On the Impact of Transmission Technologies in Metropolitan Networks

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***Abstract*— Current metro networks are deployed using IP/MPLS equipment on top of ring physical topologies. Such networks are migrating from 10G interfaces to 100G. Such evolution must consider not only the packet layer, but also the underlying infrastructure with its limitations.**

This paper assesses alternative deployments to upgrade metro networks in terms of cost efficiency. For scenarios with low traffic profiles, operators use dark fiber and grey interfaces in the packet equipment. However, transmission techniques helps to reduce the utilization of the fiber pairs. Results demonstrate that the cost of the fiber infrastructure greatly conditions the deployments. Based on the cost relation between 10G and 100G, it is more efficient to maintain the network in 10G technologies. However, the technical limitations on the metro equipment as well as the operational complexity justifies the migration to 100G.

Keywords—metropolitan network; coloured interfaces; grey interfaces; techno-economic study;

I. INTRODUCTION

The network operators have to deal with a never-ending increment of the traffic without increasing the end customers incomes. The video content is the main traffic source, which is driven by the Over The Top (OTT) services as well as the video quality increment. The utilization of Content Delivery Networks (CDNs) or transparent caching minimize the traffic in the backbone network, but the metro networks have to transport the traffic. The cost of the CDN and the demarcation points of the IP backbone complicates to move closer the content to the end user in an efficient way.

Current metro networks are deployed using IP/MPLS equipment on top of ring physical topologies. This physical infrastructure is based on ring ducts from the SDH deployment, where the number of fibers was limited. The IP/MPLS equipment evolved from 1G to 10G technologies, but now they must migrate from 10G interfaces to 100G. Such evolution must consider not only the packet layer, but also the underlying infrastructure with its limitations.

Metro architecture is typically composed by three main levels of aggregation. Beginning at the bottom of the architecture, the components that can be found are Gateway Terminal (GWT) and Switches Terminal (SWT), which are devices that aggregates the traffic from the mobile and fixed subscribers. The GWT aggregates traffic from different base stations (BS), which aggregate traffic from mobile subscribers and, similarly, the SWT aggregates the traffic from the Digital Subscriber Line Access Multiplexers (DSLAMs) and Optical Line Terminals (OLT). The traffic from multiple GWTs and SWTs is received by the SWD (Distribution Switches). Finally, at the top of the hierarchy the traffic is sent to the Concentration Switches (SWC).

Depending on the regions, this architecture can vary. For urban areas with Fiber To The Home (FTTH) deployments, the SWTs are not required as the number of OLTs is high and they can be co-located in the same central office that the SWD. On the other hand, extra hierarchical levels with low capacity links can be found in remote areas, where number of subscribers (and the bandwidth requirements) is small.

The metropolitan networks were not designed to carry out the huge amount of bandwidth that is transported today. This motivates this work, which evaluates alternatives to deploy transmission in metro scenarios.

Although in the last years many studies have focused on the metro architectures [1], to the best of our knowledge, only the work presented in [2] compares the cost of traditional and optical metro networks. However, the maximum traffic considered in this study (40 G) is low taking into account the current traffic growth rate. They also use a cost model published in 2008, whose prices are no longer up to date. Moreover, they do not consider 100 G equipment or include the cost of fiber deployments in the study.

The remainder of this paper is as follows: Section II presents in detail how the metro networks are deployed in network operators. Section III describes the network models for each alternative deployment. Section IV carries out a techno-economic comparison with the cost model and the results. Finally, Section V concludes this work.

II. METRO ARCHITECTURE IN REAL DEPLOYMENTS

Common transmission deployments rely on technologies with moderate performance in terms of reach and overall capacity for metro scenarios. So far, the most common architecture to deploy metropolitan networks is not supported on an optical transmission layer. That is, in the source, destination and each intermediate node the information is aggregated in the electrical domain and transmitted via grey interfaces. Although the capacity of the network can be upgraded using interfaces with higher performance (i.e. 100 G instead of 10 G ports), this architecture presents a number of limitations, regarding the computation capacity of the intermediate nodes and the number of fibers to be deployed or used. An example of these networks with a ring structure is depicted in Fig.1. In this network, traffic from SWDs (20G) is aggregated in each of the intermediate SWDs through its way to the SWCs. The ring in Fig.1 is dimensioned to support single failure, so the fiber between SWD$_1$ and SWC$_1$ has to support 60 G (20 G from SWD$_1$, 20 G from SWD$_2$ and 20 G from SWD$_3$, the two latter to support failure of the SWD$_3$-SWC$_2$ fiber).

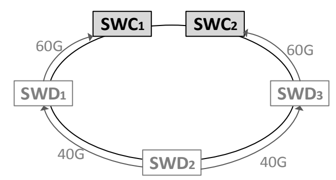


Fig. 1. Example of metro ring topology with no optical layer

However, with the increment of the traffic demand in recent years, these architectures have to evolve to be efficient. One possibility would be to deploy new fibers from the SWDs to the SWCs, converting the physical topology from a ring to a star/tree topology, where each SWD has a direct fiber connection to each SWC using dark fiber (as it is depicted in Fig.2).

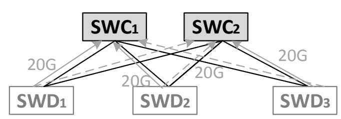


Fig. 2. Example of tree topology with no optical layer

Other possibility relies on the use of Wavelength Division Multiplexing (WDM) optical networks. In this sense, each SWD is logically connected to each SWC by means of a different wavelength. Thus, conforming a logical star/tree topology under a ring physical topology. Fig. 3 shows the physical and logical topology of these WDM coloured networks. It can be seen that, using the same ring fiber infrastructure, the logical topology is a star with all SWDs connected directly to the SWCs.

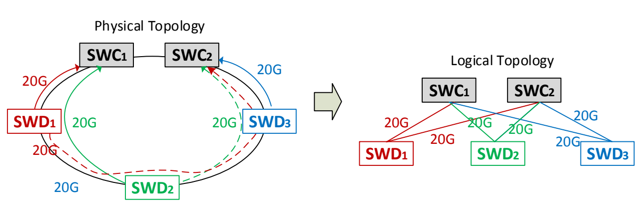


Fig. 3. Physical and logical topology for coloured ring deployments

To deploy this type of networks, (Coarse WDM) CWDM and Dense WDM (DWDM) can be used. In some cases, non-amplified structures based on CWDM buses or rings, with a limited number of channels can be enough. In other cases, metro performance DWDM rings enable covering the remaining network scenarios. Optical meshes are commonly restricted to densely populated areas, with higher needs of capacity and redundancy. In any case, optical nodes usually provide no reconfiguration capabilities (are based on Fixed Optical Add and Drop Multiplexers (FOADM)) or control plane driven restoration. Data equipment for this approach is connected to the "client side" of CWDM or DWDM transponders by means of "grey" interfaces. Then, the "coloured" optical signals can be amplified or not depending on their nature (DWDM vs CWDM) and filtered at the optical nodes. However, this architecture has the inconvenience of deploying new optical nodes with active equipment and an additional network management system for the optical layer. An example of this architecture can be seen in Fig. 4.

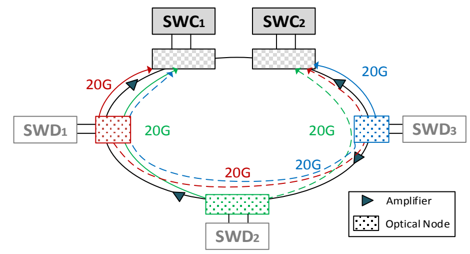


Fig. 4. Example of CWDM/DWDM metro architecture with optical nodes

An alternative simpler approach to deploy logical trees, can be based on the direct use of coloured interfaces at the data equipment, using simple passive filters for the sake of adding/dropping signals (optical passive deployment). Even though there is a possibility to amplify the DWDM signals coming from the data nodes. This would imply the maintenance and control of an active additional equipment, i.e. to deploy a "reduced" optical node (with no transponders) collocated with every router/switch to compensate the filtering and transmission loss. It would be pretty convenient to leverage the specific parameters found in the metro environment (few nodes to be traversed from origin to destination, short link distances, low number of channels) to avoid amplification and consider a simple and inexpensive architecture based on the use of end-to-end optical paths established over a set of passive WDM filters.

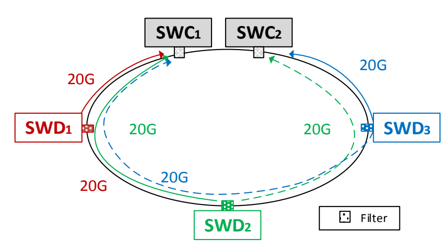


Fig. 5. Example of passive optical metro architecture

The architecture allows considering logical star topologies (with lightpaths to headend nodes using separate wavelengths) over a shared ring based fiber deployment. This will be feasible over metro scenarios subject to some restrictions, as coloured interfaces will have an operating margin in terms of sensitivity. This margin will translate into a maximum level of fiber+filtering compound losses (attenuation and insertion at every filter) that ensures an adequate power level at the ends of every light path. The maximum number of nodes and fiber length of a feasible structure will depend on the number of WDM channels (the lower the better), the filter characteristics in terms of loss and the fiber quality and span lengths. An example of this architecture can be seen in Fig. 5.

III. Network Model Description

In this paper two alternatives to deploy metropolitan networks are compared in terms of cost effectiveness. In this section, the node architecture for each alternative is explained.

A. *Dark fiber deployments*

The first architecture considered is based on the use of dark fiber in the transmission layer. In this way, a ring topology is transformed in a tree topology by adding fibers between each SWD to the SWCs, as depicted in Fig.2.

The simplified block model for the node architecture is shown in Fig. 6. As it can be observed, the Ethernet layer is composed of common parts of the node (switching matrix, power supply and mechanics) and the interfaces are composed of line cards (LCs) with different number of ports, where optical transceivers are inserted. For this architecture, the connection to the transmission layer is done via grey pluggables, which are directly connected to the fiber. Thus, for each pluggable a fiber has to be deployed and the reach cannot be so high (few kilometres, normally ranging from 10 km to 40 km depending on the type of pluggable). Therefore, this proposal is only appropriate for metropolitan areas, where the distance to the SWCs and SWDs is not so high and normally there are enough fibers deployed.

Regarding the LCs, different port granularities can be considered from different capacities. In the example of Fig. 6, line cards of 2, 4 and 10 interfaces of 10G and line cards of 1 and 4 interfaces of 100G are considered.

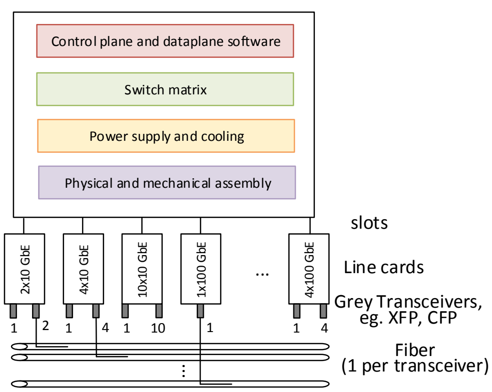


Fig. 6. Node architecture for dark fiber deployments

B. *Pasive optical deployments*

The second architecture considered is based on the use of coloured transceivers and a passive filter in each node to extract the corresponding wavelengths (Fig. 5).

Therefore, the simplified block model of the node architecture is depicted in Fig. 7. As it can be observed, the common parts remain the same as in the previous architecture. However, the pluggables used are connected to the transmission layer via coloured interfaces without amplification. This means that different transceivers transmit on the same fiber using different wavelengths. Applying this to a physical ring topology, it transforms into a logical tree topology, without the necessity of adding more fibers and avoiding the use of optical transponders. To achieve this, it is necessary to include a passive filter tuned in to the corresponding wavelengths.

The schematic of the filter is shown also in Fig. 7. As it can be seen, it is composed of two blocks, one in charge of dropping the corresponding wavelengths and the add-block which incorporates the corresponding wavelengths. Each block has insertion losses, which have to be taken into account to ensure a good quality of signal at the destination. There are filters with different number of channels, but the insertion losses that they add are higher as the number of channels grows. For the analysis described in this paper we will consider insertion losses of 3 dB from the input to each of the drop ports. The losses from any add port to the filter output will be considered to have the same 3 dB value, as well as the “through out” to “through in” ports for the express traffic [3].

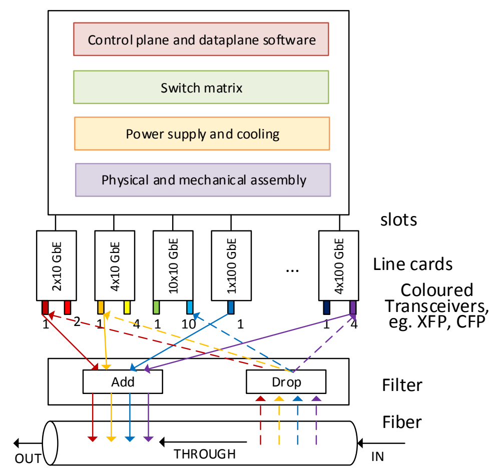


Fig. 7. Node architecture for passive optical deployments (coloured transceivers)

IV. Techno-Economic Comparison of the Alternatives

A. *Scenario description and assumptions*

To evaluate the techno-economic comparison of the two architectures analysed in this paper, a typical scenario for a metropolitan network segment is assumed. Specifically, a ring topology with 2 SWC sites and 5 SWDs is considered. The SWDs are distributed in two concentric rings (Fig. 8), with 2 SWCs and 2 SWDs in one ring, and the 2 SWCs and 3 SWDs in another ring.

Regarding the traffic on the metro network, it has been assumed that each SWD in mean generates from 1 Gb/s to 80 Gb/s (a total network load of 400 Gb/s. Moreover, to dimension the network and determine the number of line cards and transceivers, the network has been designed to support single failure of links and nodes. Also, the maximum link occupation bound has been set to the 80%.

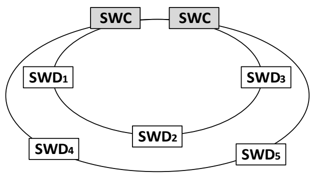


Fig. 8. Network scenario of the study

To carry out the techno-economic evaluation, the cost model presented in [4] has been assumed, which is, to the best of our knowledge, the most recent cost model available in the literature. All cost values presented in this study are normalized by the cost of a grey transceiver of 100 G, likewise in [4]. For the Ethernet node cost, the normalized prices for the chassis and line cards are shown in Table I [4].

TABLE I. NORMALIZED COST VALUES FOR ETHERNET SWITCH COMPONENTS

Switch Basic Nodes		
Number of slots	***Slot Capacity***	***Cost***
16.0	20	2.47
16.0	40	3.42
16.0	100	10.00
Line Cards		
Type	**Cost**	
2x10 G	0.85	
4x10G	1.70	
10x10G	3.40	
1x100G	4.70	

Regarding the cost of the transceivers, 4 types of them have been considered, 10 G and 100 G short reach transceivers with grey and coloured interfaces as shown in Table II [4].

TABLE II. NORMALIZED COST VALUES FOR TRANSCEIVERS

Grey Interface Transceivers	
Type	**Cost**
10 G	0.1
100 G	1
Coloured Interface Transceivers	
10 G	0.9
100 G	14

In the case of the passive optical deployments, passive filters have to be added in each node. These filters are characterized by the number of channels they support. We have considered a filter with 8 channels, which has a normalized cost of 0.03 per filter [5].

Another important cost to take into account is the fiber cost. In a metro environment like the one described above, amplification is not needed. Thus, it can be assumed that all fiber connections have the same cost. However, estimate a fixed cost for providing fiber is a hard task, since it depends on multiple variables: if there is available fiber (normally fibers are not deployed individually but in bundles organized in cables), if a possibility to rent fiber exists or if a new deployment can be done. Depending on these cases, the fiber cost is quite different. Therefore, to examine in more detail the influence of this parameter, a sensitivity study has been done considering a range of fiber cost, to reflect from the cheapest cases (when fiber is available) to the most expensive cases (when a new plant has to be deployed, including digging and trenching costs)[6][7]. To determine this range, we have assumed the values presented in [6] normalized by the cost of a 100 G gray transceiver. The considered range for this study goes from free cost per km to a normalized cost of 1 per km, to simulate cases where a previous fiber plant and no fiber plant exists, respectively. A mean distance of 20 km, an intermediate value for metro networks, has been considered. Additionally, we have assumed that half the fibers needed in the scenarios are available and add no cost.

B. Numerical results

Following the scenario description above, we are going to compare the following alternatives: grey ring topology (Fig.1) grey tree topology (Fig. 2) and logical coloured tree topology (based on a passive ring physical topology as in Fig.3 and Fig. 5). In all scenarios, it is assumed only the use of 10G or 100G transceivers.

The first analysis carried out was done considering free fiber (i.e. operator installs a great amount of dark fiber to future deployments). As it can be observed in Fig. 9, where the total network cost versus the traffic variation for the six scenarios is depicted, the most cost-effective deployment depends on the total network load of the metro network. For low network loads, the most cost-effective option is to use a grey ring topology of 10 G. As traffic increases, grey tree topology becomes the most cost effective. Moreover, coloured topologies are expensive since the use of coloured transceivers is not necessary due to the fact that fiber is already deployed and assumed as free of charge to the operator.

If we consider the results, we can see that, even for high loads, tree 10G topology is the most cost-effective. On the other hand, topologies of 100 G are also more expensive than 10G topologies due to the fact that fiber is free and 100 G equipment is more expensive. However, the number of fibers when using 10 G transceivers leads to a situation where technical limitations appears as well as the operational complexity justifies the migration to 100G. In this way, there is usually a maximum number of interfaces that can be aggregated on the same link.

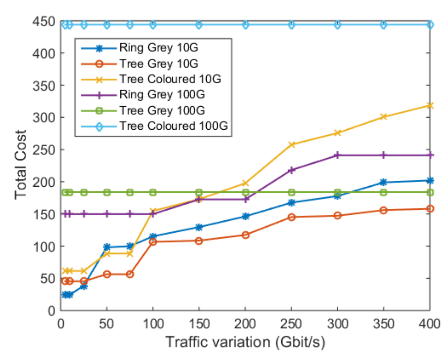


Fig. 9. Total Cost vs. Traffic variation when considering free cost fiber

Fig. 10 shows the number of fibers needed in each scenario. As it can be observed, grey topologies of 10G of both ring and tree configurations are the two scenarios which have the highest number of fibers, followed by grey scenarios of 100G. On the other hand, the coloured 10G and 100G trees use the lowest number of fibers. For the network loads considered, both coloured topologies use only the minimum number of fibers to deploy the physical ring topology of Fig. 8.

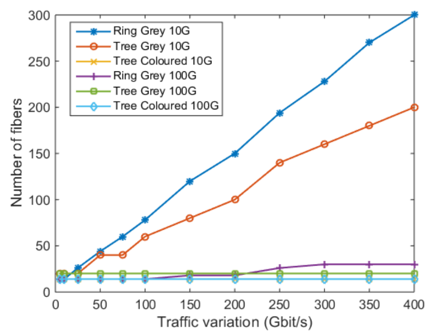


Fig. 10. Number of needed fibers for each deployment vs network traffic variation

This is the reason why the fiber cost is a significant parameter to take into account. In this way, in order to evaluate the influence of the fiber cost in the different deployments, we have selected two traffic rates and calculate the total network cost for different fiber costs. Specifically, Fig. 11 depicts the cost of the different deployments for a total traffic in the network of 50 Gbit/s. As it can be observed, when the cost of fiber is lower than 0.15, the most cost effective solution is the Tree grey of 10G. On the other hand, for fiber costs higher than this value, the most cost-effective deployment is the coloured tree of 10G. This is consistent, since for 50 Gbit/s, this technology uses the lower number of fibers from those with the cheapest equipment (10 G).

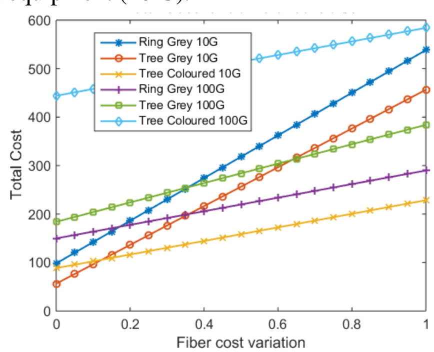


Fig. 11. Total cost network vs. fiber cost variation for a total traffic of 50 Gbit/s

When traffic increases (e.g. 200 Gbit/s), it can be seen in Fig. 12 that differences between coloured tree of 10G, grey ring of 100G and grey tree of 100 are very small. When traffic reaches 400 Gbit/s (Fig. 13), even from low fiber costs (0.05), tree grey of 100 G is the most cost-effective topology.

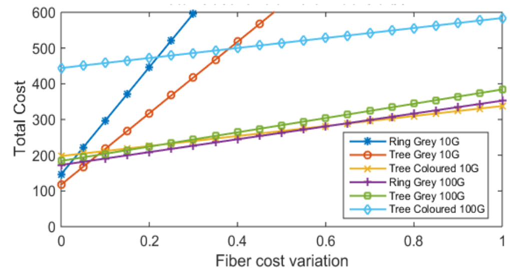


Fig. 12. Total cost network vs. fiber cost variation for a total traffic of 200 Gbit/s

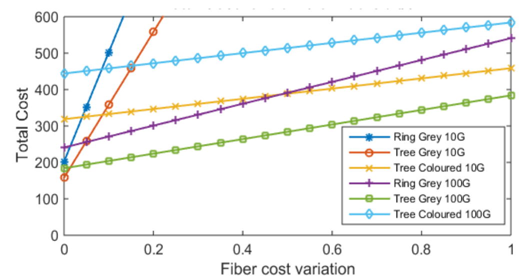
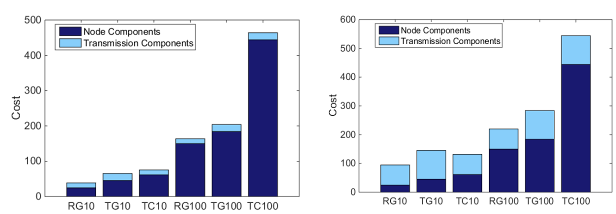


Fig. 13. Total cost network vs. fiber cost variation for a total traffic of 400 Gbit/s

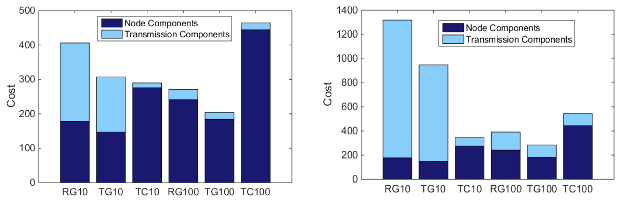
To demonstrate the influence of cost fiber in each topology, Fig. 14 (a) and (b) show the contribution of the network cost of the transmission components (fiber) and the node components (chassis, slots and transceivers) for a network load of 10 Gbit/s for a cost fiber of 0.1 and 0.5, respectively. Similarly, Fig. 15 (a) and (b) shows the results for a network traffic of 300 Gbit/s. In both figures (Fig. 14 and Fig. 15), the names on the X axe reference to the six topologies considered: T/R indicates a Tree/Ring Topology, G/C are Grey/Coloured and 10/100 indicates the use of X form-factor pluggable (XFPs) and C form-factor pluggable (CFPs). As it can be observed, topologies with grey 10G infrastructure (TG10 and RG10) have the lower cost of the node, since grey transceivers of 10G are the cheapest. However, their transmission cost is highly variable depending on the load and the cost of fiber.

Regarding 100G topologies, the main contribution to the cost independently of the load and fiber cost is the common parts, since 100 G transceivers have a high cost (specially the coloured one). Finally, the coloured tree 10G (TC10) topology, has an intermediate node cost, and fiber costs influence is lower.



(a) (b)

Fig. 14. Comparison of component costs for each topology for traffics of 10 Gbit/s when considering (a) cost fiber of 0.1 (b) cost fiber of 0.5



(a) (b)

Fig. 15. Comparison of component costs for each topology for traffics of 300 Gbit/s when considering (a) cost fiber of 0.1 (b) cost fiber of 0.5

Therefore, we can conclude that the selection of the most cost effective topology depends on the traffic that it is going to support, the availability of free fibers and the cost of the connection of new fibers. In this way, for network with low loads, if there is free fiber available or the cost of new fiber deployments is very low, tree topologies of 10 G are the most cost-effective. On the other hand, for low and medium network loads and if there is no free fiber available, the coloured tree topology of 10 G is a good option, since its cost is more independent from fiber cost than other topologies and the node equipment cost is not so high. Finally, when network loads are very high, a grey tree topology of 100G is a good proposal.

C. *Important considerations*

In the different proposed architectures, it is necessary to take into account some parameters which have a great influence in their feasibility.

In both deployments, grey and colored, one of the key parameters is the distance. As we have mentioned before, the CFPs and XFPs transmitting directly to the fiber have a short reach, of few kilometres (mainly a maximum of 40 km [8][9]) without amplification (which is the configuration assumed). Therefore, the distance is going to be one limiting factor for these two deployments in a general deployment. Nonetheless, most metropolitan networks typically have these ranges of distances, which makes it possible the use of this architecture for metro networks.

In addition, regarding the passive optical deployment, one issue that has to be taken into consideration is the insertion losses of the passive filters. In this way, since the signal passes through a different number of filters, calculations taking into account the maximum number of intermediate nodes, transmission power and fiber attenuation have to be made for each particular case in order to ensure that the signal arrives with enough quality. For the scenario considered in this example, and with typical values of insertion and attenuation losses, this architecture is completely feasible.

V. CONCLUSONS

Metropolitan networks, so far typically deployed as rings topologies, have to be updated to cope with the increment of the bandwidth experienced in recent years.

In this paper we have presented alternative deployments, with grey and coloured interfaces, and compare them in terms of cost efficiency. The architecture with grey interfaces relies on the use of grey 10G or 100 G pluggables directly transmitting into the fiber. In this way, logical and physical topologies are the same, and the network can be deployed in a ring or tree topology, by means of using dark fiber. The other alternative uses coloured transceivers to transmit into the fiber. Therefore, physical ring topologies are transformed into logical tree topologies, where the data transmission of each transceiver is done in a specific wavelength.

Results have demonstrated that there is not an optimum deployment for all scenarios. Depending on the bandwidth and the fiber availability, different architectures are the most cost-effective. Moreover, since estimating the cost of deploying new fiber is a hard task due to the high number of variables (available fiber, possibility to rent fibers, new fiber deployment under different type of pavements, joint deployment of fiber with other services like gas, electricity...) a sensitivity study has been carried out considering different costs. Results have demonstrated that the fiber cost has a great impact into the cost of all topologies, but especially on those based on 10 G grey transceivers.

Finally, it is necessary to emphasize that although these architectures present length restrictions, they are feasible for metro networks, where normally the threshold distances are not exceeded. However, coloured solutions present some limitations in terms of sensitivity due to the insertions losses added by the filters. As future work, the authors will consider the utilization of OTN technologies in the ring deployments.

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REFERENCES

[1] B. Uščumlic, I. Cerutti, A. Gravey, P. Gravey, D. Barth, M. Morvan, P. Castoldi, Optimal dimensioning of the WDM unidirectional ECOFRAME optical packet ring," in Photon. Netw. Commun. Vol. 22, no. 3, pp. 254-265, December 2011.

[2] A. Bianco, T. Bonald, D. Cuda, R.M Indre, "Cost, Power Consumption and Performance Evaluation of Metro Networks," Journal of Optical Communication Networks, vol. 5, no. 1, January 2013.

[3] Cisco Prisma DWDM Passives Data Sheet. Available at: http://www.cisco.com/c/en/us/products/collateral/video/optical-passive-components/datasheet-c78-730313.html

[4] F. Rambach, B. Konrad, L. Dembeck, U. Gebhard, M. Gunkel, M. Quagliotti, L. Serra, V. López, "A Multilayer Cost Model for Metro/Core Networks," in Journal of Optical Communications and Networking, vol. 5, no. 3, pp. 210-225, March 2013.

[5] CWDM/DWDM filters. http://datainterfaces.com/low-cost-cwdm-solutions.aspx

[6] K. C. Guan, V. W. S. Chan, "Cost-Efficient Fiber Connection Topology Design for Metropolitan Area WDM Networks," in Journal of Optical Communications and Networking, vol. 1, no. 1, June 2009.

[7] Z. Havic,B. Mikac, "Economic Model for FTTH Access Network Design," in Telecommunication, Media and Internet Techno-Economics (CTTE), 10th Conference of , vol., no., pp.1-5, 16-18 May 2011

[8] Cisco 100GBASE CFP Modules Data Sheet. Available at: http://www.cisco.com/c/en/us/products/collateral/interfaces-modules/transceiver-modules/data_sheet_c78-633027.html

[9] Huawei S9700 Switch Datasheet. Available at: http://e.huawei.com/in/related-page/products/enterprise-network/switches/campus-switches/s9700/brochure/Switches_S9700