Techno-economic evaluation of alternatives for the deployment of a photonic mesh

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The continuous and significant growth in IP traffic due to converged IP networks, forthcoming high-bandwidth services and new Internet users is expected to drive current network capacity to its limit. Therefore, carriers are seeking to improve their networks with higher bandwidth optical links. In this paper we present a techno-economic comparison between DQPSK and DP-QPSK technical approaches for deploying a photonic meshed backbone at 100 Gbps. Given the different theoretical characteristics of both modulation technologies, we develop a cost model to select the most suitable technology depending on the backbone size.

1. Introduction

Triple play services offered by telecommunication operators are increasing the bandwidth demand yearly due to both new users and new high-bandwidth services (IPTV, HDTV, HSDPA…). In the access network, new broadband technologies will allow subscribers to enjoy these new services in fixed (VDSL/VDSL2, GPON, WDM-PON) and mobile networks (HSPA, WIMAX…). This important growth of capacity per user, as well as the increasing broadband penetration, involves that the carriers need to upgrade their transport network to avoid bottlenecks.

One way to cope with the growing demand is increasing rate in transmission links. In that sense, carriers are already deploying new 40G interfaces (STM-256/OTU-3). Evolving from current 10G transmission techniques to higher capacity ones implies an important effort in optical and electrical engineering. Thus, transmission impairments must be reviewed carefully if the current or longer link distance is desired. In this way new multilevel modulation formats [1], improved receivers and novel dispersion compensation techniques [2] have been investigated. On the other hand, as 40G optical interfaces are deployed, 100G transmission has become the current outstanding point under study in order to fulfill future traffic demands. This challenge makes researchers increase their efforts to carry out with the adverse transmission conditions. The innovations achieved for 40G must be revised to accomplish the 100G optical communication scenario [3].

In the meanwhile, operators are becoming more and more interested in all-optical meshes. Current optical networks based on point-to-point high-bandwidth links might be cost-effective no longer because of the great growth of traffic which leads to a significant express traffic in the nodes. In this scenario, all-optical meshes may be a cost-efficient solution to offer higher bitrates, simplify the control plane management and reduce costs thanks to transit traffic bypassing.

According to above mentioned drivers, in this paper we compare different alternatives for deploying a photonic mesh at 100Gbps.

This study is organized as follows: first of all, the most popular technological alternatives for 100G transmission are reviewed. Afterwards, in section 3 the network and dimensioning model is presented along with the link specifications and lightpath design. Section 4 includes the cost model for the considered solutions. A case study scenario based on a Spanish reference network is described in section 5. Finally, the results of the cost analysis and the conclusions of the study are presented in sections 6 and 7, respectively.

2. Alternatives for 100G transmission

Several solutions have been proposed to achieve 100G transmission. The first and simplest way is the inverse multiplexing. This technique allows 100G traffic to be split into multiple lower data rate carriers such as 10G. However, it has been proven that this solution makes network management more difficult and shows important problems at the receiver due to parallel transport synchronization complexity. On the other hand, 100G serial transmission must cope with challenging penalties arisen from the very restrictive optical impairments in such a high bitrate, as shown in table 1.

	10G	40G	100G
Bit interval [ps]	100	25	10
Optical spectrum [nm]	0.1	0.8	2
CD tolerance	1	1/16	1/100
PMD tolerance	1	1/4	1/10
Noise tolerance reduction [dB]	0	6	10
Relative reach	1	1/4	1/10

Table 1. Optical impairments depending on the bit rate.

The best solution to deal with these restrictions is evolving towards more sophisticated modulation schemes with more than one bit per symbol so that the symbol rate becomes lower, relaxing optical impairments. Many modulation formats have been proposed [4] but DQPSK and DP-QPSK seem to be the most supported strategies by vendors.

DQPSK is a differential phase modulation format with 2 bits per symbol, so the symbol rate is 50Gbauds. DP-QPSK is a multiple polarization scheme with 2 bits per polarization (QPSK) resulting in 4 bits per symbol and 25Gbauds transmission rate. Increasing the symbol rate improves impairments tolerance and relaxes electrical complexity for modulators. In return, DP-QPSK optical transponder is a more complex and, therefore, costly system in terms of the number of components at the transmitter and receiver.

Thanks to DP-QPSK lower symbol rate, optical reach is greater than DQPSK one; thus, the reach for links in an all-optical mesh topology depends strongly on modulation format. This paper tackles the economical study to analyse the cost feasibility for an all-optical mesh by comparing transparent optical links developed over either DP-QPSK or DQPSK. Furthermore, for achieving the same link length, DQPSK solution with electronic regeneration may be cost-effective because of the lower cost of DQPSK transponders in relation with DP-QPSK ones. As a result, a practical comparison between the two strategies is given regarding the length and the number of cascaded ROADMs that are traversed in a traffic path.

3. Network model and dimensioning

We consider two types of network nodes:

Aggregation nodes: These nodes are in charge of collecting all the traffic from the regional networks. Thus, the aggregation node is the border with the IP network. For every direct connection of the aggregation node to other nodes, a transceiver is needed. This transceiver feeds the client interfaces of the ROADM. These nodes act both as transit nodes and traffic generating nodes.

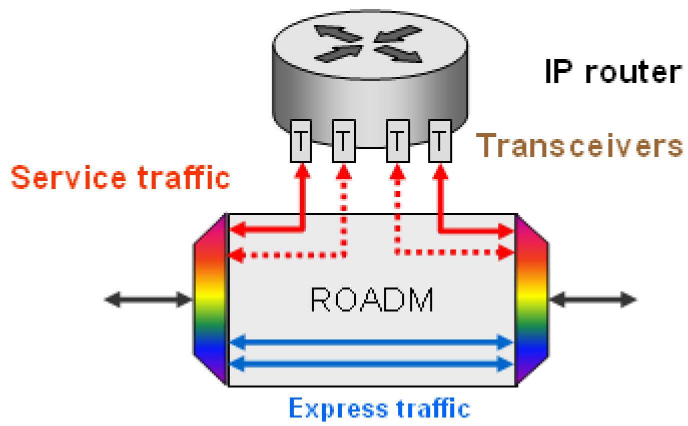

Figure 1. Structure of an aggregation node

Transit nodes: These nodes consist of ROADMs with WSS with a nodal degree up to 4. These nodes are, in the first step of the photonic mesh, in charge of cross connecting the WDM channels. The transit nodes do not insert new traffic in the network

Link design

In the event of an optical mesh deployment, we foresee the use of G-652 fiber in all links, both in the case of already installed fiber and the newly deployed where needed. For the sake of simplicity, we will assume that independently of the transmission technology, one amplifier will be placed every 80 km (l_{span}). Also, a dynamic gain equalizer is needed every four spans. Moreover, every amplifier will be placed together with a chromatic dispersion compensator module. The chromatic dispersion compensation can be done either by a DCF, whose length is calculated in order to compensate almost all the cumulated dispersion -remaining certain uncompensated amount to mitigate non-linear effects- or by a Fiber Bragg Grating [5]. The number of Optical Line Amplifiers (N_{OLA}) and Dynamic Gain equalizers (N_{DGE}) is given by:

$$N_{OLA} = \left\lfloor \frac{l_{link}}{l_{span}} \right\rfloor \qquad N_{DGE} = \left\lfloor \frac{\left\lfloor \frac{l_{link}}{l_{span}} \right\rfloor}{4} \right\rfloor$$

Connection and Lightpath design

Direct connections of 100Gbps will be established between the IP routers of the aggregation nodes. These connections will be made of a set of lightpaths where regeneration may be needed at given points. The transmission technology will determine the maximum length of the lightpaths. The number of regenerators (N_{reg}) needed per 100Gbps connection (l_{conn}) will be:

$$N_{reg} = \left\lfloor \frac{l_{conn}}{l_{\max}} \right\rfloor .$$

The study in [6] determines the maximum transmission length (l_{max}) for DQPSK (700 km) and DP-QPSK (1,600 km).

The connections will traverse several ROADMs. The tolerance to traverse ROADMs depends on the modulation format of the transmission. Using the DP-QPSK modulation format, ROADM cascability (around a number of sixteen) in 50 GHz grid is similar to the cascability of DQPSK in 100GHz grid, due to the different bit per symbol ratio of both modulation technologies. This means an advantage for DP-QPSK as it consumes twice the transmission capacity of an OF.

4. Cost Model

In order to compare the cost of the different modulations, a ratio between the cost of the transponders must be decided. On the one hand, DP-QPSK transponders duplicate DQPSK modulation components and need a polarization multiplexing device. On the other hand, DP-QPSK hardware works at half the frequency of DQPSK electronic components, resulting in less complexity and, therefore, lower cost. Thus, it is assumed that cost of DP-QPSK transponder is twice the cost of DQPSK.

Taking into account the previous hypotheses regarding the reach and transponder cost, it can be derived the following graph comparing DQPSK and DP-QPSK cost as a function of the lightpath distance.

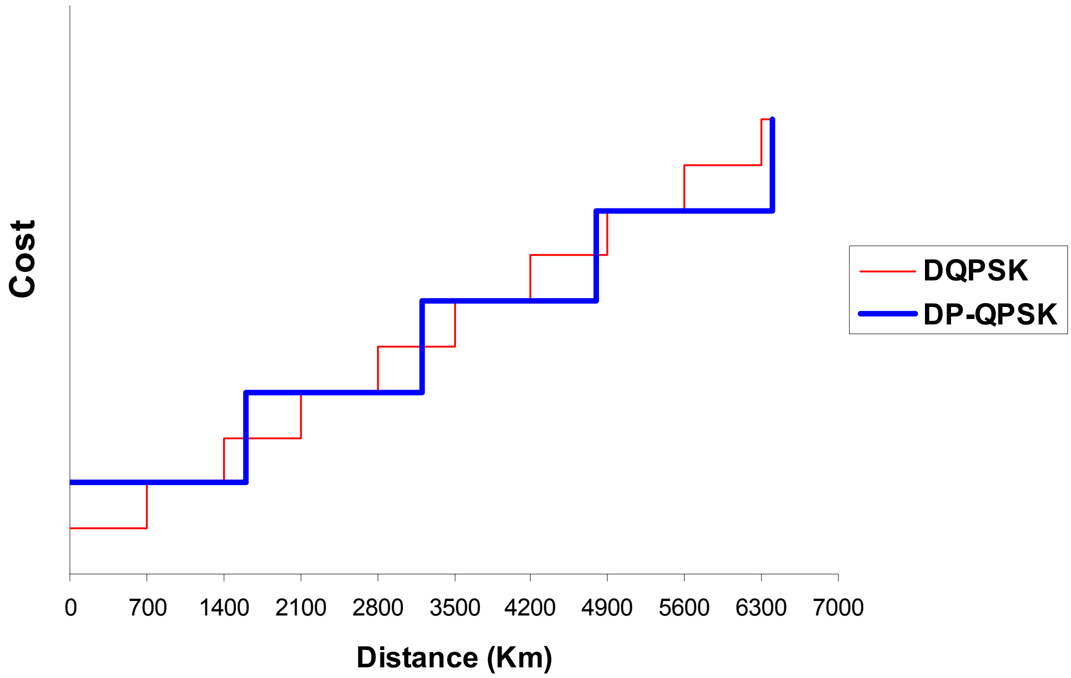

Figure 2. Cost of DQPSK and DP-QSK as a function of distance

For a feasible interval up to 4900 km, the optimal cost solution depends strongly on the lightpath distance. Further than 4900 km, DP-QPSK will always be the best solution in terms of cost. Furthermore, It is worthy of notice the fact that DQPSK consumes twice the OF capacity, which may be a significant advantage to fulfil forthcoming traffic demands. Besides, given that DQPSK modulation format involves a 100 GHz optical grid, new ROADMs with 32 x 100 GHz channels should be employed instead current 64 x 50 GHz.

5. Case study

We consider an optical mesh in Spain to carry all Internet traffic. Taking into account geographic and population factors, aggregation and transit nodes have been placed. So the mesh consists of 29 nodes with a minimum physical connection degree of 3. Only aggregation nodes are supposed to need 100G channels.

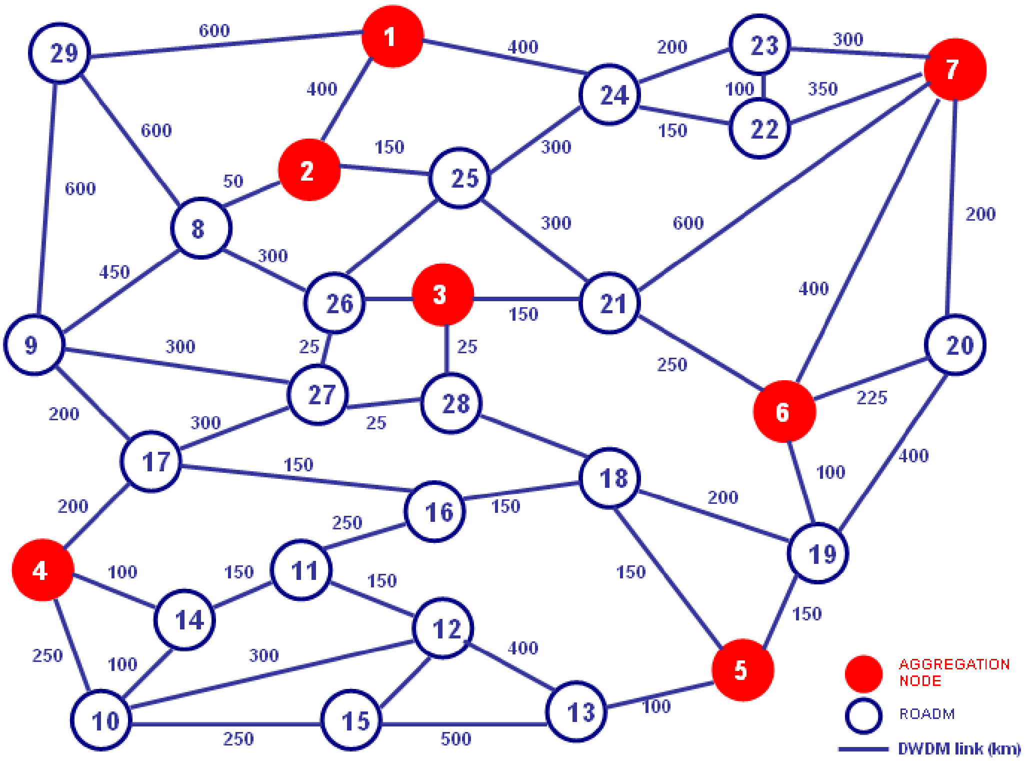

Figure 3. Network scenario

This study has the aim of comparing the main options of transmission technologies so we aim not to a full optimization. Thus, the strategy to calculate the connections is the following:

1- Route all traffic through the Shortest Path.

2- Split the traffic in 100G connections

3- For every connection, calculate a backup link disjoint path.

4- Each path (working and backup) is split in lightpaths, according to the maximum transmission length of the considered technology. No optimization will be done in the regenerators placement. Thus, regenerators will be placed when needed.

5- One lambda is assigned per lightpath. No wavelength conversion is assumed

For the scenario given and considering only shortest path route, DP-QPSK is 27% more expensive than DQPSK, as most lightpaths are shorter than 700 Km. The gap between both technologies is reduced to 18% when disjoint backup paths are considered given that these paths are longer. Thus, the cost of DQPSK solution is similar or even higher than cost of DP-QPSK.

6. Cost analysis results.

In order to extend our study to countries of different sizes, calculations have been done for different values of mean distance per link and maintaining the original topology. Figure 4 summarizes cost ratio of DP-QPSK / DQPSK for a mean link distance ranging from 100 to 9000 km. Above one, cost of DP-QPSK will be higher and DQPSK more cost-effective. Below one, DQPSK will be higher and DP-QPSK more cost-effective.

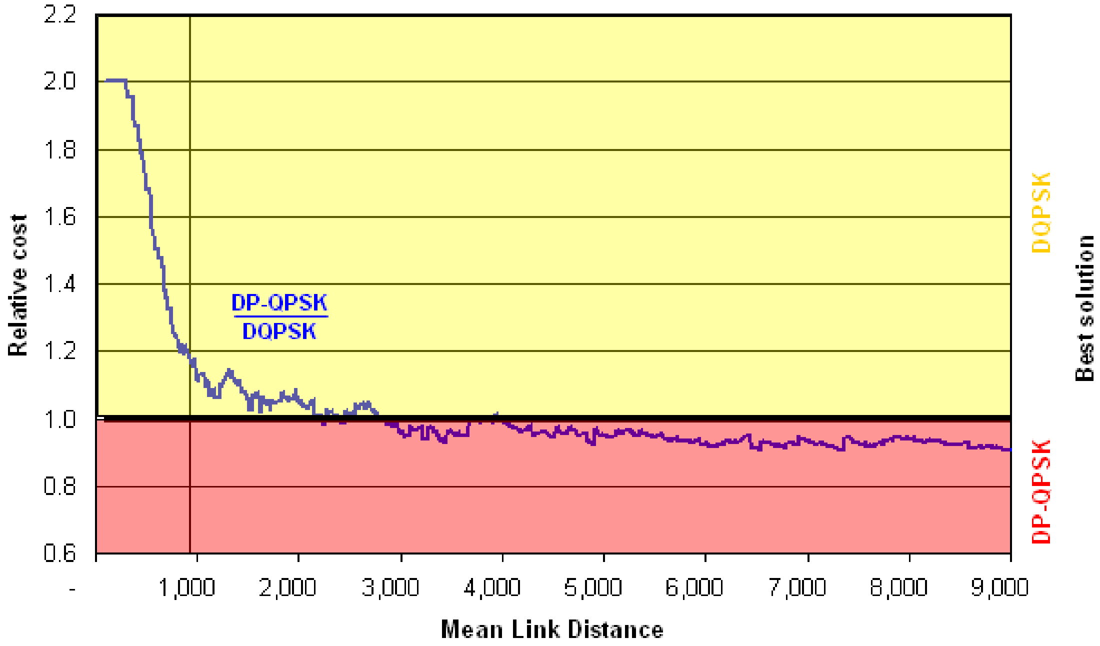

Figure 4. DP-QPSK / DQPSK cost ratio as a function of mean lightpath distance

In small and medium sized countries with low covered surface (link lengths up to 3000km), DQPSK solution is preferable due to its lower deployment cost. However, in cases of big countries with longer lightpaths (USA) or intercontinental backbones, DP-QPSK will be the best choice due to the longer reach and the saving in regenerators.

7. Conclusions

This study includes a techno-economic comparison of different technical approaches for deploying a photonic meshed backbone at 100Gbps. In particular, we evaluated two of the most supported modulation formats by vendors: DQPSK and DP-QPSK. According to our results, we can conclude that, in green-field deployments, the required investments for each option would strongly depend on the network size, so that while DQPSK would require lower investments in medium size scenarios, DP-QPSK would be a more cost effective option in the biggest networks. On the other hand, DP-QPSK channels can be transported over existing 50 GHz optical grids, therefore it would be a better option than DQPSK when 100Gbps channels are introduced over existing 10/40 Gbps photonic networks.

Next table summarizes the above conclusions.

	Mean Link Reach < 3000 Km	**Mean Link Reach > 3000 Km**
Greenfield photonic mesh at 100 Gbps	DQPSK	DP-QPSK
Migration from an existing 10/40 Gbps photonic mesh	DP-QPSK	DP-QPSK

Table 2. Recommended solution and deployment scenario

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