View metadata, citation and similar papers at core.ac.uk
brought to you by CORE
provided by CiteSeerX

A Low Cost Migration Path Towards Next Generation Fiber-To-The-Home Networks

Reynaldo I. Martínez[1], Josep Prat[2], José A. Lázaro[2] and Victor Polo[2]

1: Universidad Simón Bolívar (USB), Dept. Electrónica y Circuitos, Sartenejas, Baruta, Edo. Miranda, 89000 (Venezuela)
2: Universitat Politécnica de Catalunya (UPC), Dept.of Signal Theory and Comm., c/Jordi Girona, 1-3, D4-S107, E-08034 Barcelona (Spain)
reynaldo.martinez.reyes@gmail.com, {jprat,jose.lazaro,polo}@tsc.upc.edu,

Abstract: A highly-scalable access architecture achieving high-user-density and enabling resiliency, centralized light-generation control, remote amplification and colorless ONU with Reflective Semiconductor Optical Amplifier (RSOA) is presented as the bridge between the already deployed Fiber-to-the-Home infrastructures and the advanced optical access networks. A techno-economical comparison of these optical access networks is done, depicting the proposed solution –SARDANA- as the most cost effective migration path towards the Next Generation Passive Optical Networks.

1 Introduction

Nowadays, there is no *technical* reason why any residential user could not have broadband internet access, gigabits/s of data to their home, using optical access systems already available in the market today – the obstacles are purely economics [1]. Therefore one of the fundamental scopes of today's optical communication research community has to be the cost reduction. Not only an effort in the reduction of the cost of the optical components or devices, but mostly in the creation of new architectures in order to make possible the delivering, in a cost effective way, of high bandwidth demanding integrated services through optical fiber up to the user premises.

Already standardized, the TDM-PON constitutes, without any doubts at all, the first step in the migration from cupper based access technologies to all-optical access networks (FTTH). Not only because of its low price but also because by means of its outside plant -splitters and fiber- it stands as the most simple and easy to maintain optical access architecture.

Once the first generations of FTTH networks are introduced, it is expected that capacity (in terms of speed and number of users) and scalability parameters will be the ones that are going to drive the design and the deployment of the Optical Access Networks (OANs). The user is going to start requiring more bandwidth demanding services with a strict QoS level, and here is where the WDM PONs will play a crucial role, because of the inability of the TDM PON in fulfilling those user demands. It is well know the efficiency of the WDM PONs in exploiting the optical fiber, achieving levels of capacity and scalability unreachable for their TDM counterparts due to their lack of multiplexing in the wavelength domain. But as it was mentioned above, the cost of the components used in these next generation architectures remains high, making economically prohibitive for the operators the migration from their already deployed BPON/GPON/GE PON to the Next Generation Passive Optical Networks (NgPON).

This high initial capital expenditure required for the NgPON deployment compels network designers and operators to assure migration paths that guarantees fully future usage of the infrastructure investments, avoiding bottlenecks at any demand increase [2].

In this work we propose and demonstrate a low cost migration path towards future optical access networks topologies, based on a novel network topology that we have recently proposed [3] named SARDANA, which stands for Single-fiber-tree Advanced Ring-based Dense Access Network Architecture, aiming at offering: high user density, extended reach, flexibility, scalability and resiliency in a cost effective way.

In this document, a techno-economical comparison of the proposed network topology with other advanced optical access topologies is done, focusing in the Capital Expenditure (CapEx) per user on each network architecture. The total cost of each access solution is compared and also extrapolated in time.

This work is organized as follows: Section 2 is devoted to explain the proposed optical networks for analysis that can be found in the literature, the ones that are going to be compared with our solution.

Section 3 deals with the technical details about the architecture that we propose as the migration path in this work, the SARDANA solution. The analysis made in this section does not aim to fully explain the whole functionalities of the architecture. Here is just a general idea of what SARDANA is about, in order to situate the reader when making the comparison among the other FTTH solutions.

In Section 4 we present the results of the economical comparison between all the network topologies in terms of total cost per user and for different take rates. Finally in Section 5 we give the same economical comparison but using some future prices that the optical components within these networks are expected to have in some years from now.

2 Proposed Network Architectures for Analysis

In comparison with the SARDANA architecture we analyze five different already known FTTH solutions. They have been designed combining different multiplexing and optical techniques and are the following:

2.1 Point to Point – Two Fibers Network

As seen in Fig. 1, it has two fibers for every connection, therefore giving the complete network bandwidth for every direction [4].

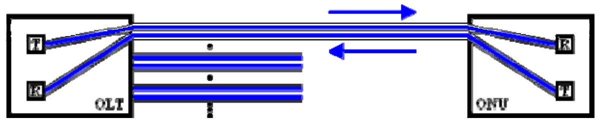

Fig. 1. P2P – 2 Fibers Network

2.2 Point to Point – Single Fiber Network

It is also a P2P Architecture but with a single fiber between the Optical Line Terminator (OLT) and the Optical Network Unit (ONU), which reduce to the half the cost in cabling [4]. It is shown in Fig. 2**.** It uses two different wavelength lasers for downlink and uplink directions in order to avoid Rayleigh Backscattering impairments.

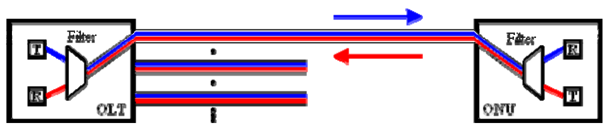

Fig.2. P2P – Single Fiber Network

2.3 TDM – PON

Shown in Fig. 3, it is the classical point to multipoint PON, where an optical splitter divides the signal coming from the OLT in N identical signals, sending them to N ONUs [4]. The users are multiplexed in time since they all receive the same signal.

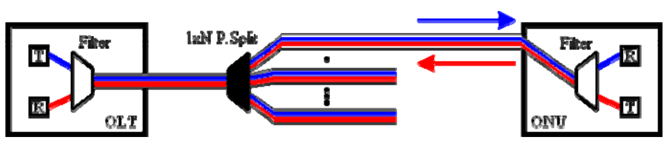

Fig. 3. Single Fiber TDM PON

2.4 Coarse WDM – PON

It uses M Distributed Feedback Lasers (DFB) at the OLT to address through the Arrayed Waveguide Grating (AWG) a specific power splitter, creating a virtual TDM PON for every wavelength [4]. It uses a Reflective Semiconductor Optical Amplifier (RSOA) as ONU, and it is represented in Fig. 4.

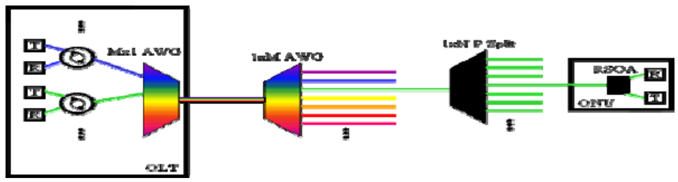

Fig. 4. Coarse WDM PON with Reflective ONU

2.5 Dense WDM –PON

Uses tunable lasers in the OLT to select the output port of the MxM AWG in the OLT as well as the 1xN AWG output port, which connects to a single ONU, where data is sent [5]. This architecture uses the Latin Routing characteristic of the AWG in order to have more flexibility when transmitting information to different users. It is shown in Fig. 5.

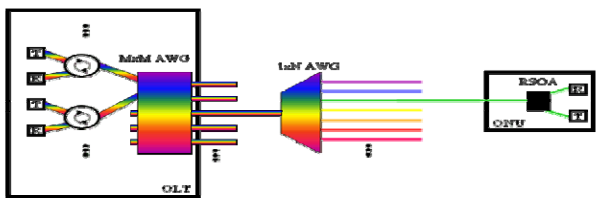

Fig. 5. Dense WDM PON with Reflective ONU

3 SARDANA: Single-fiber-tree Advanced Ring-based Dense Access Network Architecture

The proposed Architecture (SARDANA), shown in Fig. 6, is based on a WDM double-fiber-ring with single-fiber wavelength-dedicated trees connected to the main ring at the Remote Node (RN). Remote amplification is introduced at the RN by means of Erbium Doped Fibers (EDFs) for compensating Add/Drop and filtering losses. Pump for the remote amplification is provided by the pumping lasers located at the CO. The CO uses a stack of tunable lasers for serving the different tree network segments on a TDM basis.

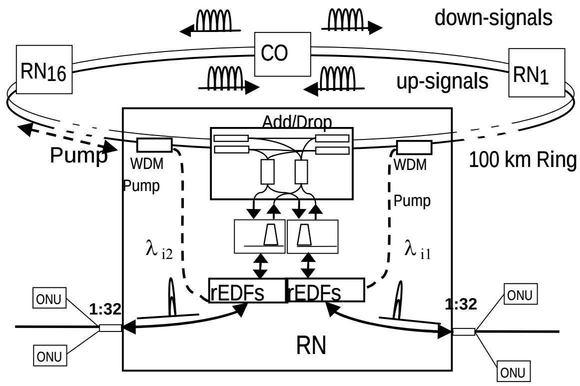

Fig. 6. Example of a 16RN-100Km Ring SARDANA Network Arquitecture – Double fiber completely transparent ring with wavelength dedicated trees

Downstream (λ^D_i) and upstream (λ^U_i) signals are coupled into the corresponding ring fiber through optical switches (OS) at the CO, which allows for dynamically adjustment of the direction of the transmission of each wavelength, always providing a path to reach all the RNs even in case of fiber failure and also offering traffic balancing capabilities. Pump can be coupled either to downstream or upstream fiber by pump/signal WDMs. The pump powers propagating through fiber ring to the RNs provides some extra Raman amplification. Because of this, upstream fiber is then preferred for pump propagation as upstream signal powers are usually weaker than the downstream ones. Two 1480nm pump lasers are required for bidirectional, balancing pumping and resilience against fiber failure.

At the RNs, a simplified OADM is accomplished by two fixed splitting ratio couplers (for the OADM function) and a 50/50 coupler (for protection function), for each of the two ring fibers. The fixed filters determine the dedicated wavelength of each Network Tree. Pump is previously demultiplexed and led to the EDFs for amplification of Up/Downstream of each tree. Two single fiber PON trees are connected to each RN by means of couplers; a 32 TDM PON is considered at each tree-PON network section. As a half-duplex system, the tunable laser of the CO is providing to the ONUs an optical carrier during half of the time for ASK upstream modulation by the RSOAs. Further details can be found in [3].

The SARDANA network can be scaled to reach a very large number of users; e.g. with 16 RNs and 32 wavelengths (as shown in Fig.6) it can serve up to 1024 ONUs. Finally, for a much more convenient network implementation with identical ONUs, we propose wavelength agnostic transmission devices. RSOAs are suitable devices due to their capabilities for re-modulation and amplification, as well as their wavelength independent nature.

4 Cost Analysis

The cost analysis in this work was done trying to keep similar conditions for all the networks topologies, in terms of number of users served, bandwidth delivered to each one and geographical conditions. This in order to be able to make fair comparisons between the total costs of the solutions. We obtained the equations of the CapEx of each one of the six different networks serving ≈5000 users, with ≈100 Mbps per user, in an urban area located in the city of Barcelona as depicted in Fig. 7, establishing those characteristics as our case of study.

In order to do so, we totalized the cost of all the components and lengths of fiber necessary in each part (OLT, Feeder, Distribution, and ONU) of each network architecture in order to deliver service in the proposed case of study (5000 users, 100Mbps per user, location of Fig.7).

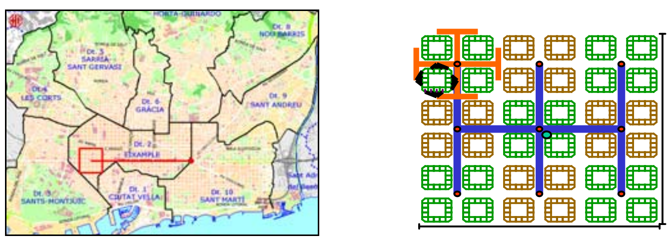

Fig. 7. Left: Picture of Barcelona and the considered area of study Right: Cabling Model used in the calculations on the cost of the outside plant-

We decided to choose the area of the Fig.7 because of its population density, which was similar to the potential client density. This situation, joined with the fact that the average OLT-Home distance in the selected area for coverage was similar to the distance between the OLT and the center of the area, allowed us to compute the average amount of feeder and distribution cable per home needed, and therefore compute the total cost in outside plant cabling of each architecture. The price of the components and devices employed in each architecture (AWG, splitters, RSOAs, lasers, receivers, circulators, etc) was averaged from the quotations of several vendors.

Figure 8 shows the total cost per user of each one of the studied networks with the obtained current prices for different take rates[1] (Installation and digging costs not included in the calculations).

---

[1]Take Rate: Relation between the number of homes connected to the network and the number of homes that can be connected to the network

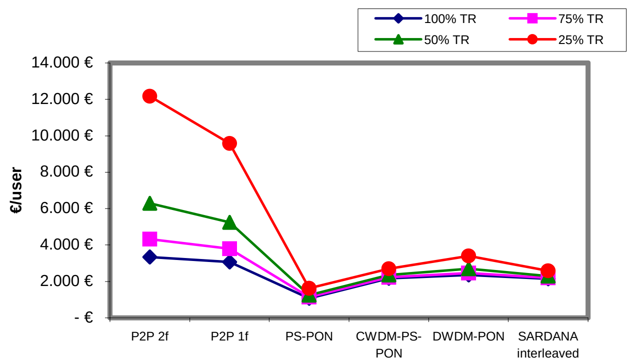

Fig. 8. CapEx per user with current prices for different take rates (TR).

The first thing that can be seen from Fig.8 is the incapacity of the point-to-point solutions to deliver the services in a cost effective way. In fact in some cases, the cost of the P2P approach is 8 times the total cost of the point-to-multipoint approach [6]. This is due to the huge amount of fiber that is needed in this architecture, as can be seen in Fig.9. The total cost of cabling scales directly with the number of users, because the P2P architectures require at least one fiber from each ONU up to the OLT. In a more efficient way, the point to multipoint architectures arrive to the served area with a single fiber from the OLT, and the segregation in one fiber per user is performed near the clients, reducing in that way the cabling cost.

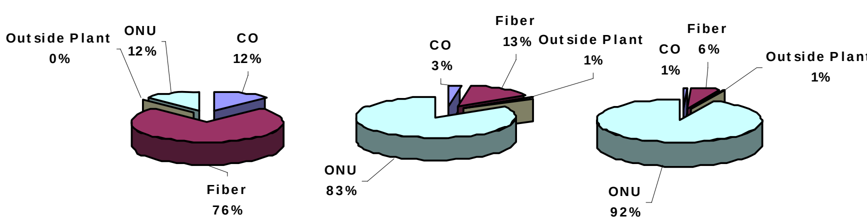

Fig. 9. Contribution to the total cost by each part of the network. Left: P2P Network, Center: TDM PON Network, Right: SARDANA

Another thing that can be seen from Fig. 8 is that with current prices, the TDM PON is the most adequate solution in terms of the CapEx for deploying a FTTH system. It is even a more cost effective solution than our proposed Arquitecture (SARDANA).

But while these already standardized TDM PONs are currently in deployment as the first step in all optical access networks, recent research is focused in the NgPONs as we claimed before, aiming at offering higher user density, extended reach, flexibility, scalability, resiliency [7] among other characteristics, which are going to be mandatory for the future user demands, and which can not be achieved with TDM PON architectures.

By the time those next generation services start to appear in the market, we demonstrate in the next section that the SARDANA, an architecture able of delivering such services, will have a cost even lower than the –by then obsolete- pure TDM PONs, assuring a cost effective migration path to Advanced Optical Networks, like the Dense WDM PON, which by that time maybe would still have prohibitive costs for the operators.

5 Cost Analysis with Expected Prices

The cost of optical networks has decreased over the years as the underlying technology has advanced and manufacturing volumes have increased. The cost of the underlying electronic and optical technologies (lasers, optical fibres, ASICs, etc) is well-known to follow a cost reduction with volume known as a learning curve. A learning curve is defined as the percentage decline in the price of a product as the (cumulative) product volume doubles. Technologies typically follow an ~80% learning curve which means that the price of the product at volume 2V will be ~80% of the price at volume V [1].

Another important tendency curve is a law that has been in the literature for more than 40 years, called the Moore's Law[2]. It could be interpreted that the density of transistors doubles every year.

Combining these two ideas it would not be risky to expect that the prices of the components based in semiconductors will follow a similar learning curve, and therefore the access technologies based on semiconductors will follow a cost reduction as well.

It would be a huge mistake to expect that the total cost of the P2P solution for example, will be reduced following the mentioned learning curve because, as we concluded from the previous section and from the Fig. 9, most of its cost is due to the huge economical inversion in optical fiber cabling (≈76%), and we can not assume that the price of the optical fiber is guided by the Moore's Law.

In the same Fig. 9 we see something very interesting: in SARDANA the 92% of the total cost of the network is due to the ONU, which is an RSOA as we explained in Section 3, a semiconductor which is expected to follow the cost reduction ideas explained above. So it should be no surprise that the prices of SARDANA, and the other networks topologies that employ components which follow the learning curves explained, might get down.

We can therefore use this historical learning curve and extrapolate the prices of the components which are affected by those curves. We did that and saw how the total cost of each one of the network topologies considered in section five changed through time, as it is shown in Fig. 10.

---

[2] " Moore's Law in Action at Intel" , Microprocessor Report 9(6), May 8, 1995.

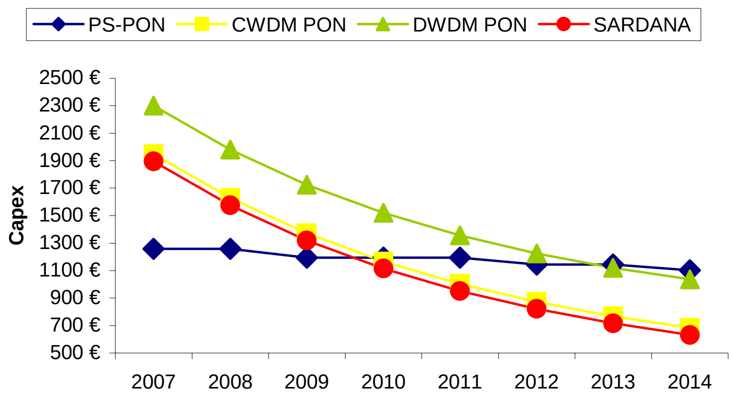

Fig. 10. Expected prices for network topologies considered in the study for the next decade (Take Rate=50%).

As it was expected, not all the Capital Expenditures experiment a reduction in the same way. This because not all the network architectures considered have the same amount of components that are affected by the learning curve (semiconductors). In fact, as it can be seen from figure 10, the PS-PON topology price barely varies through time. The SARDANA Architecture, having a total cost which is constituted in 92% by a semiconductor device, is the most affected architecture by the learning curve in the cost, and it is the first to beat the TDM PON topology in terms of the CapEx, having in addition the properties of capacity, speed, user density, scalability, resiliency and flexibility that allow this architecture to fulfill the future user demands.

6 Conclusions

Hybrid dual-fiber-ring with single fiber-trees access network topology with a wavelength agnostic ONU made of an RSOA demonstrates to provide a cost effective bridge between the already standardized and deployed Time multiplexed PONs and the Next Generation PONs, which have nowadays costs economically prohibitive for any telecommunication operator.

Further Economic studies have to be done in order to include the civil work costs (digging and installation) which in this work were not considered. Doing this the differences in the total investment between P2P and PON infrastructures would not be as high as the ones presented in this work. But the advantage of developing a PON infrastructure, due to their point-to-multipoint approach and resource sharing nature, is that it can take profit of all the dark fiber available in a city, minimizing the digging and installation costs in a way that a Point-to-Point approach can not.

The Techno-Economical comparison done in this work proves that SARDANA is, in terms of the cost and in terms of future usage of the existing infrastructure, the best migration path towards the truly broadband for all era.

Acknoledgments

This work was partially supported by the Spanish MEC, TEC2005-05160 (SARDANA) and the Ramon y Cajal Program.

Authors sincerely thank Raúl Sananes for his valuable contributions.

References

[1] J.Prat, P.Chanclou, R.Davey, J.M.Finochietto, G.Franzl, A.M.J.Koonen and S.Walker, “Long Term Evolution of Passive Optical Networks” in proceedings AccessNets 2006, Athens Greece

[2] J.Prat, C.Bock, J.A.Lázaro and V.Polo, “Next Generation Architectures for Optical Access”, in Proceedings ECOC 2006, Cannes, Th2.1.3

[3] J. A. Lázaro, R. I. Martínez, V. Polo, C. Arellano and J. Prat "Hybrid dual-fiber-ring with single-fiber-trees dense access network architecture using RSOA-ONU," Optical Fiber Communications Conference, OFC/NFOEC’07, Proceedings, OTuG2, Anaheim, USA, March 2007.

[4] M. Nakamura, H. Ueda, S. Makino, T. Yokotani, and K. Oshima, “Proposal of networking by PON technologies for full and Ethernet services in FTTx,” J. Lightwave Technol. 22, 2631–2640 (2004).

[5] C. Bock, J. Prat, J. Segarra, G. Junyent, A. Amrani: Scalable Two-stage Multi-FSR WDM-PON Access Network Offering Centralized Dynamic Bandwidth Allocation*, in Proc. ECOC 2004 Stockholm, Tu4.6.6*

[6] R.Sananes, C.Bock, S.Figuerola and J.Prat, “Advanced Optical Architectures Evaluation”, in FTTH Conference 2004, Orlando, October 2004

[7] R.Davey et al, “The Future of Optical Transmission in Access and Metro Networks- an Operator’s View”, in Proceedings ECOC 2005, Glasgow, We2.1.3 (2005)