Lepida: a Passive WDM Fiber Access Technology Example in Europe

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***Abstract*—Likely unique in Europe, due to its own peculiar service delivery paradigm Lepida, the network of the public government organizations of the region Emilia-Romagna, in the north of Italy, chooses a passive Wavelength Division Multiplexing (WDM) fiber access technology. Passive WDM deeply exploits the frequency domain in order to multiplex multiple signals in the same optical fiber. In particular, a full Coarse WDM (CWDM) approach, deployed in a pre-existent network, can increase reliability, bandwidth, security and configuration cleanliness in a pay-as-you-grow way. In this paper, we present benefits, costs, pros and cons, and how we achieve them, of an interesting concrete implementation of WDM fiber access technology in a wide and complex territory.**

***Keywords*–Passive WDM; CWDM.**

I. Lepida Network Introduction

Lepida Network (Lepida for simplicity in the following) is the fiber optic network that reaches almost all the public administration offices in the Emilia-Romagna (Italy) regional territory; one of its design constraints is that Customer Premise Equipment (CPE) uplinks should be GigaEthernet (GE) links or 10GE links. A second design constraint is the CPE capabilities: they have to be simple and cheap switching devices.

LepidaScpA [1], the entity that currently owns Lepida Network, is an in-house providing company established by a Regional Law (11/2004, “Regional Development of the Information Society”) to represent the operational instrument in the service of its shareholders (Public Administrations, Public Entities, Universities). Currently, it counts 436 shareholders, all Public Administrations and Public Entities. LepidaScpA is involved in the governance of the regional Information and Communications Technology (ICT) plan and has been given responsibility for planning, development and management of the ICT infrastructures and for development and supply of ICT services for the Public Administrations.

Lepida has been originated by a public investment in which public organizations contributed to build multiple networks cooperating with different network operators, retaining a fraction of fiber in each fiber cable. After that, from 2010, a single network has been obtained by combining all the local infrastructures; because of the original design each backbone cable of the unified network Lepida consists of at most of 24 fibers. Moreover, in 2010, in order to cut the Total Cost of Operation (TCO), the Points of Presence (POPs) number has been minimized and typical inter POP distances are since close to 80km.

As seen in Figure 1, the 12 fiber optic pairs in each section, i.e., a network segment between Lepida POPs, have to be used both to interconnect POPs and to connect the end-users to POPs. As the need of a network growth appeared, the impact of the increase in the number of users was essentially twofold:

- counterintuitive fiber optic pair routes design, i.e., users positioned in the same backbone cable (*Users 3* and *4*) could be connected to a different couple of POPs;
- transit on CPEs in order to connect new users, i.e., some CPEs, in Figure 1 *Users a*, *b*, *c*, *d*, e and *f*, have been configured as if they were a POP.

We point out that, if the first point “just” leads to a greater effort to the Network Operations structures, the second one will be deeply investigated. First of all, the latter leads to a more complicated network topology and, in order to achieve better uptime, to build CPE meshes, i.e., *User a* relies on *POP a* and *User b* in order to reach *POP c* instead of being connected to *POP a* only. This interdependence leads to a more complicated troubleshooting effort and to upgrade most of the equipment of the mesh on the basis of a single user needs, e.g., if *User b* needs a 10 Gigabits bandwidth, *Users a*, *c* and *d* should also be upgraded.

In this paper, we present how LepidaScpA faced the above presented issues, implementing a passive Wavelength Division Multiplexing (WDM) fiber access technology in its network, over a wide and complex territory. Benefits, costs, pros and cons, and comparison between different technology approaches are also discussed.

The rest of the paper is organized as follows: Section II briefly presents the previously used technology and then it introduces the passive WDM solution; Section III describes the events that lead LepidaScpA to choose a full passive WDM access approach; Section IV briefly illustrates the used solution in order to track passive WDM uses; Section V describes and compares passive WDM costs between different solutions; Section VI concludes the paper.

II. PON vs Passive WDM

A Passive Optical Network (PON) [2] is a fiber access technology used to provide fiber to the end-user. PON implements a point-to-multipoint architecture, in which unpowered fiber optic splitters/combiners are used to enable a single optical fiber to serve multiple end-points. PON consists of an Optical Line Terminal (OLT) at the service provider’s POP (hub) and a number of Optical Network Units (ONUs) or Optical Network Terminals (ONTs), near end-users. Typically, downstream signals are broadcast to all premises sharing multiple fibers. Upstream signals are combined using a multiple access protocol, usually Time Division Multiple Access (TDMA). Downstream signals are combined by OLT and transmitted at the same wavelength. When the signal reaches a splitter, it does not strip off the individual signal but instead splits the signal. This results is a duplication of the same signal with reduced power. At this point, the split signal is sent into

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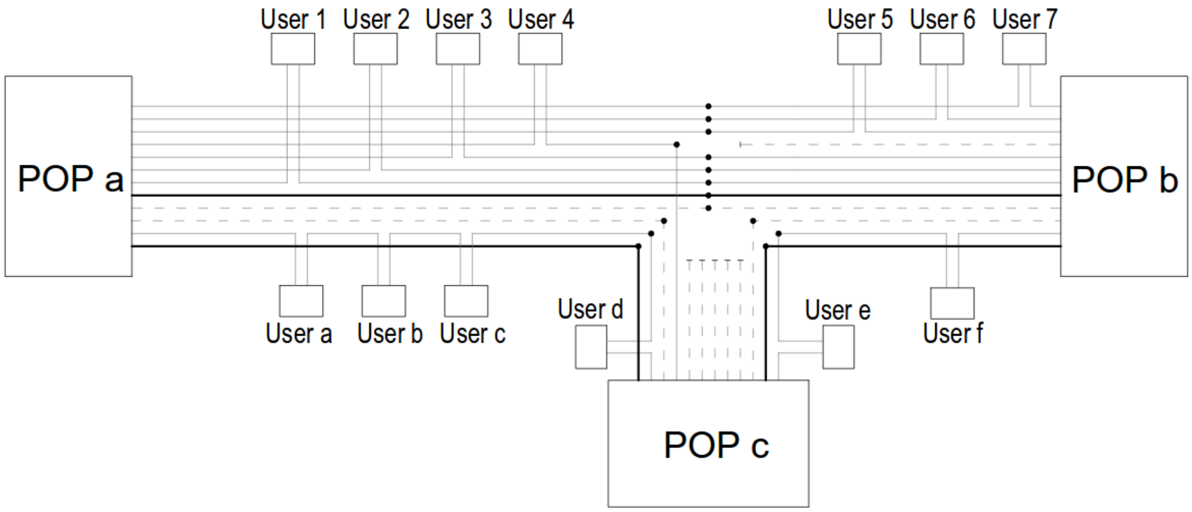

Figure 1. An arrangement of a group of 12 fiber optic pairs in a network segment between Lepida POPs.

ONU/ONT and it pulls off the data that is meant for that user based on addressing. In the upstream, all the subscribers go through the ONU or ONT and get put together again, though not necessarily sequentially, and sent upstream on another wavelength.

Passive WDM [3] deeply exploits the frequency domain in order to multiplex multiple signals in the same optical fiber. There is no need of point to multi-point media access control or to define different roles such as OLT and ONTs: each signal is *assigned* to a wavelength, also named "Color", at the device port. This means that the switch or router that originates the signal will utilize a WDM transceiver instead of a standard 1310nm or 1550nm one. Moreover, it also means that signals are combined, multiplexed, but do not interact. In Passive WDM technology there are two main kinds of multiplexer: simple multiplexer (MUX) and Optical Add and Drop Multiplexer (OADM). The first one picks the Colors from single Color fiber pairs (of fiber patches) and multiplexes them into a single fiber pair. The second one adds and drops a selected subset of Colors to and from dedicated fiber pairs and allows all the others to pass.

III. Full passive WDM access approach

In this section, we focus on the events that lead to choosing, in the Lepida network, a passive WDM solution as the main fiber access technology.

The first attempts of passive WDM multiplexing were done at the beginning of 2013. The goal was to free fiber pairs in a fiber cable and the key idea was to exploit WDM (both Coarse and Dense WDM) instead of buying new dark fibers or building new infrastructures.

Subsequently, we started replacing some active devices with passive WDM ones in order to reduce some housing costs. In the previous SDH-like [4] network topology (Figure 2.a) the backhaul devices were located in other Internet Service Provider (ISP) sites. The updated network topology became an hub-and-spoke one: passive WDM devices are fully transparent and all the end-user are logically connected to the main Lepida POP site by means of a Color, i.e., a single GE WDM signal (Figure 2.b).

The focal point was the awareness of a new capability: introducing passive WDM equipment, the physical topology and the "colored topology" can be splitted. The passive WDM quickly became a design weapon that has been used to overcome the exhaustion of optical fibers or simply to redesign the access network.

Due to the introduction of passive WDM, the paths of the Colors stretch to longer distances compared to the ones of the links in the outdated network topologies. The availability of cheap WDM transceivers whose power budget can span up to 41 dB allows us to overcome the distance constraints. A flexibility improvement leads to a network redundancy improvement like in Figure 2.c . If we compare Figures 3 and 1, we see that passive WDM is exploited in order to free 6 fiber pairs and to remove a POP site (*POP C*).

Until the end of 2015, passive WDM devices have been installed close to the active devices (see Figure 3). The capability to route WDM signals directly inside the fiber optic splice closure leads to a Color path optimization like in Figure 4; moreover, by means of the integration between passive WDM device and fiber splice closure each signal in fiber pair can be added (and dropped) into another fiber pair without any kind of cabinet or power supply.

The end of 2016 was the end of the experimentation phase. A massive transition to passive WDM fiber access technology was rolled out after a 4-year test, more than two hundred passive WDM devices installed and about five hundred CWDM transceiver plugged in existing equipment. The transition has been split into two steps:

1) the standard transceivers have been and will be replaced by WDM ones taking advantage of the POP devices upgrade planned between 2017 and 2019 without any fiber optics rerouting;
2) deploying a passive CWDM solution, FIST-FCASA2 [6], that can be smartly managed within the Fiber Infrastructure System Technology (FIST) fiber splice

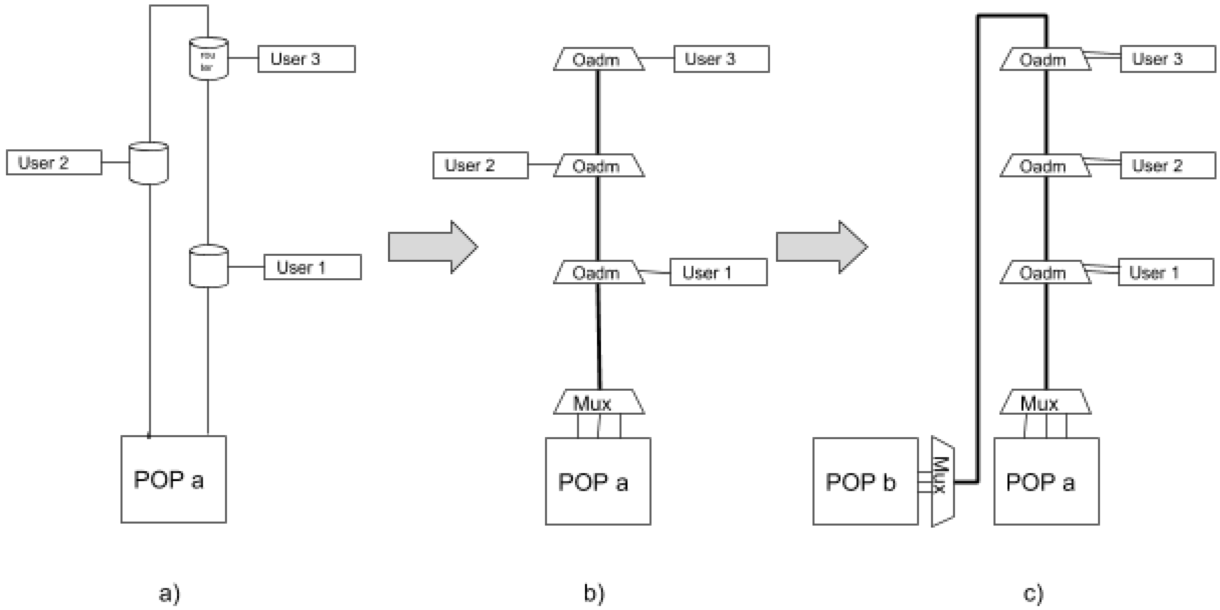

Figure 2. Evolution of implemented multiplexing solutions.

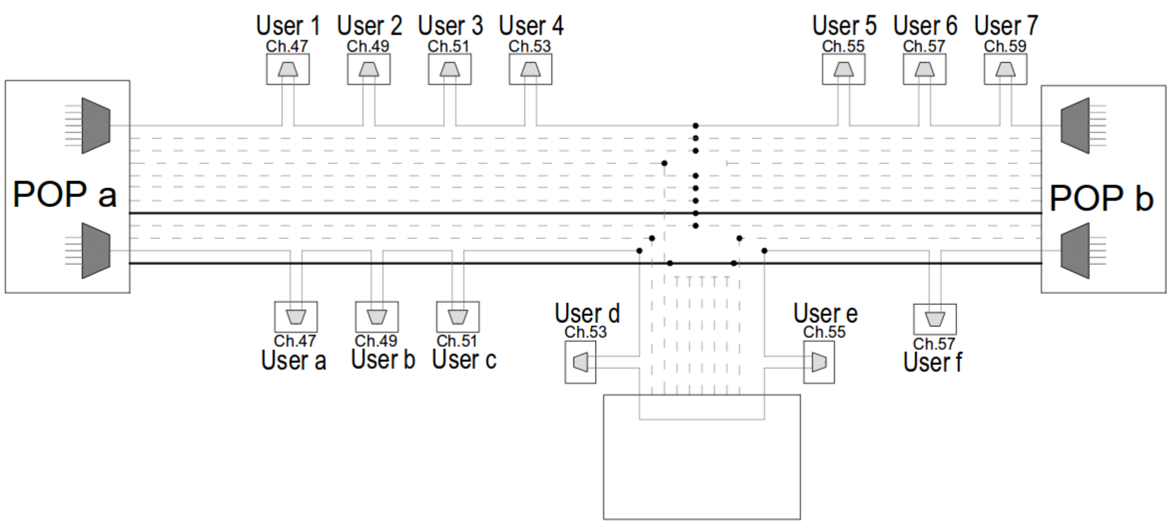

Figure 3. An arrangement of a group of 12 fiber optic pairs in a network segment between Lepida POPs exploiting CWDM Multiplexing devices.

closures, i.e. the most common fiber splice closure in Lepida.

In order to shrink the supply chain, a framework agreement with CommScope [5], the owner of the FIST brand, has been done.

A representative figure: the 6-month forecast of June 2017 indicates a need for more than 3 hundred (about 10% of the number of Lepida users) of FIST-FCASA2 devices. Each FIST-FCASA2 should have added and dropped a single CWDM Color toward a Lepida end-user. The aim is to connect each end-user to a couple of POPs by means of a single Color like in Figure 4.

What are the advantages of this full passive WDM approach? Those pursued by Lepida are the following:

- In each section between two POPs, the maximum number of end-users directly connected to two POPs are constrained by the amount of the available fiber pairs. The end-user maximum number is the product of the available fiber pairs and the number of Colors admitted by the chosen passive technology, e.g., passive CWDM solutions fix the gain to 8 or 18 compared to the solution without WDM.
- Switching from a dedicated fiber pairs approach to a dedicated WDM Colors approach frees fiber pairs that can be rented or exploited in order to connect new users.
- Each user can be connected directly to POP without any aggregation equipment: a) Each user can be in-

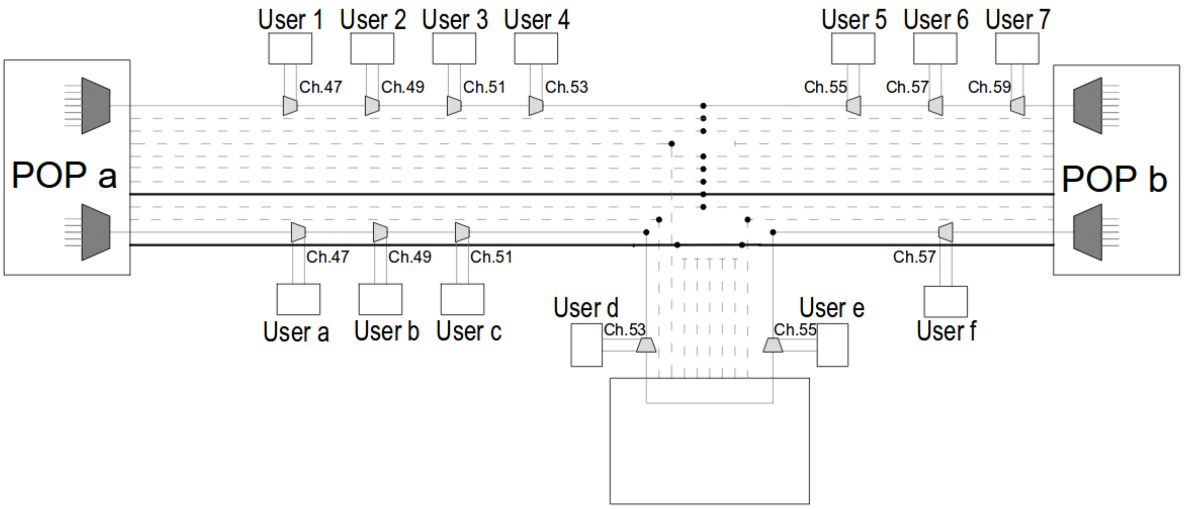

Figure 4. An arrangement of a group of 12 fiber optic pairs in a network segment between Lepida POPs exploiting CWDM Multiplexing devices inside the fiber optic splice closure.

dependently upgraded from 1GE links to 10GE links b) Aggregation network devices can be avoided (nor maintained or upgraded).

- The same regular "colored" network topology (and also the same set of configuration rule between CPE and POPs) can be achieved in distinct fiber optic network topologies.

IV. Passive WDM Colors tracking and troubleshooting

Each Color spans over multiple fiber links and has its own path. Working in a network environment without the Colors, a signal loss can be related to different failures: an electrical failure, a device failure or a fiber cut. On the other hand, working in a network environment that exploits the Color paths, a fiber cut can be located by overlapping the path of the Colors involved in the failure event. Vice versa, single active equipment failure can suggest an electrical or device failure. At the end, the color path diversity can help to improve the troubleshooting process.

Colors are essentially a new degree of information about the network and have to be mapped on top of a traditional fiber network documentation. Maintaining all the information related to the Color paths require a new asset management layer. This new layer should also aid the correlation between the Color path diversity and the failure events.

In order to operate and to maintain a such complex network architecture, in a business environment, it is crucial to provide reliable and complete information about network topologies, free/used fibers and Color paths. LepidaScpA implemented a resource manager software, provided with a web-based interface and a relational database.

This resource managers software adds to the main Lepida geo-database, that stores all the network asset data, all the Color-related information. This Colors tracking function, available through web URL endpoints, provides a simple web interface that the network manager can use to check the paths

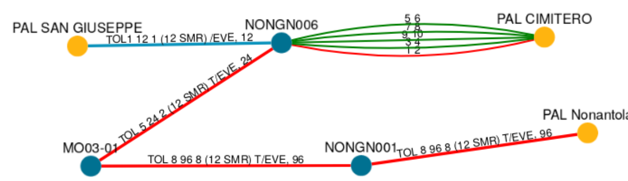

Figure 5. Resource Manager: selection of a fiber pair.

of the failure affected Colors (Figure 5) and network designer can use to manage name and path for each selected Color (Figure 6).

V. Passive WDM equipment costs

An application on such a large scale of Passive WDM is not so common in Europe and finding a partner that can deliver a complete solution has not been easy.

CommScope proposes a CWDM FIST-FCASA2 Solution in EMEA but It is not able to share detailed information on its end customers; It only declares, referring to applications such as mobile backhauling and point-to-point interconnection, that widespread use of this technology can be found only in the Far East (Korea or Malaysia).

Nevertheless, the transition to a passive WDM approach can be achieved step-by-step in a pay-as-you-grow model and without large investments.

Which is the right passive WDM technology? It depends only on the number of users. CWDM ones range between 8 and 16 end-users, DWDM ones range between 40 and 96. CWDM solutions are cheaper than the DWDM ones but, today, all the solutions settle down, if exploited to reach the maximum number of users, to 300 € per user (see Figure 7).

Lepida users are not so dense, hence we started by choosing a CWDM solution in order to reduce the initial economic

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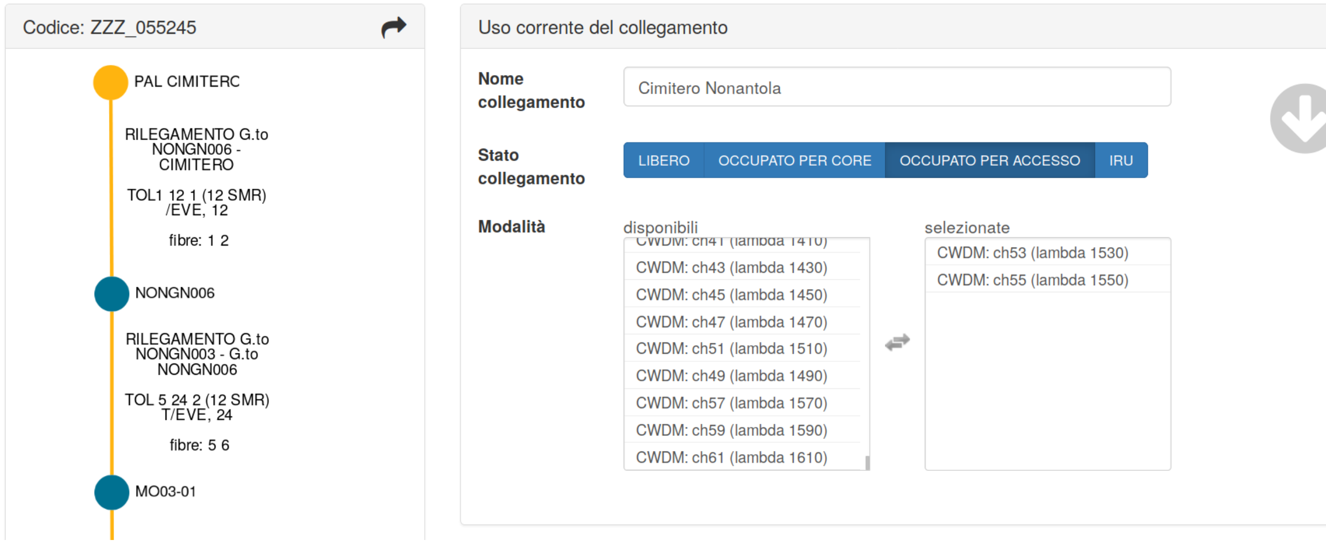

Figure 6. Resource Manager: Color assignment to a fiber pair.

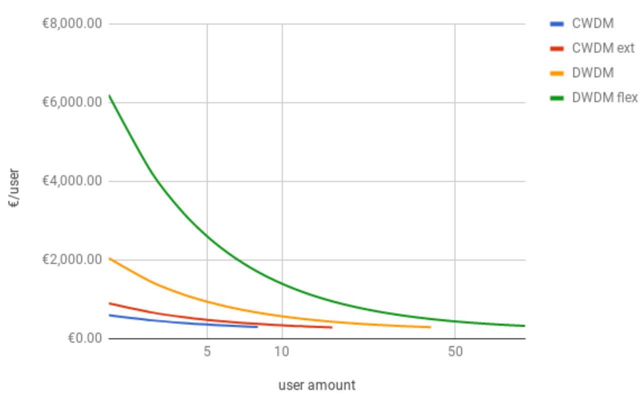

Figure 7. Cost per user comparison between WDM solutions.

effort; the main obstacle to starting the transition to the passive CWDM solution was to find a product that could be integrated inside a fiber optics splice closure.

Thanks to the frame agreement with CommScope, FIST-FCASA2 device series have been re-introduced in the Italian market and now it is the easiest-to-install and highest reliable solution.

VI. Conclusion

Both PON and Passive WDM are broadband access technology for optical networks.

PON and its evolution (G, XG, etc.) have the advantage of a huge deployment that has lead to product maturity and to shrink the equipment cost. Nevertheless, OLT and ONT introduce power budget constraints, i.e., a short distance between OLT and ONT. PON is designed to match a small point-to-multipoint environment with a huge number of end-users with shared bandwidth and shared computational resources.

Passive WDM addresses point-to-point systems that can be managed or upgraded independently. A passive WDM solution can decouple the fiber pair routes and the Color routes over the same network. Moreover, Colors with very high power can be exploited in order to span between a very long distance. The result is that Passive CWDM can be exploited in a pre-existent network in order to increase reliability, bandwidth or configuration cleanliness in a pay-as-you-grow approach. Passive WDM Color routing can also achieve greater security: using a dedicated channel per each subscriber is often considered to be safer than sharing resources. At last, passive WDM can aid fault handling.

What is the best technology? No one. They target different applications: XG-PON is envisioned for residential applications while Passive WDM is investigated for business or bandwidth intensive backhaul. Passive WDM is quite unused in Europe but has found in Lepida the perfect match as described in this contribution.

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