Optical access evolutions and their impact on the metropolitan and home networks

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Abstract : *This paper describes broadband optical access networks evolutions including high speed home interfaces for fixed and mobile services. Technical challenges are also discussed, namely concerning optical extended budget, 10 Gbit/s interfaces as well as the impact of access evolutions on the metropolitan network.*

Introduction

The advantages of employing Passive Optical Network (PON) have been largely recognized. Already standardized G-PONs (Gigabit-capable Passive Optical Networks) are being deployed in many countries since they are a promising technology for cost-effective user-shared system infrastructure. Recent developments in PON technologies offer a solution to operators to increase the splitting ratio or the optical budget dedicated to the reach. These facts enable an access network evolution in the future with an optimum number of central offices with an impact on metropolitan network architectures. Fixed and mobile services could also be merged in the same optical infrastructure in order to optimize systems localization (base station and central office). The low cost of 10Gbit/s interface is also a challenge for the future generation of PON system. Also, if 100Mbits/ or 1Gbit/s interfaces are now feasible for FTTH users, the bottleneck could be the high speed connectivity in home network. In order to deliver such interfaces coming from the access everywhere in the home area, different solutions have been analyzed in terms of easiness and future capability.

Capable architecture evolution of access network

The deployment of an optical budget extension module (G.984.6) [1-3] 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 figure 1. It focuses on the use of extended budget module for a largest customer's eligibility area.

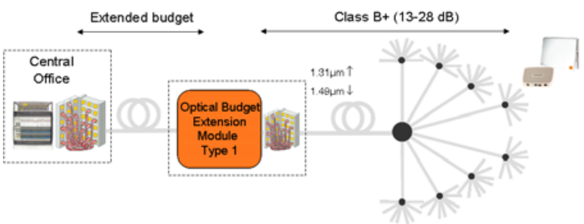

Figure 1: Use of extended budget for a larger eligibility area.

Another scenario (cf. F ig. 2) is to achieve a high efficiency in terms of homes connected per OLT (Optical Line Terminal) PON port. 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 home connected. This scenario is particularly interesting when the take-up rate grows slowly. This scenario offers [4] also a potential reduction of operational works in the optical distribution network because the entire fibre infrastructure is lighted at the initial stage. So we reduce the time for the connection of fitir customer. This solution is shown in figure 2.

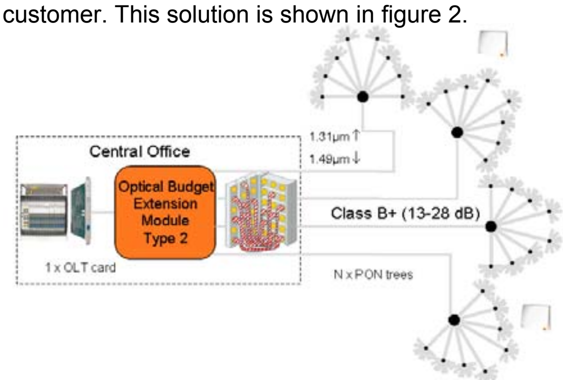

Figure 2: Use of extended budget for increasing splitting ratio.

Of course a solution which can combine both previous benefits could be very useful. Figure 3 shows this scenario in which a remote extender box is used to multiplex "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. At the central office, the use of time and/or wavelength multiplexer extender module [5] would open a path by multiplexing several G-PON OLT ports. Furthermore this multiplex interface could also be shared between other interface types, as for example point to point Ethernet interfaces dedicated to Digital Subscriber Line Access Multiplexer (DSLAM) collect. This solution would allow 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 demarcation device of the future access-metropolitan network of tomorrow.

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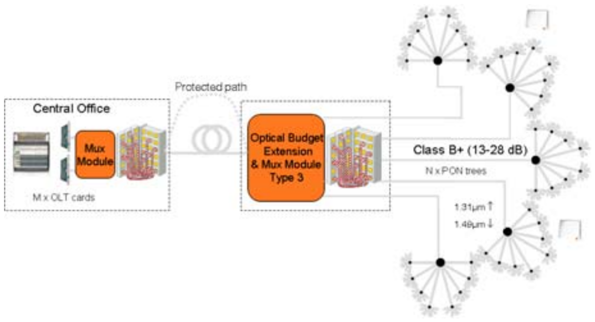

Figure 3: Solution to combine extended budget and multiplexed traffic.

Among different options for offering FTTH, the evolution of solutions to increase the optical budget and to multiplex signals allows a network operator to increase the number of customers accommodated in a GPON system by extending the PON reach, splitting ratio and filling ratio.

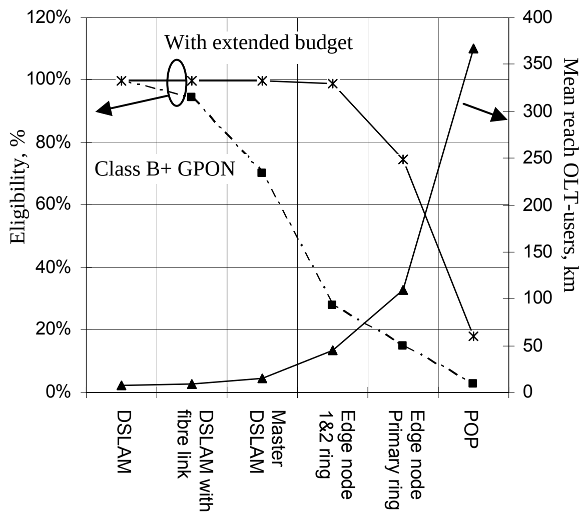

Figure 4: Eligibility and mean reach as a function of the OLT cards localization in the network.

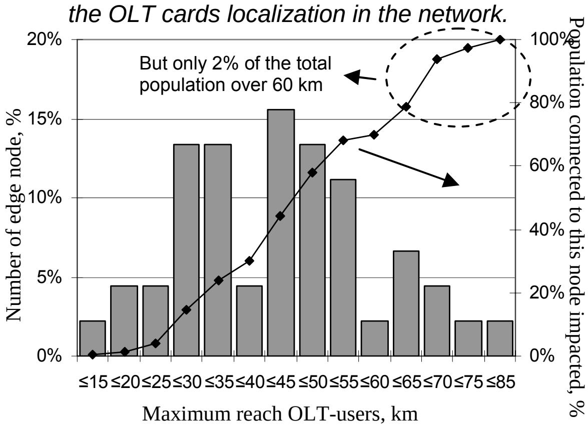

Figure 5: Percentage of OLT sites as a function of maximum reach OLT-users in the case of OLT and edge node co-location.

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, for 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 mixing high and low population density. Customer's eligibility is a function of the optical budget (with and without extended module) inside the 60km maximum reach. Of course OLT localization has a strong impact on customer's eligibility results. We propose here six scenarios (cf. figure 4) where OLTs are co-localized with DSLAM, DSLAM connected by a fibre link, master DSLAM, metropolitan edge node on the primary and secondary ring, metropolitan edge node on the primary ring only, and POP (Point Of Presence). When extender modules are used, they are sited inside an existing central office. We also illustrated on figure 4 the mean reach between the OLT and the users.

In the particular case where OLT cards are localized only in the metropolitan edge node on the primary and secondary ring, figure 5 presents the evolution of these number of OLT sites (and also percentage of users impacted) as a function of the maximum distance (not the mean) between the node and the user.

Metropolitan and access merger

By increasing the reach of optical access system and by the necessity to ensure service reliability, some metropolitan functionalities 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. figure 6). The optical budget extension modules could be passive based on wavelength routing and remote amplification like SARDANA architecture [4] or active based on optical packet switching like ECOFRAME architecture [5].

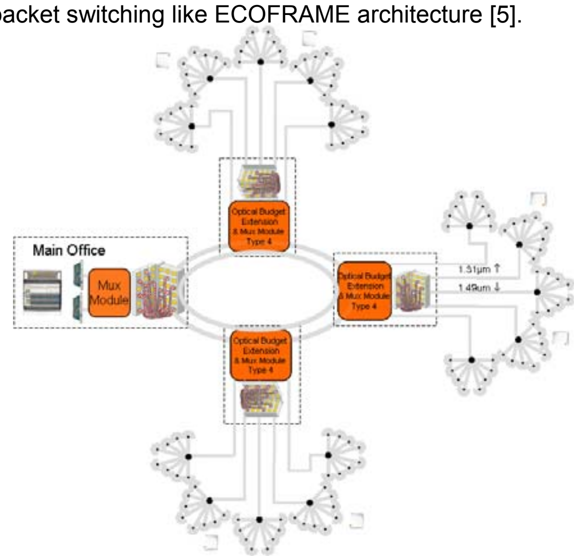

Figure 6: metropolitan and access merger approach.

Convergence of radio and fibre technologies

A new optical fibre infrastructure is deployed for FTTH users. 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 over a shared fibre network [6]. 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 using cell site gateway (CSG) and more centralised nodes like multi aggregation site gateway (MASG) (cf. figure 7-a)). The second scenario, figure 7-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. figure 7-c)) could be the use of digital radio over fibre (D-RoF) technology, in which analog radio signals are digitallized. 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 transmit the D-RoF signal inside the native frame traffic of PON systems and 28 dB optical budget adaptation of RoF systems (cf. ALPHA project [7]).

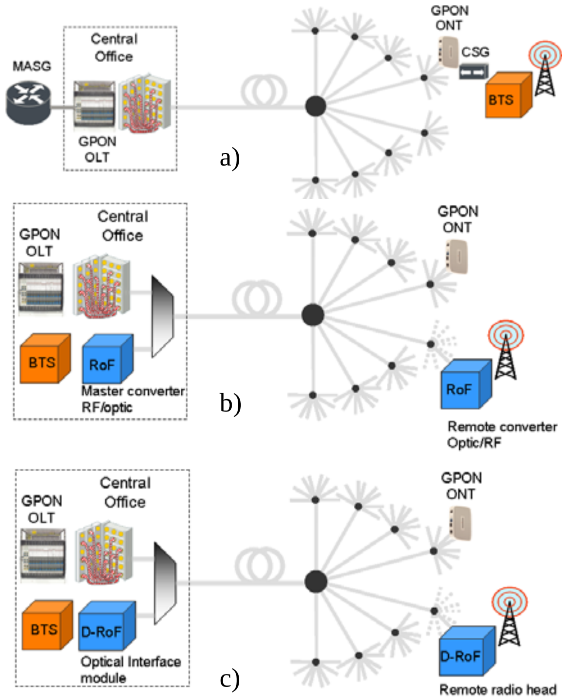

Figure 7: Convergence of radio and fibre technologies

10Gbit/s interfaces for access

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

In order to limit the cost of a solution at 10Gbit/s upstream signal in burst mode, continuous devices must be re-used [8]. Figure 8 illustrates the results obtained by using a photo-receiver stage constituted by APD-TIA photodiode AC coupled to an electrical amplifier and a continuous phase-lock-loop clock recovery at 10.7Gbit/s. We receive burst traffic coming from two directly modulated DFB lasers at 1.3 µm. The burst traffic is acheived by two alternate packets of 4.8 µs with 10.7Gbit/s PRBS sequences at 2^9 and a variable guard time without any optical signal. We also introduce 20 and 60 km of fibre between the receiver and the two lasers. We observe in figure 8 a) and b) the penalty evolution as a function of the guard time and fiber length.

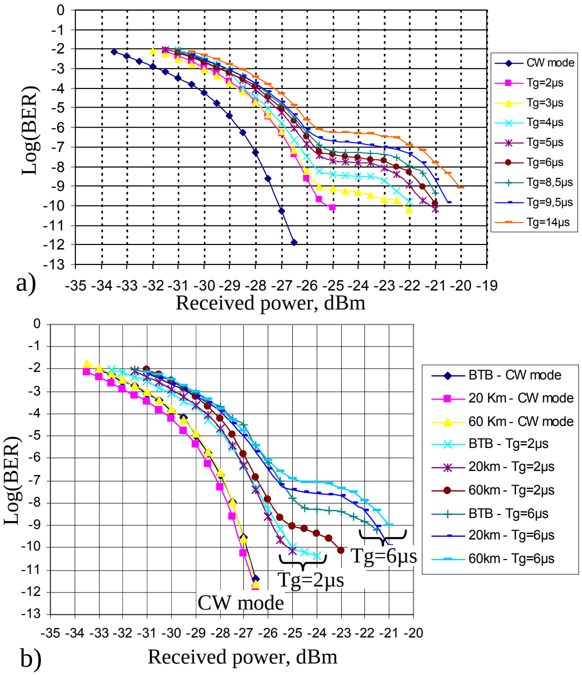

Figure 8: Bit error rate curves of continuous photo–receiver.

Another solution to reduce the cost of 10Gbit/s interface is to re-use 2.5 GHz opto-electronic interface with advanced modulation format [9]. We experimentally demonstrate the feasibility of using Adaptively Modulated Optical OFDM (AMOOFDM) also known as Discrete Multi-tone (DMT) modulation to modulate directly the low 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 10Gbit/s AMOOFDM signal was generated by direct modulation of 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. Figure 9 illustrates the experimental bit error rate performances of these optical sources.

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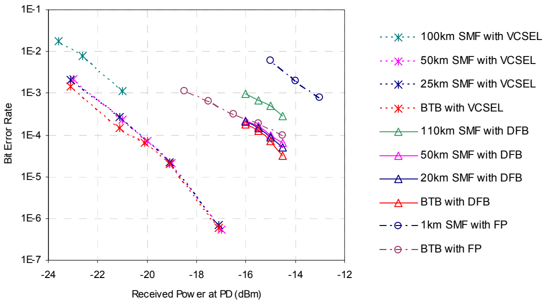

Figure 9: 10Gbit/s transmission performance for direct modulation of VCSEL, FP and DFB lasers

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 (1Gbit/s). New revenue generating services could be offered/extended/developed to fill the 1Gbit/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 fulfil these requirements but, if self-installation is achievable, 1Gbit/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 CAT-5/6 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) whose core diameter (1 mm) is large enough to allow the user to terminate it by simply cutting the end with a sharp knife. An SI-POF cable has only 3 to 4mm 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 1Gbps over 50 to 100m of SI-POF has already been demonstrated using a combination of modulation and digital processing techniques [10-12]. 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 maximise adaptively the throughput transported in the SI-POF [13]. Using these techniques with a set-up similar to that described in [13] 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. figure 10). Sampling frequency is set to 1GS/s in the TX side while we used a 2GS/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.

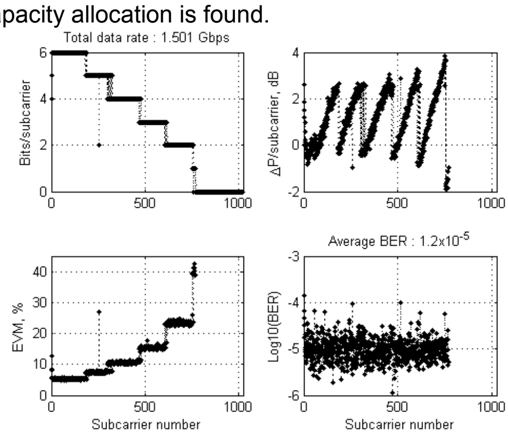

Figure 10: POF transmission results: Optimum bit allocation (top left), power allocation (top right), computed EVM (bottom left) and evaluated BER (bottom right).

Conclusion

We describe a possible evolution of the optical access networks using optical budget extension in order to optimize the number of optical central offices. Convergence of radio and fibre technologies is discussed as well as the evolution of 10Gbit/s optical access interfaces. We also focus this paper on the feasibility of delivering 1 Gbit/s inside the home network over SI-POF with 1 mm core diameter.

Acknowledgments

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