gbps. We can see that single channel transmission requires average bandwidth of 25 and 45 GHz for 56 e 100 Gbps signals, respectively. For multichannel systems, 56 and 100 Gbps will require 40 and 75 GHz respectively.

In Fig. 3 (a & b), show the SER against channel spectral width on the system considering the fiber links of 100 and 300 Km. Note that the signal quality improves with the transmission distance and also between single and multi-channels. The shortest the distance and single channel the smaller the required bandwidth, i.e., lower the number of slots. Also, note that for longer transmission distances and multi channels the required bandwidth for a SER= 10^{-9} increases.

5. CONCLUSIONS

In this work were analyzed the minimum signal bandwidth to transmit a multilevel modulation format and multi-channels with high transmission rate on EON. Analytical results based in calculations that account the reduction of spectrum consumed comparing with WDM network that adopt grid standard defined by ITU, was realized and indicate that the ITU fixed slots grids offer much more bandwidth that the required for the signal to be allocated. The results of simulations obtained indicate that the number of channels and the distance affect the SER of the signal due mainly to the physical layer impairments.

For future work, we will be investigate with more details the impact of each physical impairments in optical links.

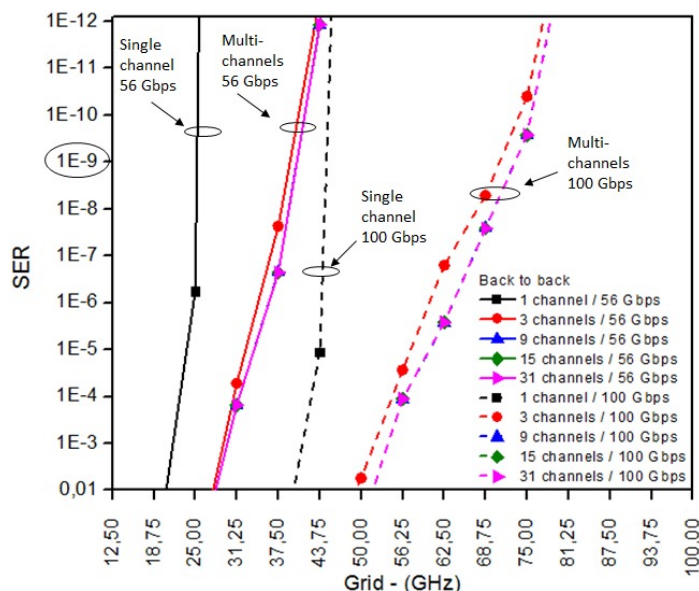


Figure 2: Back to back transmitter – QPSK

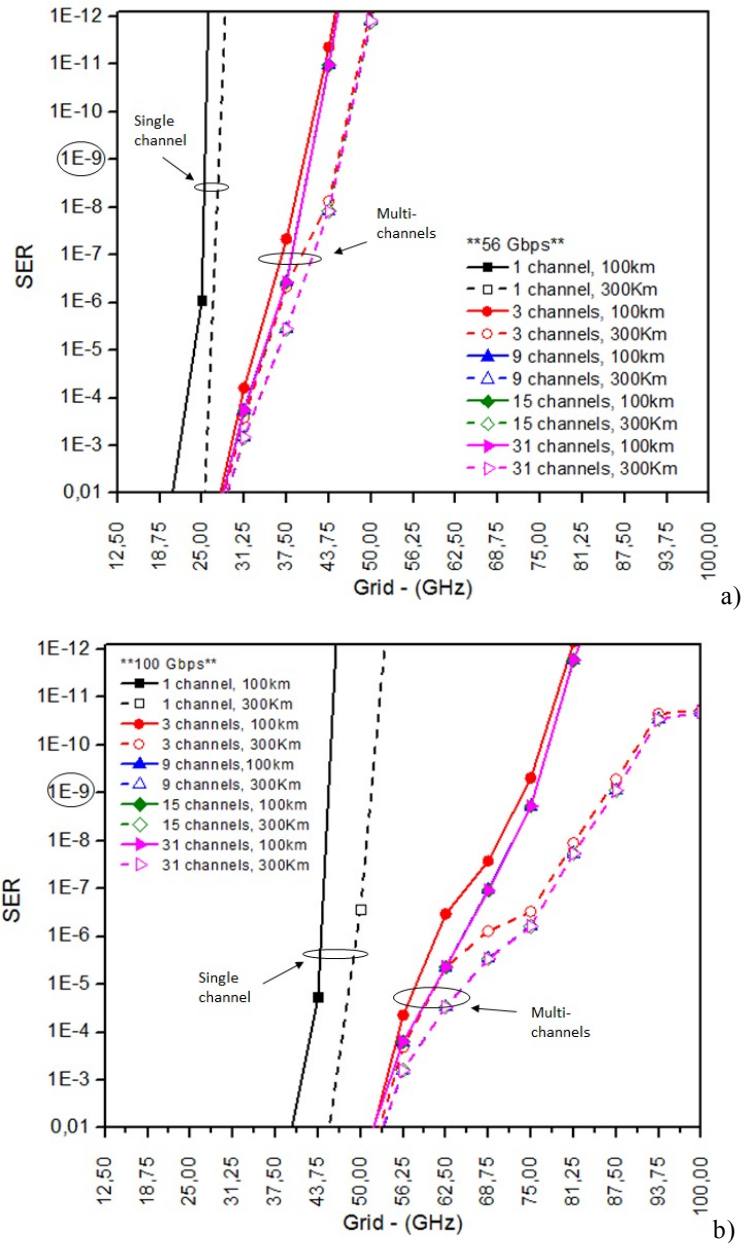


Figure 3: Fiber link of 100 and 300 Km – QPSK (a) 56Gbps, (b) 100 Gbps.

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