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Migration Steps Towards Flexi-grid Networks

Arturo Mayoral, Oscar Gonzalez de Dios, Victor Lopez, Juan Pedro Fernandez-Palacios
Telefonica I+D , Spain, Email: ogondio@tid.es

Abstract: This paper first identifies a realistic expectation of modulation formats for the next 10 years and quantifies the possible capacity gains. It is studied when the capacity using fixed grid is exhausted and studies several evolution strategies towards flexi-grid. Results show the capacity will be exhausted by 2019 and by applying flexi-grid the network life can be extended five years. A shorter-term rationale to migrate to flexi-grid is the availability of cost-effective 400Gbps and 1Tbps transmission.

Keywords: flexi-grid, migration, core network.

1. Introduction

Telecommunication carriers are continuously exploring new solutions to upgrade their networks in order to handle the ever-increasing Internet traffic demand. Although CAPEX and OPEX reduction of new solutions is the most important driver for the adoption of a new technology, operators have to consider in this evaluation the migration process towards this new solution.

Existing DWDM optical communication systems divide the C-band optical spectrum into discrete bands, spaced usually by 50 or 100 GHz, which are normalized in the ITU G.694.1 Grid [1]. Conventional transponders provide individual wavelengths carrying a client demand (which might be Ethernet or OTN, and might have a payload of anything up to 100 Gbps), which can be accommodated, in just one of these discrete bands. However, Elastic Optical Networks (EON) [2] enable the optical spectrum to be used in a more flexible way, where chunks of spectrum can be defined more arbitrarily than currently. The ITU has extended [1] and [3] to include the concept of flexible grid. To do so, two modifications are done: a new set of nominal central frequencies and the concept of "frequency slot", which is the spectrum occupation of a signal.

Several research studies, trying to quantify the potential benefits of EON architectures have been recently performed [4], [5], [6]. One claimed advantage is that the spectrum ("frequency slot") assigned to a channel is adjusted to the real spectrum needs, so there is a less waste of spectrum. On the other hand, another advantage is the possibility to use advanced modulation schemes that have bigger spectrum needs than a typical 50 GHz (or even 100GHz) slot. Capital expenses, overall network capacity, blocking ratio and energy efficiency, between others, have been the subjects for comparison between the new EON approach and the traditional one. Although the above improvements are claimed in the literature, there is no work which analyses what are the real benefits for network operators and when EON technologies will be needed.

This paper first identifies a realistic expectation of modulation formats for the next 10 years from an operator point of view and quantifies the theoretical capacity gains. Moreover, the Telefonica Spain reference scenario is used to determine if the Routing and Spectrum Assignment (RSA) algorithm can achieve such theoretical gains and quantifies the maximum capacity of a deployed mesh. Then, three evolution strategies: (1) continuing with current fixed grid, (2) migrating to a flex-grid assuming that the already deployed

WSSs are flexi-ready (e.g. LCOS) and (3) a deployment of flexi-grid when capacity of existing network is exhausted and the deployed WSSs are not flexi-capable (e.g. MEMS). Finally, rationale to migrate to flexi-grid based on the demand of efficient 400 Gbps channels is presented.

2. Spectrum Efficiency improvements of Flexi-grid based optical network

One of the benefits of flexi-grid is the ability to adjust the spectrum reserved for a channel to the actual spectrum needs of the optical signal. Thus, the theoretical capacity increase of a flexi-grid network is obtained by comparing the spectrum used in flexi-grid (size of the best-fitted frequency slot) and the spectrum used in Wavelength Switched Optical Networks, WSON, (fixed to the channel spacing).

Following, a theoretical analysis comparing WSON and Spectrum Switched Optical Networks (SSON, used as an acronym of Flexi-grid network throughout the paper) is done considering optical channels between 10Gbps and 400Gbps. The signal characteristics of each type of connection (modulation format, spectrum efficiency in bits/symbol and guard band) are summarized in Table 1, obtained from data in several transmission studies [7], [2], [8]. For each channel type, the spectrum need is shown. 10 Gbps connections using NRZ-OOK require in Flexi-Grid a slot size of 25 GHz (m=2), while 50 GHz (1 channel) is used in the fixed grid case. The rest of the connection types (40 Gbps, 100 Gbps and 400 Gbps) use DP-QPSK as a modulation format, achieving a spectral efficiency of 4bits/symbol. The spectrum needs shown in Table 1 consider a guard band of 7GHz between optical channels based on the WSS filtering analysis in [2] and assuming a longest path of 8 hops. The study takes into account the impact of the FEC by increasing the data rate by 12%, as proposed by Jinno *et al.* [2]. In the fixed grid case, 400 Gbps channel demands are served with four 100 Gbps channels, therefore using 4 lambda channels (200 GHz in total in case of 50GHz grid).

Demanded channel	**SSON (Flexi-Grid)**			**WSON (Fixed 50 GHz Grid)**			**Gain**
	Modulation format	**m**	**S (spectrum)**	**Modulation format**	**lambdas**	**S (spectrum)**	
10 Gbps	NRZ-OOK SE=1bit/symbol GB=7GHz	2	25 GHz	NRZ-OOK SE=1bit/symbol GB=7GHz	1	50 GHz	100%
40 Gbps	DP-QPSK SE=4bits/symbol GB= 7GHz	2	25 GHz	DP-QPSK SE=4bits/symbol GB= 7GHz	1	50 GHz	100%
100 Gpbs	DP-QPSK SE=4bits/symbol GB= 7GHz	3	37.5 GHz	DP-QPSK SE=4bits/symbol GB= 7GHz	1	50 GHz	33.3%
400 Gbps	OFDM-DP-QPSK SE=4bits/symbol GB= 7GHz	10	125 GHz	DP-QPSK SE=4bits/symbol GB= 7GHz	4	200 GHz	60%

Table 1: Spectrum needs of modulation formats

The width of the frequency slot (m) is calculated through (1), where *Bw* is the bandwidth of the connection in Gbps, *FEC* is the % of Forward Error Correction overhead, *SE* is the spectral efficiency and *GuardBand* is the guard band needed between signals. Let us remark that slot granularity is assumed to be 12,5GHz as defined in ITU.

$$m = (((Bw * (1 + FEC))/SE) + GuardBand)/(12.5) \quad (1)$$

Table 1 shows the theoretical capacity gain for each connection type, which is directly obtained from the spectrum occupation. This capacity increase does not take into account the network constrains and the Routing and Wavelength Assignment (RWA) in the WSON case, and the Routing and Spectrum Assignment (RSA) in the Flexible grid case. Thus, in a first exercise, the expected theoretical gain is validated computing the total capacity served by the Spanish reference network (see Figure 1) [9] in both cases SSON and WSON. With this aim, the Spanish reference network is filled with connections of 10, 40, 100 and 400 Gbps until the capacity is exhausted. These connections follow the real traffic distribution based on the 2012 Spain Network traffic demands.

The results, shown in Figure 2, are obtained with 1000 simulations with different order of connection arrival. The 95% confidence intervals have been measured. These confidence intervals are bellow 1% of the mean value, so they are not shown in the figure. The black bars show the maximum network capacity in Tbps of the Spanish reference network [9] when WSON is used and the network is filled with connections of a given capacity (either 10/40/100/100). The red bars show the maximum network capacity for the SSON case, and on top of the red bar it is shown the capacity gain with regards to the fixed-grid case. The results show that, when optical connections using DP-QPSK modulation format are used, the total network capacity can be increased by 34% using 100 Gbps channels, or by 65% in case 400 Gbps channels are used. The obtained results are coherent with theoretical values of Table 1, with at most a 5% difference due to the RWA/RSA process in this scenario.

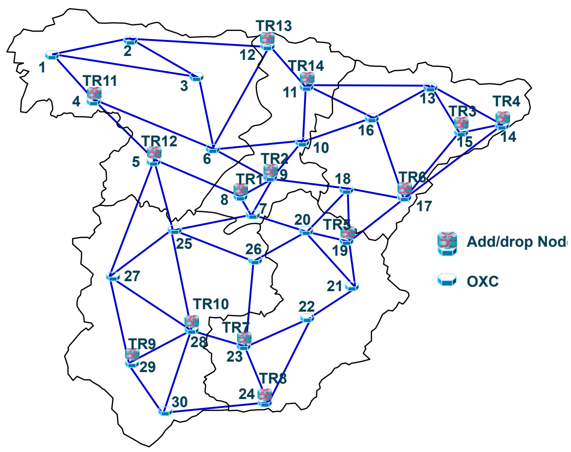


Figure 1 Reference network based on Spanish national backbone [9]

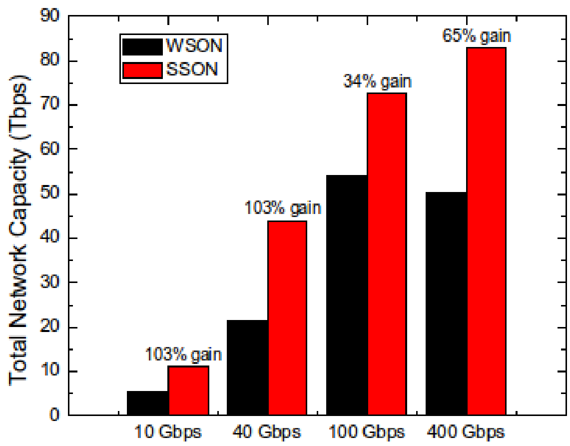


Figure 2 Capacity Gain SSON vs. WSON and total network capacity filling the network with different types of optical channels

The total capacity increment using SSON, in combination with the possibility of introduce the transmission beyond 100G in long haul reaches, are consistent reasons to motivate a technology step onto EON concepts. However, from the network operator perspective, it is important to know when this augment of capacity will represent a real solution for their networks, in other words, when the network capacity will be a problem.

3. Evolution strategies of current fixed-grid Network

This section studies the evolution of a national optical transport network comparing a strategy that follows current fixed grid architecture (WSON strategy) and an alternative strategy where flexi-grid architecture is implemented (SSON strategy). Specifically, it is intended to determine the year when the installed capacity will be depleted and new optical links would need to be deployed. This information will be useful in order to check if the capacity gain given by the introduction of Flexi-grid is a necessity in the coming years and if it is worth to implement Flexi-grid in a real network.

In this paper we will use the term WSON to refer to the fixed grid-based architecture. This WSON evolution model represents the continuity of the already deployed infrastructure. On the other side, the SSON model represents a scenario where the Flexi-grid capability is present. There are two possible cases in the SSON model: 1) it is possible to activate the Flexi-grid functionality in the WSSs by a software upgrade, 2) the deployed WSSs can not implement flexi-grid capability and would need to be replaced, this can be considered as a Greenfield scenario. This section considers the case where WSSs are upgradable, while the next section, dealing with migration strategies, considers both cases.

3.1 Reference scenario

This subsection describes the reference scenario used in the comparison of the WSON and SSON evolution models. The reference network is, as in the previous study, the Spain Reference Transport network publicly available in [9] and shown in Figure 1. The network is a mesh of transport nodes, specifically, Reconfigurable Add-Drop Multiplexers (ROADMs). The study assumes that all the traffic demand comes from the IP network, and that each IP router is connected to a couple of transport nodes for protection purposes).

The same traffic pattern and annual traffic growth is applied to both evolution models. The initial static traffic matrix is based on the current Spanish Network traffic demands and shows the demand between IP routers. Then, a fixed annual traffic growth of 30% has been assumed, based on the traffic forecasts, to obtain the yearly traffic matrix. The total yearly demand is first satisfied using the existing optical connections in the network and, if the existing channels do not fulfil all the capacity needed, new optical connections are established until all the capacity is transported. When the spectral resources are exhausted and no more optical channels can be established, new switching optical equipment and new fibres will be introduced to upgrade the capacity of the network in order to accept more demands. The study assumes the same level of protection requirements as in current networks. Each demand between two IP routers is served by two link and node disjoint optical channels. Additionally, half of the optical channels are also protected to provide additional survivability guarantees.

The reference scenario considers that the initial deployed DWDM optical channels are based on 10 Gbps OOK-NRZ and 40 Gbps DP-QPSK lambda-based optical channels (*lightpaths*). It is foreseen that in the next years the capacity transmission of the available commercial transponders will increase to 100 Gbps and beyond. Table 2 shows a forecast of the commercial availability of the transmission technologies and the spectrum needs and maximum reach of each technology (obtained from [2], [7], [8], [10]). In the study, a given technology will only be used after the forecasted year of release.

Transmission technology	Number 12.5 GHz slots / Spectrum	Distance (Km)	Year Of Release
OOK-NRZ – 10 Gbps	2 / 25 GHz	2200	Commercially available
DP-QPSK – 40 Gbps	2 / 25 GHz	2800	Commercially available
DP-QPSK – 100 Gbps	3 /37.5 GHz	2800	2015
OFDM - DP- QPSK - 400 Gbps	10 / 125 GHz	3560	2017
OFDM - DP- QPSK – 1 Tbps	24/300 GHz	3560	2019

Table 2: Compendium transmission technologies: spectrum needs, maximum reach and year of commercial availability.

However, not all these transmission technologies can be supported in the WSON evolution model due to their spectrum requirements (shown in Table 2). For example, transmissions above 100 Gbps using DP-QPSK or OFDM-DP-QPSK modulation formats are not possible within the fixed 50 GHz ITU grid. Although there are high spectral-efficient modulation formats such as DP-16-QAM that could fit within the fixed grid, such formats do not have the suitable reach for long haul networks [10].

The study has been developed assuming that CDC-ROADMs (Colorless, Directionless, Contention-less) are deployed in the network. The ROADM configuration follows the standard broadcast and select architecture based on WSSs [11]. It is assumed that the routes can be automatically configured between any two nodes and no regeneration is needed with the types of signals used. The contention-less functionality allows that the same wavelength can be added/dropped to/from two or more different directions (incoming links to the node). From the network planning perspective, it implies that the only one restriction is that two different channels cannot share the same spectral resources of the same link.

The addition of a new degree to a deployed ROADM occurs when the spectral resources of an attached fibre are exhausted and consequently it is impossible to route a new channel through it. In this case, it is necessary to activate a new parallel fibre in the link between the ROADMs.

3.2 Network Evolution results.

The study assumes an initial ROADM deployment and an initial set of 10 Gbps and 40 Gbps given by the reference scenario. After the initial deployment, the network grows, on the one hand, following the WSON model and on the other hand, following the SSON model. The study compares the number of new long haul links that need to be activated following each strategy.

A heuristic RWA/RSA algorithm for WSON and SSON architectures respectively has been used for the path calculation and resource (wavelength/spectrum) assignment of the optical channels. The algorithm for the WSON model is the Adaptive Unconstrained Routing Exhaustive (AUR-E) [12] RWA algorithm. For the SSON case such algorithm has been adapted to solve the RSA problem.

Figure 3 shows the number of activations of new links needed up to a given year in both evolution models. It can be seen that the capacity of the deployed network will be exhausted by 2019 when the WSON evolution model is followed. However, by the activation of the Flexi-grid functionality the lifetime of the network is extended 5 years. This life extension in the SSON evolution model is due to both the use of high efficient modulation formats beyond 100Gpbs and the adjusted spectrum assignment.

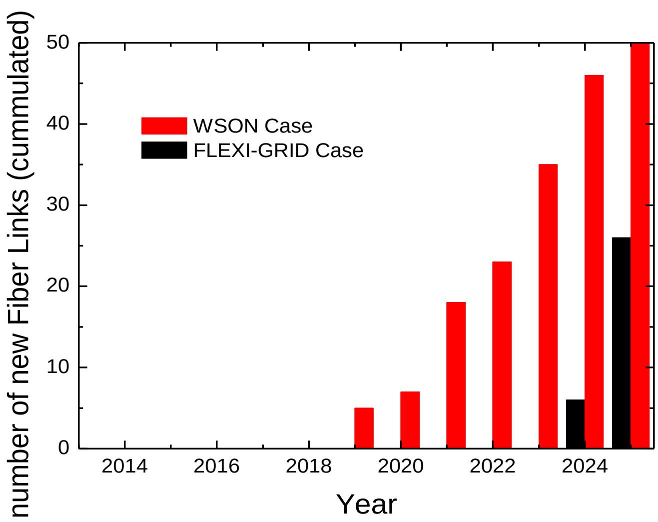


Figure 3 Number of new Fiber Links WSON vs Flexi-grid evolution models

4. Migration strategies

In the previous section it has been analysed and compared the evolution of the network following a pure WSON evolution model and a Flexi-grid evolution model, focusing on finding the time when the capacity is exhausted. This section quantifies the number of WSSs and transponders of different types following the WSON and the SSON evolution models.

The Flexi-grid evolution model considered in the previous section that the deployed WSSs in the network are flexi-ready and that by a software upgrade they can be reconverted to Flexible WSSs. In that case, the operator can choose at any time to migrate to flexi-grid. This section also addresses the case where the deployed WSSs cannot be upgraded to support flexible bandwidth channels switching and when the capacity is exhausted, instead of adding degrees to the existing ROADMs, new Flexi-grid ROADMs are deployed. In this mixed WSON-SSON scenario, the introduction of Flexi-grid technology implies a whole parallel transport network deployment with flexi-grid capable equipment. In this evolution scenario, the Flexi-grid and Fixed grid based networks would need to operate together in parallel, introducing new planning and operational challenges from the network operator perspective.

4.1 Evolution strategy towards Flexi-grid when deployed WSSs are not Flexi-grid capable

In the evolution model where the deployed WSSs are not Flexi-grid capable, the annual incoming demands are served by DWDM channels in the WSON network until a demand cannot be satisfied (no path is found for the requested optical channel). At this point, a migration strategy is followed towards a new flexi-grid network. The migration steps are done sequentially, creating only new flexi-grid links when the WSON network cannot allocate a new optical channel.

In the migration process, the demands are first tried to be allocated in the WSON network, in order to maximize the use of its available capacity. The demand in the WSON network is divided into channels that fit in the 50 GHz grid. When the channel demand cannot be satisfied in the WSON network, the optical channels are tried to be set-up in the SSON network. If in the SSON network there is no space, new ROADMs and links are deployed.

4.2 CAPEX Results

In order to be able to compare which is the most appropriate evolution strategy, this section quantifies the equipment necessary in every year of the network. The study does not assume any cost pricing for non-commercial transponders, as any specific cost assumption would bias the results. The performed network planning obtains the equipment necessary in the network in order to carry out the full traffic demands. The considered equipment is the total number of WSS required in each network evolution model and the number and type of transponders required to support the optical channels.

Figure 4 shows the number of WSSs used for the express switching (there is one WSS per ROADM degree) and the number of WSSs for the ADD/DROP chains. It can be seen that, as expected, the SSON evolution model that considered non flexi-grid capable ROADMs lead to a high number of WSSs for the express switching, as it is deployed a parallel network. Considering the number of WSSs, all the strategies follow the same pattern until 2019. At this point, the SSON non-flexi ready case needs to make a big investment due to the new parallel SSON network. However, in the long run, the WSON evolution strategy needs more WSSs in the add/drop chains than both SSON models, as it is needs to keep using a high number of transponders of 100 Gbps, while the SSON models can use less transponders (but with higher capacity), as shown in Figure 6. The WSSs needs are obtained following the node model defined in [9].

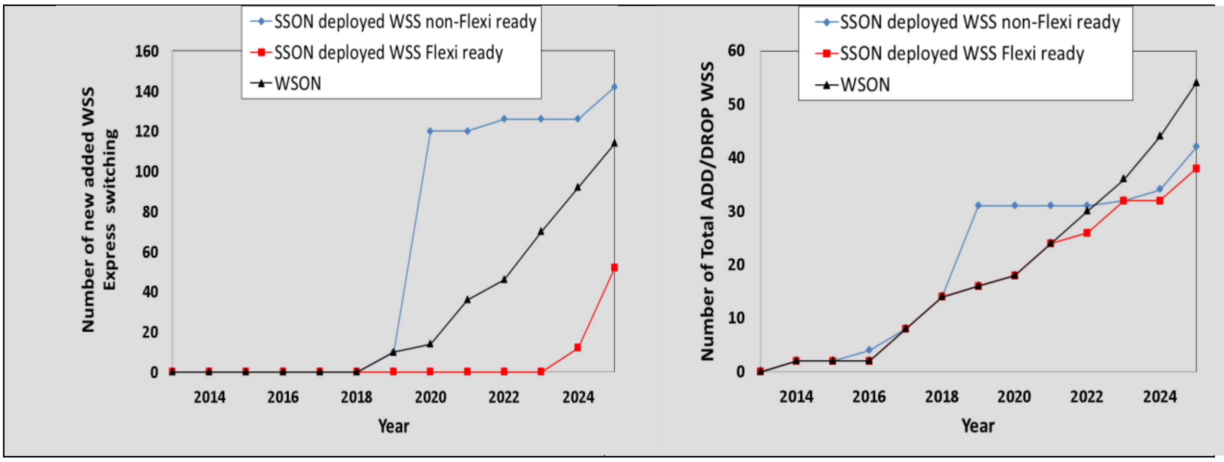
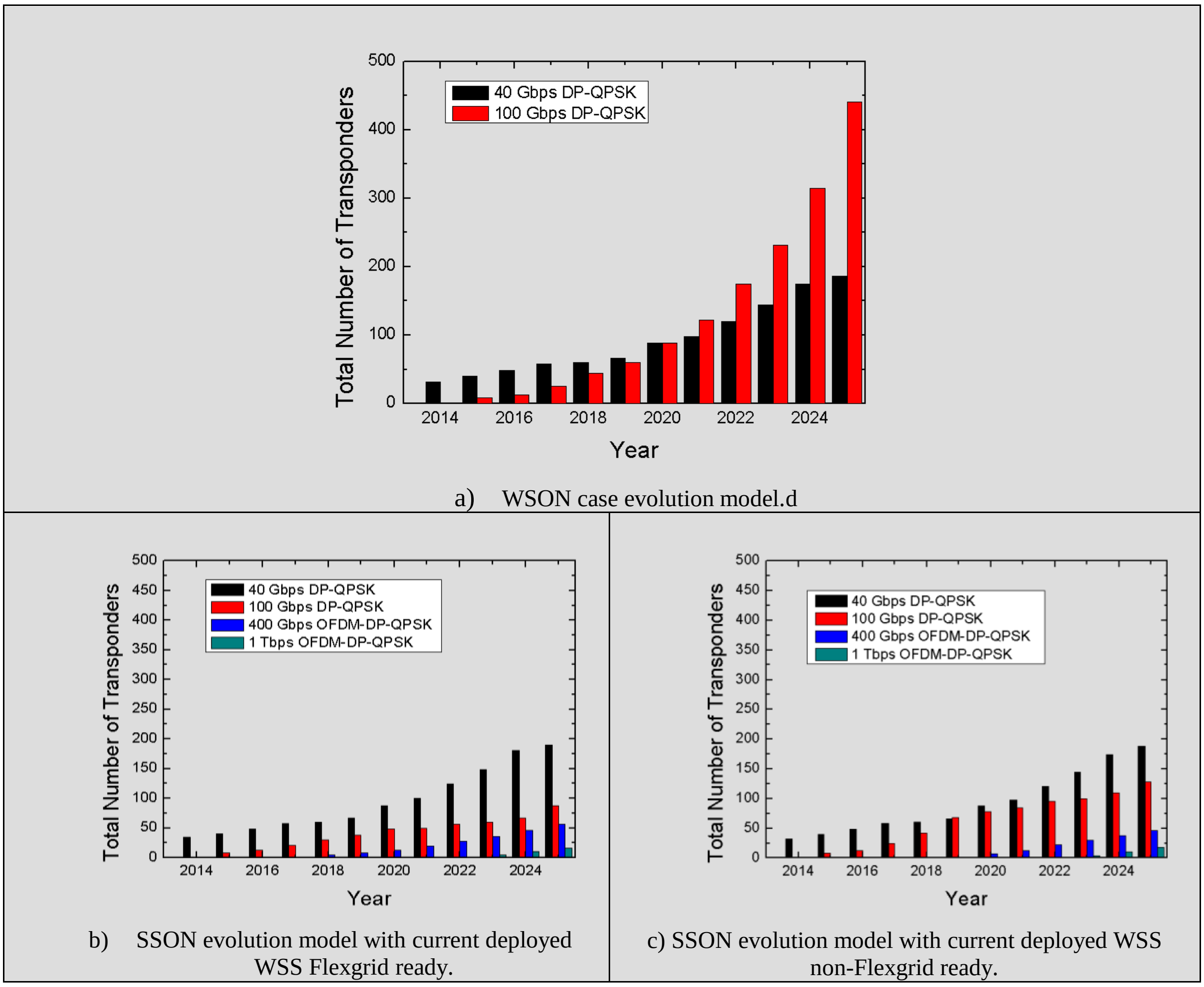


Figure 4: a) Number of 1x9 WSS in express switching, b) number of 1x20 WSS in the add/drop chain.



a) WSON case evolution model.d

b) SSON evolution model with current deployed WSS Flexgrid ready.

c) SSON evolution model with current deployed WSS non-Flexgrid ready.

Figure 5: Total number of transponders by sort in each case.

The number of transponders is shown in Figure 5. It can be observed that the number of 100G transponders in the WSON evolution model (see Figure 5c) exponentially increases. In the other two models, with the Flexi-grid introduction and therefore higher capacity channels inclusion, the increment in the number of transponders (and the add/drop equipment in general) is more gradual. However, as realistic costs of higher capacity transponders beyond 100G are not yet available, the study is focused on presenting the number of transponders, so target costs can be easily obtained to know if flexi-grid is necessary or not. If high-speed transponders achieve a high level of cost-efficiency *vs* 100 Gbps transponders, the cost to upgrade the network after 2020 using Flexi-grid will be lower, even considering the worst-case where new Flexi-grid equipment needs to be deployed.

5. Flexi-grid as enabler of 400G Transmission

A short term driver for Flexi-Grid might be the appearance of 400Gbps client signals and cost effective 400Gbps transponders. In this case study is it obtained, for the Telefonica of Spain core transport network, the number of 400Gbps demands that could be needed in the following years, with a 30% yearly traffic increase, maintaining the same traffic distribution. Figure 4 shows the number of forecasted demand of 400 Gbps per year.

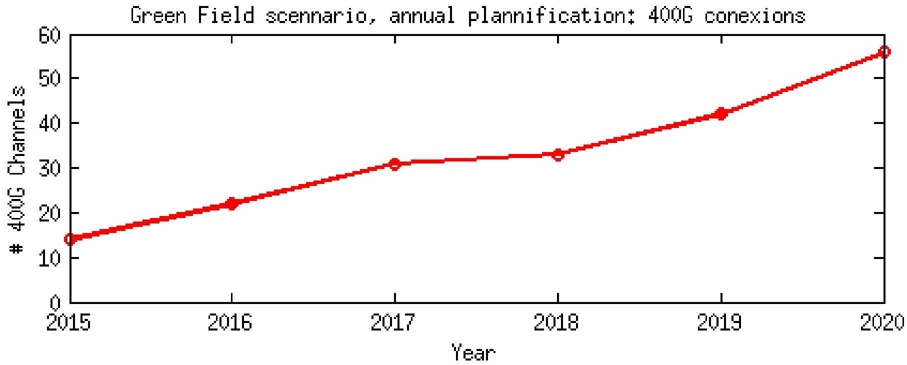


Figure 6 Number of 400G channels per year

There are two main choices for 400 Gbps transmission: 400G transmission based on OFDM-DP-QPSK over 125GHz. The reach of each subcarrier modulation format (DP-QPSK) would enable long haul deployments. However, as 125 GHz are needed, it is only feasible using flexi-grid technology. The other option is split the demand in two wavelengths with DP-16QAM 200Gbps over standard Fixed 50GHz grid. However, in this case, the reach is lower. Taking into account the length and number of ROADM of the long haul routes in Telefonica of Spain Network, approximately at least 30% of the 400 Gbps transmission using DP-16QAM would need regeneration. Such regeneration can be avoided by using OFDM-DP-QSK and enabling flexi-grid.

6. Conclusions

The study has compared the evolution of a national level optical transport network based on the current Fixed grid WSON approach and the newly proposed Flexi-grid approach. The results show that a network based on Flexgrid could extends the lifetime of the network 5 years with respect the legacy WSON. Results also show that current WSON capacity will not be exhausted until 2019.

The limitation on the maximum capacity that can be carried in a single lambda causes a dramatic increase in 100 Gbps optical channels in case the network grows following a WSON model. If the network is migrated to flexi-grid, the number of transponders is reduced. In the case that the deployed network is based on WSSs that are not Flexi-grid capable, a mixed WSON-SSON strategy has been presented. Such strategy implies starting to deploy a parallel SSON Network when the capacity of the WSON network is exhausted. At the expenses of the deployment of the parallel network, the number of transponders is drastically reduced compared to keep on the WSON network, which needs to grow adding parallel links and increasing the degree of the ROADMs.

Even though in the next years capacity in terms of spectrum is not yet an issue, and thus migrating to flexi-grid just because of the lack of spectrum makes is not urgent, a key driver to migrate to flexi-grid is the demand of high speed channels and the availability of cost-effective 400Gbs and 1Tbps transponders.

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