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Access network evolution: optical fibre to the subscribers and impact on the metropolitan and home networks

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Abstract

This article describes broadband optical access network evolution including high speed interfaces for fixed and mobile services. The impact of network access evolution on network architecture and transmission equipment localization on the metropolitan network is also mentioned. Some technical challenges are also discussed, namely concerning the optical extended budget, as well as the impact of access evolution on the metropolitan network. The access bit rate evolution has also an impact on the home network by the necessity of offering connectivity to customers at 1 Gbit/s, for example, over plastic optical fibre. ***To cite this article: P. Chanclou et al., C. R. Physique 9 (2008).***

Résumé

Évolution du réseau d'accès : fibre optique aux abonnées, et l'impact sur les réseaux métropolitain et domestique. Cet article décrit les évolutions du réseau d'accès optique large bande en y incluant les évolutions des interfaces optiques très haut débits pour des services filaires et mobiles. L'impact sur le réseau métropolitain de cette évolution du réseau d'accès est abordé en termes d'architecture de réseau et de localisation des équipements de transmission. L'augmentation du budget optique et son impact sur l'évolution des frontières entre le réseau d'accès et métropolitain sont discutés. Avec l'accroissement des débits à l'accès, la sphère domestique de l'utilisateur doit elle aussi évoluer en offrant, par exemple, des interfaces à 1 Gbit/s en fibre plastique. ***Pour citer cet article : P. Chanclou et al., C. R. Physique 9 (2008).***

Keywords: Optical Access network; Fiber To The Home (FFTH)

Mots-clés : Réseau d'accès optique ; Fiber To The Home (FFTH)

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1. Introduction

The present fast development of new broadband telecommunication services makes upgrading of access infrastructure a necessity. To run video, voice and advanced internet applications, i.e. triple play services, residential customers require the availability of high bit rate “wired” solutions. Different solutions for the access network have been developed for several years. The most important among these solutions are the Digital Subscriber Loop (xDSL), Hybrid Fibre Coax (HFC) and Fiber To The X (i.e. to Premises, Curb, Home, Building) (FTTx). The optical fibre solution has been receiving at present more attention than in the past by telecommunication operators (cf. Fig. 1) because of some important factors, such as:

Revenues increases: Optical access networks enable carriers to offer any kind of services over a single network:

- multiple voice channels using voice over IP (Internet Protocole);
- multiple quality of service data offers (bandwidth of up to or greater than 100 Mbit/s to the home);
- video may either be offered with high definition in an overlay configuration or within the data stream (e.g. video over IP).

Competition: Increased service and pricing competition force operators to differentiate their products. Furthermore, bundled services and content have been proven to be attractive and lead to a reduced ‘churn’ probability – keeping the existing customer base.

Cost reduction: As the deployment of FTTx has taken off in recent years especially in Asia (for example, in Japan, there were over 44 million homes passed for FTTH/B at the end of 2007, of which just over 11.3 million were subscribing to an FTTH/B offer – Fig. 2 shows the highest penetration rate of FTTH or FTTB in the world), volume production has picked up and the cost of equipment has started to fall. This makes fibre-rich access solutions increasingly viable over time [1]. In green field deployments, the first installed cost of FTTx networks has been shown to be nearly identical to that of legacy copper-based broadband networks.

Bandwidth demand: Access bandwidth demand has been constantly increasing due to the arrival of new applications such as HDTV (High Definition TV), 3DTV, P2P (Peer to Peer) applications, video on demand, interactive games, e-learning, the use of multiple PCs at home, etc. As a result, residential subscribers may require connections of more than 30 Mbit/s in the not so far future [2] (cf. Fig. 3).

Technology maturity: The appearance of standardized solutions drastically reduced the complexity and cost of optical access networks. Furthermore, there currently exist IP multicasting techniques and technologies that are mature enough to handle hundreds of HDTV channels. These give providers more choices from a deployment point of view. In addition, as these solutions are tested around the world, experience leads to improved systems: improved security and resilience, smaller and neater cabinets, easier techniques to build fibre infrastructure e.g. with micro-cables in existing pipes, etc. Also the fast evolution of Ethernet is reflected upon the maturity and price of solutions that leverage this technology.

Coverage: The penetration of xDSL is quite high in many European countries. However, upgrading to higher bit rates in order to meet triple play service requirements requires considerable investments. The reason for this is that while ADSL (Asymmetrical DSL) can be delivered to customer at a distance of around 3 km from the central office,

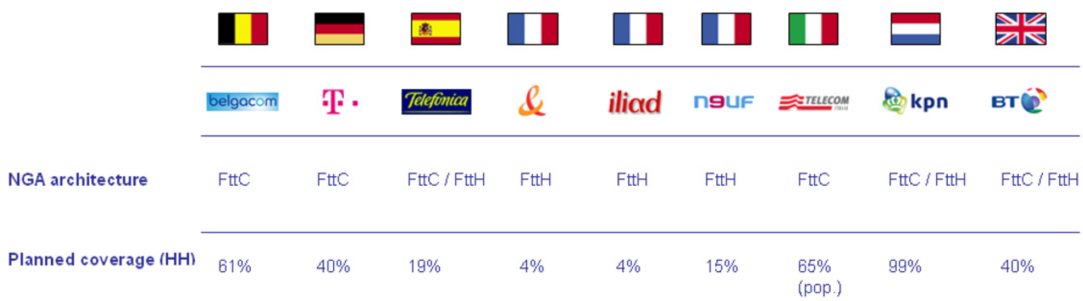

Fig. 1. Selected European initiatives of Next Generation Access (NGA) architecture with potential targeted coverage in few years (sources: operator reports, press).

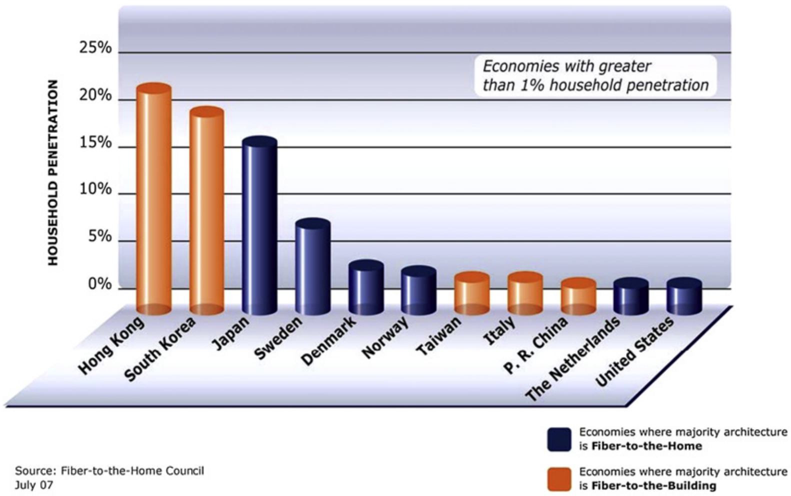

Fig. 2. Highest penetration rate of FTTH or FTTB in the world (source: FTTH-councils).

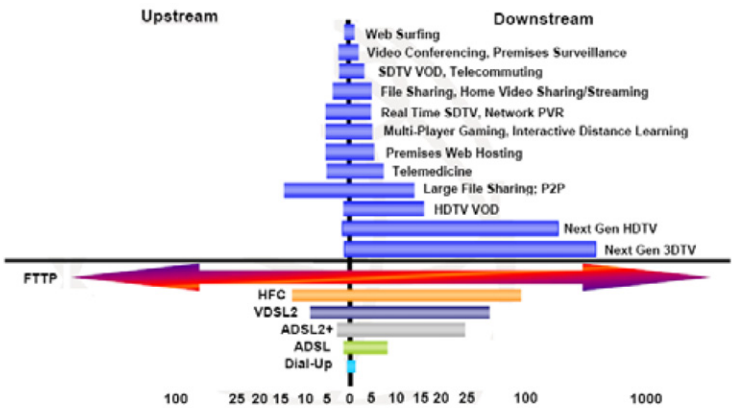

Fig. 3. Possible bandwidth requirements and provision (source: Verizon, ITU).

VDSL (Very high bit rate DSL) with a bandwidth over 20 Mbit/s have a maximum reach of less than 1 km, and this distance is drastically reduced for more symmetric solutions. The maximum bandwidth of xDSL is an inverse quadratic function of transmission distance. Hence fibre nodes need to be built within some 100 s of meters from the subscriber for xDSL to deliver triple-play services and beyond. For owners of copper infrastructure, this solution may be more economical today than building FTTH. However, it is clear than xDSL technology is not far from the end of its life cycle and that further upgrades will be more and more costly. Hence owners of fibre infrastructure will have a considerable competitive advantage in the near future. The time may therefore be ripe also for operators that own copper infrastructure to consider a gradual technology shift to fibre.

Two solutions exist to introduce optical fibre in the access loop: Point-to-Point (PtP) and Poin-toMultiPoint (PtMP).

The first solution, *PtP system*, can use Media Converter (MC) [3] to achieve an optical fibre connection with dedicated fibre runs from the central office to each subscriber. This PtP could also be proposed by dedicating a wavelength per subscriber (WDMA, Wavelength Division Multiple Access). In this specific case, a part of the fibre infrastructure could be shared by several subscribers. More precisely, a single fibre at the central office output could transmit all the wavelengths to a passive device which would de-multiplex each wavelength in separate fibres dedicated to subscribers. While this is a simple architecture, it is cost-prohibitive in most cases due to the fact that it requires significant outside plant fibre deployment (not for WDMA architecture), connector termination space in the local exchange and powered equipment in the field. Considering N subscribers at an average distance of L km from the central office, a FTTH PtP design requires $2N + 2$ transceivers and $N \times L$ total fibre length (assuming single fibre is used for bidirectional transmission – less fibre for WDMA solution). However, FTTB PtP networks could present significantly lower costs in certain scenarios such as cable UTP (Unshielded Twisted Pair) cable-installed apartment complex [1]. MC access system supports Ethernet access with best effort from 10Base-T to GbE. PtP is a very flexible solution for an operator and it can be managed remotely because the equipment in the network (Ethernet switch) is intelligent.

The alternative solution, *PtMP system*, uses a Passive Optical Network (PON) with a tree topology and passive optical splitters. PONs have several advantages over other access network architectures. The tree topology offers a single network-port over a single fibre to a plurality of subscribers. The costs of infrastructure and network element at central office are distributed over all users: for instance, in FTTH deployments the number of transceiver is $N + 1$, while PtP design requires $2N + 2$. Also each user can access the full bandwidth of the network that all users share. This allows for better service quality for a given amount of available resources. Subscribers can be up to 60 km from the Central Office (CO). So, in most cases, PON is the most suitable solution for FTTH deployments.

The challenges of the PON physical layer are associated with Time Division Multiple Access (TDMA). Because the network uses passive multiplexing, the Optical Network Units (ONU) need to be synchronized with high precision so that their respective frames will interleave correctly in the fibre system. Also, because frames from multiple ONUs are received in close succession, the Optical Line Terminal (OLT) needs a large and fast dynamic range. Note that only the upstream side of the PON is concerned by these difficulties.

The search for a TDMA system over PON was originally proposed in 1987 by researchers at British Telecom laboratories via the TPON [4], and the first TDMA-based system was developed and demonstrated in the field in 1989 [5]. Researchers quickly recognized the technological value of upgrading these in order to support ATM-based services [6]. The upstream capacity of these ATM-PON demonstrators ranges typically between 50 Mbit/s and 622 Mbit/s. Since June 1995, there has been an international initiative from telecommunication operators and manufacturers to work towards a consensus on the optical access network in order to deliver a full set of telecommunications services, both narrowband and broadband. This initiative was called Full Service Access Networks (FSAN) and has produced the initial recommendations for Broadband-PON (B-PON) since 1996, which has been normalized by the ITU-T with the G.983.x since 1998. Since APON/BPON technology is mature, most PON deployments are so far based on these standards.

In 2001, the IEEE 802.3ah (Ethernet in the first mile task force) began the definition of the Ethernet PON (EPON) that carries all data encapsulated in Ethernet frames (1000Base-x). Ethernet looks like a logical choice for an IP data-optimized access network and cost reduction of Ethernet versus ATM switches and network cards. Ethernet quality of service (QoS) techniques like prioritization and virtual LAN tagging have made Ethernet networks capable of supporting voice, data and video. Currently, there are wide EPON deployments especially in China, Korea and Japan. For the next generation access, this standard body has planed to edit a 10G EPON in 2009 working at 10 Gbit/s downstream and 1 or 10 Gbit/s upstream.

In 2003, the FSAN proposed the first recommendation for general characteristics of Gigabit-capable PON (GPON), with nominal line rates of 1.2 Gbit/s and 2.4 Gbit/s in downstream direction and 155 Mbit/s, 622 Mbit/s, 1.2 Gbit/s and 2.4 Gbit/s in upstream direction. ATM and Ethernet cells are supported in these G.984.x specifications. First commercial solutions are already available. Also concerning the next generation access, the FSAN have planed also a solution for 2012 up to 10 Gbit/s.

Fig. 4 illustrates the time evolution of PtP (Media Converter systems) and PtMP (PON systems) standards.

Already standardized G-PONs (Gigabit-capable Passive Optical Networks) are being deployed in many countries since they are a promising technology for cost-effective subscriber-shared system infrastructure.

With this in mind, this article is organized as follows. Section 2 of this paper will present the history the of optical access in France. Recent developments in PON technologies offer a solution to operators to increase the splitting ratio or the optical budget dedicated to the reach. We will describe in Section 3.1 this evolution. These facts enable an access network evolution in the future with an optimum number of central offices (cf. Section 3.2) with an impact on metropolitan network architectures (cf. Section 3.3). Fixed and mobile services could also be merged in the same optical infrastructure in order to optimize system location (base station and central office) (cf. Section 3.4). If the first generation of access network used up to 2.5 Gbit/s optical interfaces, the next generation access network will need 10 Gbit/s low cost interfaces. A possible evolution of these interfaces could be the used of advanced modulation format (cf. Section 3.5). In addition if 100 Mbit/s or 1 Gbit/s interfaces are now feasible for FTTH subscribers, the bottleneck could be the high speed connectivity in home network. In order to deliver such interfaces coming from the

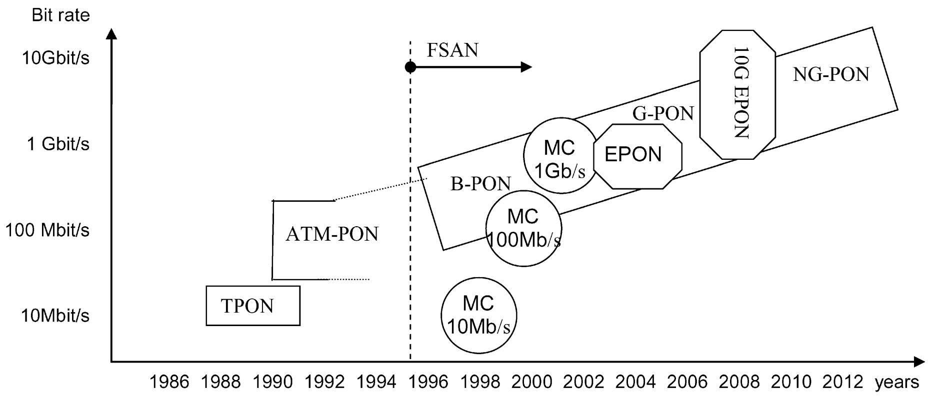

Fig. 4. Illustration off standard broadband access solutions.

access everywhere in the home area, different solutions have been analyzed in terms of easiness and future capability in Section 3.6.

2. Optical access network French history

When the French government decided, at the end of 1982, to expend a major effort in the development and installation of broadband networks (in particular, for residential subscribers), optical fibre had been chosen as the transmission medium. The results obtained by the experimental optical access network installed in BIARRITZ [7] during 1984–1985 led to the conclusion that the installation of an optical access network was now technically feasible. The basic data of this first test-bed and the following optical cable plant, were the following:

- two fibres were used per passed home (50/125 or 85/125 multimode fibre with 200 MHz/km bandwidth);
- optoelectronic modules used principally Light Emitting Diode (LED) at 840 nm wavelength and secondly laser at 1300 nm wavelength;
- a star-type optical cable infrastructure was considered in order to have a good compromise between two different constraints: minimize initial investment, but nevertheless ensure the future easy evolution of the network without requiring additional expensive long-term civil engineering;
- two subscribers could be wavelength-multiplexed on one distribution fibre. The first subscriber installed uses the window of 800 nm, the second one the window of 1300 nm and the demultiplexing is done in the outdoor branching point;
- the following signals could be frequency-multiplexed on each subscriber line: 2 TV channels selectable out of 30 channels, one HiFi channel selectable out of 30 channels, two-way digital channel of 144 kbit/s (ISDN: Integrated Services Digital Network), two-way data channel of 4.8 kbit/s.

This solution was not generalized over the French territory due to the fact that DSL technology maturity enabled operators to minimize infrastructure investment by maintaining their copper infrastructures and also that the multimode fibre did not allow transmission of an extensive bandwidth.

In 1992, the deployment of single-mode fibre was encouraged for business subscribers. The deployment was focused on business customers in the Paris area and in many business areas around France in order to connect company digital exchanges, computer networks and managed networks. No deployment and services were planned for residential subscribers at this time.

20 years after the BIARRITZ first test bed of optical fibre in access network, different French operators launched a program of FTTH. At the beginning of summer 2006, France Telecom was testing a Very High Speed offer in six districts in Paris and six cities in the Hauts-de-Seine. This experiment, based on an optical fibre service deployed into the customer's home, was covering thousands of households. Other operators had also begun experiments of FTTH deployments. Different topologies of optical access infrastructure are proposed such as PtP and PtMP. We will focus in this paper only on point to multi-point architecture.

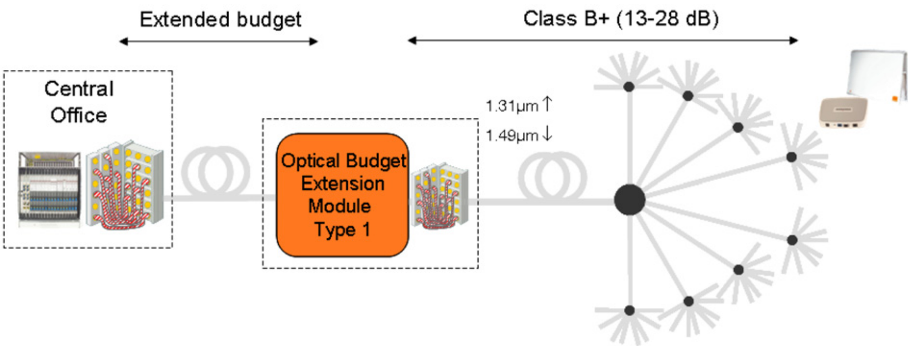

Fig. 5. Use of extended budget for a larger eligibility area.

The basic data of a deployment based on G-PON (Gigabit-capable Passive Optical Network) are:

- one single-mode fibre based on tree topology to connect subscribers; optical splitters allow to divide or combine the optical power in 32 or 64 branches with a typical reach between the central office and the subscribers under 20 km;
- bidirectional transmission of the downstream (central office to subscribers) and upstream (subscribers to central office) signals using wavelength multiplexing, at 1490 and 1310 nm respectively;
- G-PON systems operating at rates of 2.48832 Gbit/s downstream, and 1.24416 Gbit/s upstream using opto-electronic transceivers based on directly modulated distributed feedback lasers and Fabry–Perot lasers, with no temperature control;
- optical budget defined by a class; typically the more used is Class B+ which offers 28 dB maximum budget between the central office and the subscribers.

3. Optical access evolutions and their impacts on the metropolitan and home networks

The introduction of optical technologies in access network by G-PON system is the beginning of a network evolution for operators. The low attenuation of optical signal inside fibre and the possible high bit rate of opto-electronic interfaces are arguments in favour of a strong networks evolution. Optical technologies could be used, in the access network, to extend the reach of the link between subscribers and central office. An optimization of the number of central offices could be achieved while increasing the access broadband bit rate. However, an optical budget extension could be necessary to increase this reach or the splitting ratio (number of possible subscribers connected), since it would increase the affordable optical loss between central office and subscribers.

3.1. Possible architecture evolution of the access network

The deployment of an optical budget extension module (G.984.6) [8–10] inside the optical distribution network is one of the attractive solutions to enable the removal of high complexity active devices and reduce the overall access network cost. A first application of budget extension is shown on Fig. 5. It focuses on the use of extended budget module for a largest customer's eligibility area. A longer reach (so more optical signal propagation losses) between subscribers and central office could be achieved. In term of technology, the extension module could be achieved with either OEO (Optical-Electrical-Optical) repeater or semi-conductor optical amplifiers.

Another scenario (cf. Fig. 6) is to achieve high efficiency in terms of homes connected per OLT. A possible solution, especially for initial roll-out phase, is to improve the PON "filling ratio" by sharing one GPON port between several PON trees but with a maximum of 64 homes connected. This scenario is particularly interesting when the take-up rate grows slowly. This scenario offers [9] also a potential reduction of operational works in the optical distribution network because the entire fibre infrastructure is lighted at the initial stage. Thus we reduce the time for the connection of new customers. This solution is shown in Fig. 6. In this scenario, the optical budget extension module allows us to deliver the same optical power to each tree as if we had only one tree, instead of dividing the power.

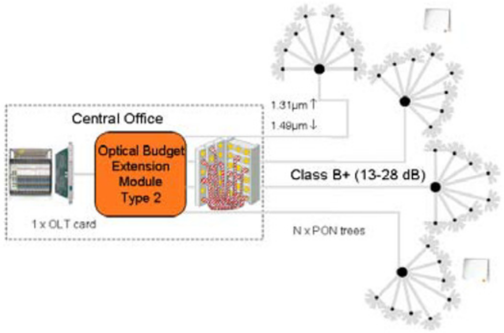

Fig. 6. Use of extended budget for increasing splitting ratio.

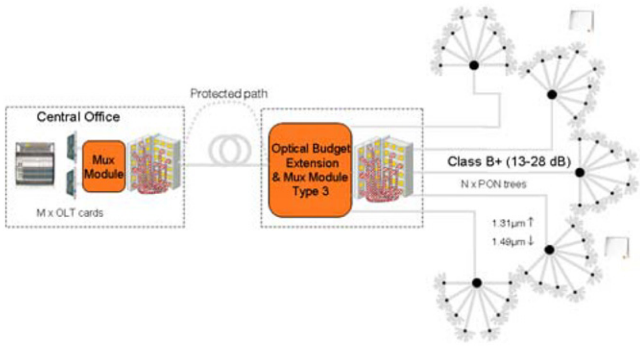

Fig. 7. Solution to combine extended budget and multiplexed traffic.

Of course a solution which can combine both previous benefits could be very useful. Fig. 7 shows this scenario in which a remote extender box is used to multiplex (in time and/or wavelength) "N" PON trees and also to increase the optical reach. In addition, the optical path between the central office and the extender box could be protected (via a protected path in case of failure of the main path). At the central office, the use of time and/or wavelength multiplexer extender module [10] would pave the way for the future increase of the number of subscribers by multiplexing several G-PON OLT ports. Furthermore this multiplex interface could also be shared between other interface types, as for example PtP Ethernet interfaces dedicated to Digital Subscriber Line Access Multiplexer (DSLAM) collect. This solution would allow one to optimize the filling efficiency of OLT ports and to increase the FTTH customer's area eligibility. Optical budget extension modules could be defined as a WDM (Wavelength Division Multiplexing) demarcation device of the future access-metropolitan network of tomorrow.

3.2. *Central office number optimization*

The benefits for operators by adopting solutions providing extended optical budget for GPON can be the reduction of OAM (operation, administration and maintenance) costs and savings due to the OLT location in a reduced number of optical central offices.

We present here, as an illustration, some results of an optimization of number of central offices equipped with class B+ GPON OLT required for a roll-out over a large area of 1.4 million subscribers mixing high and low population density. Subscriber's eligibility is a function of the optical budget (with and without extended module) inside the 60 km maximum reach. Of course, OLT localization has a strong impact on subscriber's eligibility results. We propose here six scenarios (cf. Fig. 4) where OLTs are co-localized with DSLAM, DSLAM connected by a fibre link to the metropolitan network, master DSLAM (a master DSLAM could aggregated the traffic of subscriber but also slave DSLAMs), metropolitan edge node on the primary and secondary ring, metropolitan edge node on the primary ring only, and POP (Point Of Presence is an artificial high layer demarcation point or interface point between communications entities and could be, typically, located at border between the metropolitan and core networks). In this study, we used a type one extender module with a maximum extended optical budget of 28 dB, so there is a total optical budget of 56 dB between OLT port and subscribers, and a maximum reach of 60 km. We also illustrated on Fig. 8 the mean reach between the OLT and the subscribers. In the particular case where OLTs are localized only in the metropolitan edge node on the primary and secondary ring, we obtain a significant gain of OLTs location number (around 820 central offices with DSLAM versus 48 edge nodes) by maintaining 100% of FTTH eligibility.

3.3. *Metropolitan and access merger*

By increasing the reach of an optical access system and by the necessity to ensure service reliability, some metropolitan functionality will be requested inside extended access network. Typically, a combination of ring and tree could offer superior scalability and low start-up cost with automatic protection path and supervision functions (cf. Fig. 9). The optical budget extension modules could be passive based on wavelength routing and remote amplification like SARDANA architecture [11] or active based on optical packet switching like ECOFRAME architecture [12].

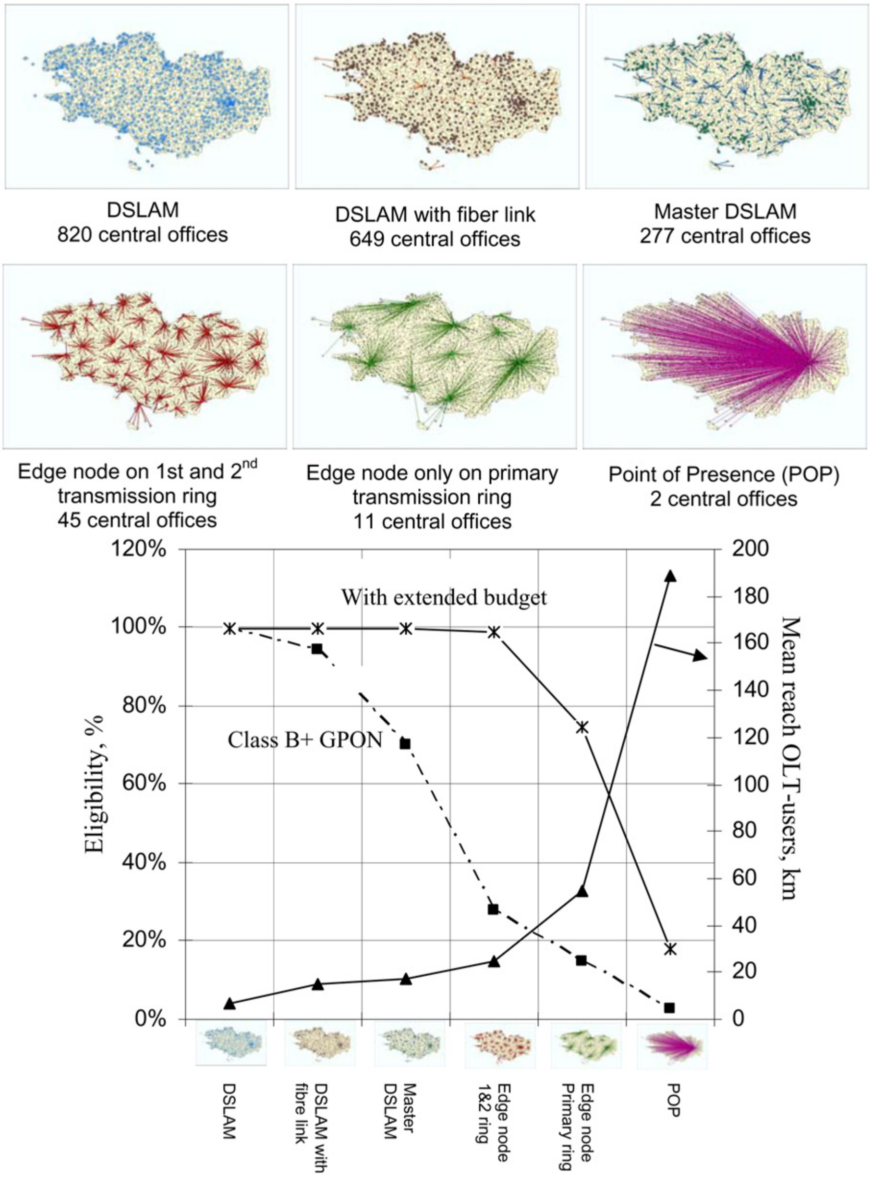

Fig. 8. Eligibility and mean reach as a function of the OLT card localization in the network.

3.4. Convergence of radio and fibre technologies

A new optical fibre infrastructure is deployed for FTTH subscribers. On the other hand, the deployment of radio systems is accelerated due to the explosion of high-speed wireless services, such as 3G mobile phone. An opportunity is present to merge fixed and mobile infrastructures over a shared fibre network [13]. Three scenarios for sharing fibre infrastructure are discussed hereafter. The backhauling over G-PON traffic is one candidate for transporting traffic between distributed Base Transceiver Station (BTS) using cell site gateway (CSG) and more centralized nodes like multi aggregation site gateway (MASG) (cf. Fig. 10(a)). The second scenario, Fig. 10(b), could be the use by a wavelength overlay of RF signal directly over optical fibre (RoF) between base station and multiple remote radio units. The last scenario (cf. Fig. 10(c)) could be the use of digital radio over fibre (D-RoF) technology, in which analogue radio signals are digitized. A digital local unit is installed at the basement and is connected to multiple digital remote units using wavelength overlay over the PON infrastructure. The open topics for the future could be the capacity to

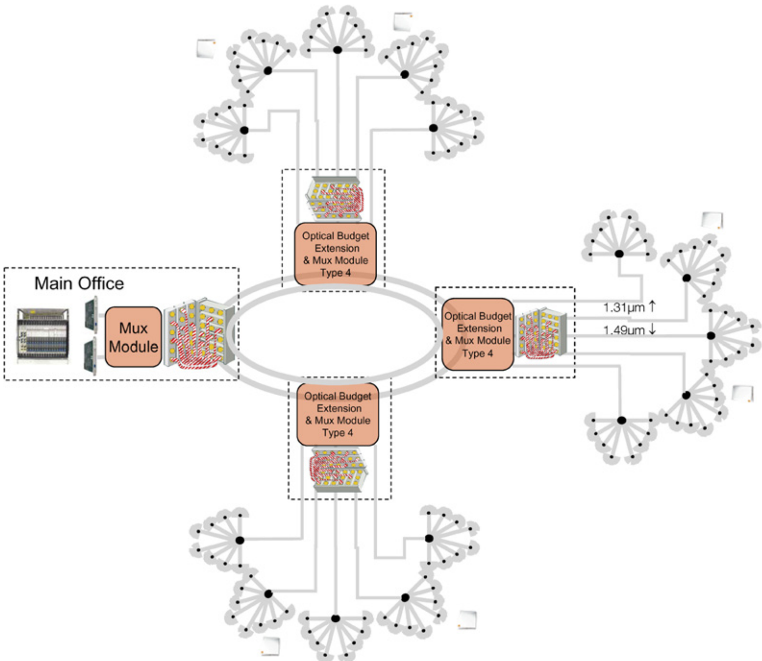

Fig. 9. Metropolitan and access merger approach.

transmit the D-RoF signal inside the native frame traffic of PON systems and 28 dB optical budget adaptation of RoF systems (cf. ALPHA European collaborative project [14]).

3.5. 10 Gbit/s interfaces for access

If an optical fibre infrastructure based on splitters is deployed for a generation of PON system with 2.5 and 1.25 Gbit/s for downstream and upstream respectively, the future generation of system must be compatible with a minimum of CAPEX (capital expenditure) and OPEX (operating expenditure). So next generation system must re-use the optical distribution network and increase the subscriber bandwidth. The low cost and optical infrastructure compatible with 10 Gbit/s interface based on time multiplexing techniques is a challenge for the future generation of PON system.

With the high spectral efficiency of M-QAM (Multilevel-Quadrature Amplitude Modulation), research in Multi-Carrier Modulation (MCM) has grown tremendously over the last few years due to the demand for high speed data transmission in optical communication systems. In order to increase the bandwidth up to 10 Gbit/s and beyond while maintaining an acceptable cost of deployment, recent research in optical access networks has been focusing on MCM like Orthogonal Frequency Division Multiplexing (OFDM) [15]. The main advantage of OFDM is that it can transmit parallel data at low rates on each sub-carrier simultaneously. Therefore a frequency selective channel is transformed into a collection of flat channels. As a result, this modulation technique inherits robustness to fiber chromatic dispersion. In addition, OFDM has become extremely popular due to its efficient implementation using Fast Fourier Transforms (FFTs) to modulate and demodulate data.

We present here results where our goal is to reduce the cost of the 10 Gbit/s interface is to re-use the 2.5 GHz opto-electronic interface with an advanced modulation format [16]. We experimentally demonstrate the feasibility of using Adaptively Modulated Optical OFDM (AMOOFDM) also known as Discrete Multi-tone (DMT) modulation (coming from xDSL signal) to modulate directly the low electrical bandwidth commercial vertical cavity surface emitting laser (VCSEL) and multimode Fabry–Perot (FP) laser as cost-effective solutions for passive optical network at a high bit rate. Here a 10 Gbit/s AMOOFDM signal was generated by direct modulation of the commercial 2.8 GHz VCSEL, 2.5 GHz multimode FP laser and 2.1 GHz DFB laser at 1550 nm. The receiver used is a 10 GHz avalanche photodiode. Fig. 11 illustrates the experimental bit error rate performances of these optical sources in function of power received for the three optical sources and different fibre reach. This solution to used advanced modulation format coming from

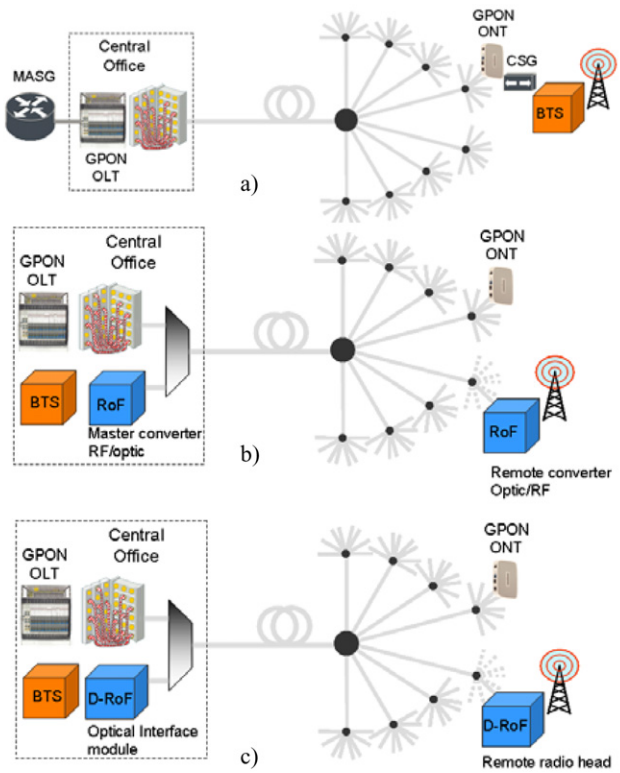

Fig. 10. Convergence of radio and fibre technologies.

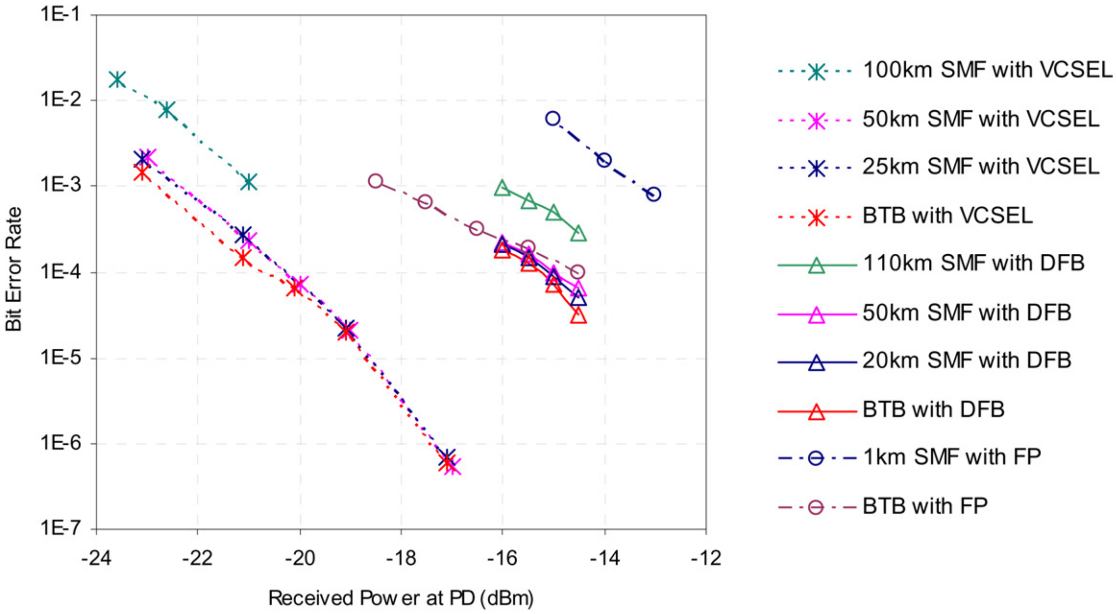

Fig. 11. 10 Gbit/s transmission performance for direct modulation of VCSEL, FP and DFB lasers with an electrical bandwidth < 2.5 GHz.

radio or xDSL systems is a promising technology to reduce the cost of high bit rate interfaces. This solution could be also used in the home network over a plastic optical fibre to increase the bandwidth.

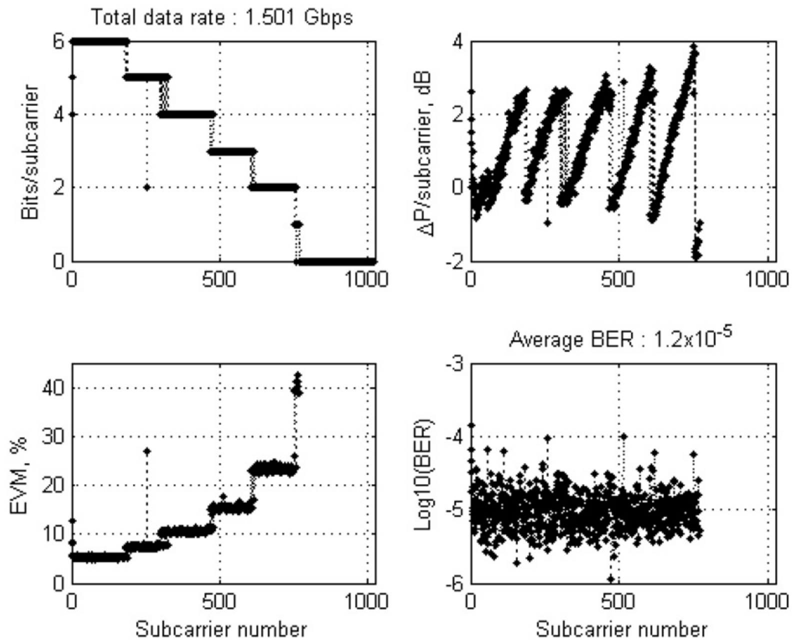

Fig. 12. POF transmission results: Optimum bit allocation (top left), power allocation (top right), computed Error Vector Magnitude (bottom left) and evaluated BER (bottom right).

3.6. Home networks

In the previous sections we have shown that significant cost reduction will be offered to operators through the deployment of PONs while maintaining the ability to offer Ultra-High Bandwidth connectivity to customers (1 Gbit/s). New revenue generating services could be offered/extended/developed to fill the 1 Gbit/s pipe to the customer doorway but a pre-requisite is that the end-users have a way to manage, transport and distribute these high speed data flows within their homes into their lounges, home offices and bedrooms. This connectivity media must comply with the requirements of being highly efficient while being easily installable (and even installable by the end-user himself). "No new wire" approaches are being investigated to fulfill these requirements but, if self-installation is achievable, 1 Gbit/s guaranteed bandwidth is not yet within reach. The only solution today to guarantee the quality of service for Gbit/s approaching applications is to use Gigabit Ethernet over copper cables. However, then, the self-installation requirement is hard to fulfil as the termination of those cables is not easy to make and the cables must be installed away from power interfering sources. One attractive solution is then to use Step Index Plastic Optical Fibre (SI-POF) [17] whose core diameter (1 mm) is large enough to allow the subscriber to terminate it by simply cutting the end with a sharp knife. An SI-POF cable has only 3 to 4 mm of diameter and is very flexible making it ideal for installation in ducts, along a plinth or under a carpet. The data transmission uses visible light which has the added advantage of simplifying the installation and attractiveness of the overall system. Transmission at or around 1 Gbit/s over 50 to 100 m of SI-POF has already been demonstrated using a combination of modulation and digital processing techniques [18–20]. We have chosen to use techniques derived from the Power Line Communication and VDSL arena with a combination of Discrete Multi-Tone Modulation and Bit Loading Optimisation algorithm to be able to always adapt the data transport to the propagation channel and thus maximize the throughput transported in the SI-POF [21]. Using these techniques with a set-up similar to that described in [21] and improved components from Firecomms (650 nm VCSEL and PIN photodiode) we have successfully transmitted 1.5 Gbit/s over 50 m of SI-POF with a BER evaluated to be 1.2×10^{-5} (cf. Fig. 12). The sampling frequency is set to 1 GS/s in the transceiver side while we used a 2 GS/s sampling frequency in the RX side. 1023 independent carriers are used over 500 MHz and, after channel probing, the optimum capacity allocation is found. Fig. 12 represents the main results obtained. First, the propagation channel is probed using a known signal and from this initial measurement (which can be repeated at regular interval), an optimum capacity allocation is derived, optimizing the number of bits (Fig. 12 top left) as well as the power (Fig. 12 top right) carried by each subcarrier to achieve a target BER (here 10^{-5}). The performance, measured in terms of Error Vector Magnitude (Fig. 12 bottom left) which is related to BER (Fig. 12 bottom right) shows a constant BER over the whole transmitted spectrum (Average BER measured to be 1.2×10^{-5}) confirming the correct optimization of the transmitted signal. A total of 1.5 Gbit/s is successfully transmitted.

4. Conclusion

This article described briefly optical access evolution in France and elsewhere in the world. Today, different French operators deploy a fibre infrastructure to connect their subscribers to a large broadband service. We have focused our technical issues on point to multi-point topology.

We have described a possible evolution of the optical access networks using optical budget extension in order to optimize the number of optical central offices. The issues of central office location were presented in function of customer eligibility. Convergence of radio and fibre technologies was also discussed, as possible topics of network development. Finally, we have described a technical issue inside the home network. It was shown that in the future it is feasible to deliver 1 Gbit/s inside the home network over SI-POF with 1 mm core diameter.

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