Grant Agreement No. 212 352

ALPHA

Architectures for fLexible Photonic Home and Access networks

Programme: Information and Communication Technologies

Funding scheme: Collaborative Project – Large-Scale Integrating Project

Final report on standardisation activities for the proposed access solutions

Due date of document: December 31, 2010

Actual submission date: April 15, 2011

Start date of project: January 1, 2008 Duration: 36 months

Lead contractor for this document:

Andrzej Tymecki, Telekomunikacja Polska SA, Poland

Project co-funded by the European Commission within the Seventh Framework Programme		
Dissemination Level		
PU	Public	X
PP	Restricted to other programme participants (including the Commission Services)	
RE	Restricted to a group specified by the consortium (including the Commission Services)	
CO	Confidential, only for members of the consortium (including the Commission Services)	

Executive Summary

This ALPHA Deliverable D2.6 gives an overview of the standardisation activities that were carried out during the project within the area of access networks. The standardisation activities are focused on two access network reference architectures: a WDM 10G TDM PON and an active optical network (AON).

Three specific examples of how the ALPHA partners have contributed to standardisation are presented in the Deliverable:

- France Telecom has presented key parts of the WDM 10G TDM PON to FSAN/ITU.
- By closely following the work in the XMD MSA (10 Gbit/s miniature device multi-source agreement), 3S Photonics succeeded in being the first company to implement a SFF TOSA (Small Form Factor Transmitter Optical Sub Assembly) module according to this standard.
- Acreo's work on GMPLS in a unified control plane for an integrated access/distribution network was based on existing standards, and specific extensions have been proposed.

Furthermore, the Deliverable contains an overview of the important optical access technologies and standardisation bodies active within the area; particularly FSAN/ITU and IEEE, which are the most relevant in the ALPHA context. Also, a brief description of practical issues in the standardisation work is given.

Finally, in the Appendix a solution for a metro network exploiting the packet add-drop multiplexer (P-OADM) technology and which can be integrated with WDM 10G TDM PON is described along with proposals for its future standardisation.

Document Information

Status and Version:	v12	
Date of Issue:	2011-04-15	
Dissemination level:	PU	
Author(s):		
	Andrzej Tymecki	Telekomunikacja Polska
	Magdalena Hamada	Telekomunikacja Polska
	Philippe Chanclou	France Telecom
	Dominique Charioni	Alcatel-Lucent Bell Labs France
	Viktor Nordell	Acreo
	Anders Gavler	Acreo
	Claus Popp Larsen	Acreo
	Emmanuel Grard	3S Photonics
Compiled by:	Andrzej Tymecki	Telekomunikacja Polska
Checked by:	Claus Popp Larsen, Dominique Chiaroni, Mikhail Popov	ALBLF & Acreo
	All partners	All partners

Table of Contents

1 General scope of the document

1.1 Purpose and Scope

The purpose of this document is to provide information on ALPHA WP2 related standardisation activities in preliminary identified standardisation bodies as the ITU, IETF, ETSI and FSAN.

1.2 Reference Material

1	*Contribution to NG-PON2*, F. Chanclou, F. Bourgart, B. Landousies, F.Saliou, N. Genay, B. Capelle, FSAN (November 2009)
2	*Contribution to NG-PON2 - workshop1 Achievable Optical budget projections*, P. Chanclou, B. Charbonnier, N. Genay, F. Saliou, A. Gharba, S. Gosselin, L. Anet Neto, R. Xia, E. Pincemin (Orange Labs), C. Kazmierski, R. Brenot, M. Achouche (Alcatel Thales III-V Lab), FSAN (Munich meeting August-September 2010)

1.3 Acronyms and Abbreviations

10G-EPON	new generation PON IEEE (802.3av)
10G-PON	new generations of PON including ITU-T NGPON1 and IEEE 10G-EPON
AES	Advanced Encryption Standard
AN	Access Node
APD	Avalanche photodiode
APON	ATM PON
AON	Active Optical Network
ATM	Asynchronous Transfer Mode
AWG	Array Wave Guide
BBCoC	Broadband Code of Conduct
BBF	Broadband Forum
BPON	Broadband PON
BMRX	Burst Mode Receiver
BMTL	Burst Mode Tuneable Source
BSI	British Standards Institution
CAPEX	Capital Expenditures
CENELEC	European Committee for Electrotechnical Standardisation
CO	Central Office
CNE	Concentrateur Numérique Eloigné (distant digital concentrator)
CPE	Customer Premise Equipment
DBA	Dynamic Bandwidth Allocation
DKE	Deutsche Kommission Elektrotechnik, Elektronik, Informationstechnik im DIN und VDE
DOCSIS	Data Over Cable Service Interface Specification
DS	Downstream
E2E	End to End
EAM	Electroabsorption modulator

ECL PLC	External Cavity Laser on a Planar Lightwave Circuit
EDFA	Erbium Doped Fibre Amplifier
E-PON	Ethernet PON
ETSI	European Telecommunications Standards Institute
FA-LSP	Forwarding Adjacency Label Switched Path
FEC	Forward Error Correction
FSAN	Full Service Access Network
FTTX	Fibre To The X (X=Cabinet, Node, Curb, Building, Home, Office)
GbE	Gigabit Ethernet
GE-PON	Gigabit Ethernet PON
GMPLS	Generalized Multi-Protocol Label Switching
GPON	Gigabit PON
GW	Gateway
IEC	International Electrotechnical Commission
IEEE	Institute of Electrical and Electronics Engineers
IETF	Internet Engineering Task Force
ILEC	Incumbent Local Exchange Carrier
IPR	Intellectual Property Rights
ISCD	Interface Switching Capability Description
ISO	International Organization for Standardisation,
ITU	International Telecommunication Union
JSA	Japanese Standards Association
LAN	Local Access Network
LTE	Long Term Evolution
MAC	Media Access Control
ML	Multi-Layer
MSA	Multi Source Agreement
MSE	Multi Service Edge
MZI	Mach-Zehnder Interferometer
NG-PON1	Next Generation PON 1st step
NG-PON2	Next Generation PON 2nd step
OλI	Open Lambda Initiative
OAM	Operations, Administration, and Management
ODN	Optical Distribution Network
OE	Optical toElectrical
OEO	Optical to Electrical to Optical
OMCI	ONT Management and Control Interface
OLT	Optical Line Terminal
ONT	Optical Network Terminal
ONU	Optical Network Unit
OPEX	Operational Expenditures
OSPF-TE	Open Shortest Path First – Traffic Engineering

OTL	Optical Trunk Line
P2P	Point to Point
P-OADM	Packet Add-Drop Multiplexer
PCE	Path Computation Element
PCEP	Path Computation Element communication Protocol
PE	Provider Edge
PON	Passive Optical Network
POTS	Plain Old Telephone Service
PR	Symmetric-rate
PRX	Asymmetric-rate
PWE	Pseudo Wire Emulation
QoS	Quality of Service
RN	Remote Node
RoF	Radio over Fibre
R-OADM	Reconfigurable Optical Add-Drop Multiplexer
ROSA	Receiver Optical Sub Assembly
RSVP-TE	Resource Reservation Protocol - Traffic Engineering
RX	Receiver
SIEPON	Service Interoperability in Ethernet Passive Optical Networks
SOA	Semiconductor Optical Amplifier
SFF	Small Form Factor
SFU	Single Family Unit
TDM	Time Division Multiplexing
TDMA	Time Division Multiple Access
TOSA	Transmitter Optical Sub Assembly
TX	Transmitter
TRX	Transceiver/Transponder
US	Upstraem
VHBB	Very High BroadBand
WAN	Wide Area Network
WBF	Wavelength Bandwidth Filter
WDM	Wavelength Division Multiplexing
WDM1	WDM filter 1 for Central Office
WDMA	Wavelength Division Multiplexing Access
XDSL	(X=Asymmetrical or Very High Bit-Rate Digital Subscriber Line)
XG-PON	10G-PON
XG-PON1	Asymmetric 10G/2.5G NG-PON1 FSAN/ITU-T
XG-PON2	Symmetric 10G/10G NG-PON1 FSAN/ITU-T
XMD	10 Gbit/s Miniature Device
xPON	Either EPON or GPON

1.4 Document History

Version	**Date**	**Editor**	**Comment**
01	2010-11-17	A.Tymecki	RAS
02	2010-12-19	A.Tymecki	Incorporation of partners comments
03	2011-02-08	A.Tymecki	Corrections after ALPHA Obertauren meeting
04	2011-02-21	E. Grard A.Tymecki	Integrating input of 3S Photonics
05	2011-04-05	C.P.Larsen	Proof reading + corrections
06-12	2011-04-08 – 2011-04-15	C.P.Larsen, Dominique Chiaroni, M.Popov	Final version

2 Introduction

Today in the rapidly changing telecoms industry, it gets increasingly harder to cope with the numerous technical solutions appearing on the market quite often not compatible one with each other. To solve the problem it is of utmost importance to standardise technical solutions in order to assure compatibility and preferably also interoperability between various manufacturers' products. Most equipment vendors have realized the necessity of standardisation even though it often requires them to relax some proprietary requirements.

It was of key importance for ALPHA to follow standardisation activities in selected areas and provide feedback to relevant standardisation bodies with the most recent information from the consortium. For that reason, at the start of the project, the most important standardisation bodies for each WP were identified. In case of WP2 these were: ITU, IETF, ETSI and FSAN.

Subsequently, the industrial partners participating in these standardisation bodies took efforts to provide mutual exchange of information between the ALPHA consortium and the respective standardisation organizations.

2.1 Structure of the Deliverable

This Deliverable presents results of standardisation activities by the partners involved in ALPHA WP2 over the course of the project. Activity results are presented from the perspective of initial WP2 achievements with main focus on selected metro and access networks reference technologies. The Deliverable comprises three parts;

In Chapter 3 the two selected access network reference architectures are described; namely an active optical network (AON) and a WDM 10G TDM passive optical network (PON). These have been subject to standardisation work within ALPHA. The selection of stated reference technologies for further consideration was supported by results of techno-economical analysis within the project.

Chapter 4 gives an overview of the global standardisation activities within optical access networks. The emphasis has been put on FSAN/ITU and IEEE since they are the most important standardisation bodies within the area. In order to do standardisation within the area it is crucial understand the technologies the different players described in Chapter 4. However, even when understanding these, there are thresholds for both small and large organizations to perform effective standardisation work. This is briefly touched upon in the chapter.

In Chapter 5, three selected activities have been addressed to show how the ALPHA partners have worked with standardisation. These include contributions to FSAN on parts of the reference model WDM PON, proposals for extensions to standards for a unified control plane in a collapsed AON access and distribution network, and finally an example how following the XMD multisource agreement closely can lead to state-of-the-art products.

3 ALPHA network concepts

This chapter provides comprehensive information on two network architectures (models) that were used as reference architectures in WP2. Selected technologies for access networks were targets for contributions to relevant standardisation bodies. Moreover, an appendix has been added at the end of the document to describe a metro network solution. Its late introduction in the project (during the last year) prevented standardisation activities during the project, but the material provided could be reused for a further standardisation activity beyond ALPHA; this is outlined in the appendix.

3.1 Active optical network (AON) architectures

Figure 1 shows a diagram of a possible ALPHA AON target network. It comprises an access part and a distribution part that have been collapsed into a single network. This is one of the reference architectures considered in WP2.

The topology of the network and the data plane technology's choice of network elements depend on the requirements that the services put on the network. Certain services have requirements on uptime and this leads to requirements on the network stability and handling of protection and restoration. In order to make this possible there is a need for more advanced access network topologies. This may be solved in numerous ways. In the simplest case it leads to providing redundant fibres in the metro access part, while in the most complex scenarios this leads to a higher degree of diversified physical fibre infrastructure in both the metro access and last mile, i.e. meshed topologies also in these network segments. Meshed last mile can be utilised in order to have a higher total bandwidth of the network and using customer premises gateway nodes as part of the access network in order to transmit traffic to other customers.

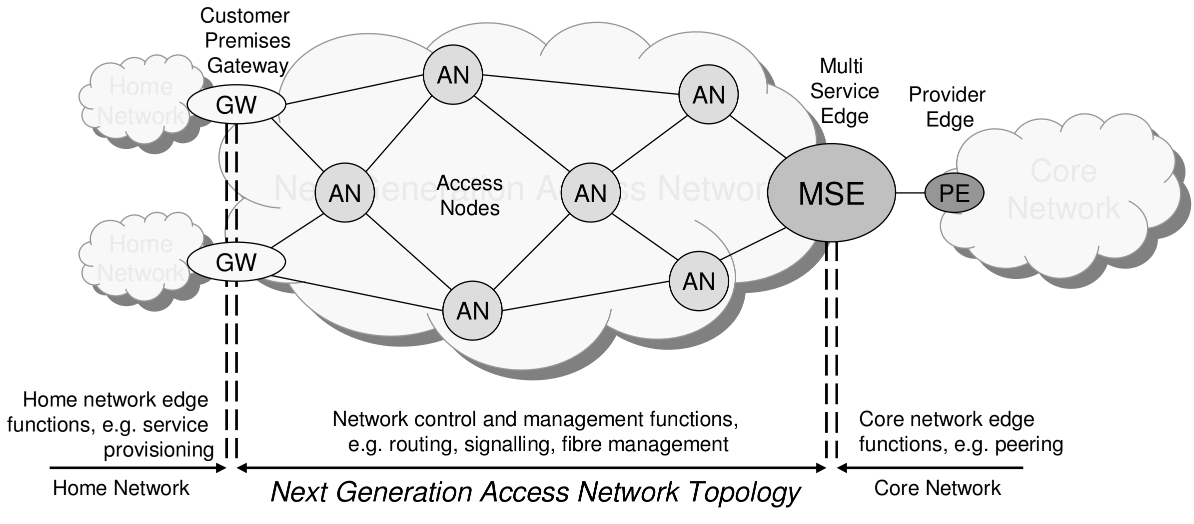


Figure 1: The target network of a next generation access network depicting a high degree of mesh.

In the context of AON the control plane should be interpreted as the functions that control allocation and maintenance of data plane resources which in turn allow data traffic flowing from a network source to a network destination. Examples of these functions can be signalling and routing functions. A data plane should be interpreted as the encoding of transmitted data on network links and the forwarding of the data through network nodes. The management plane handles configurations and keeps track of the state of e.g. data plane resources.

The above requirements need to be met by the next generation access control and management plane protocols. This means that e.g. signalling have to result in single or multiple data plane technology allocation along a path that optimises the network and through nodes that support one or more of these technologies. Routing protocols should be able to disseminate compactly encoded information that describes unique features of different technologies, and management protocols should configure and exchange link information of different technologies. All of these should take place in an orderly fashion in response to e.g. a service provisioning request with a certain QoS demand and of a certain technology layer, or a rapid change of the number of links in the network.

The main requirement for nodes of ALPHA reference AON is multi-technology data plane support. This means that the topology depicted could have nodes of a single technology or different technologies. If the nodes are of different technologies there has to be a certain hierarchy, i.e. an Ethernet layer is a client of an optical layer. Such hierarchies can either be implemented through nodes of a certain technology hierarchically connected to nodes of another technology, or through single nodes that can support different data plane technologies. There can also be a combination of single data plane technology nodes and multi data plane technology nodes.

Another requirement is multi-layer services, e.g. IP, Ethernet, pure optical, or dark fibre services. If this service should be terminated by another node than the customer premises gateway, i.e. within the home network, also the customer premises gateway has the possibility of multi-technology data planes.

3.2 WDM 10G TDM PON system

The wavelength division multiplexing (WDM) 10G time division multiplexing (TDM) PON system is foreseen as a potential next generation of XG-PON systems.

We propose here to add the WDM dimension to increase the connectivity of the network and to offer a larger flexibility in terms of bandwidth allocation that could go from a time shared bandwidth on one wavelength to a full wavelength capacity for dedicated services.

Figure 2 shows a WDM 10G TDM PON network model and the specifications of the network. This is the reference architecture studied in ALPHA WP2.

Basically, the WDM 10G TDM PON proposed in the figure 2 comprises:

- a cascade of passive couplers to provide easy flexibility and upgradeability,
- a central bidirectional amplification stage, called extended box, to manage the power budget in this WDM configuration,
- a burst mode transmitter and synchronous receiver at the optical network unit (ONU) side,
- a burst mode receiver and linear transmitter at the optical line terminal (OLT) side.

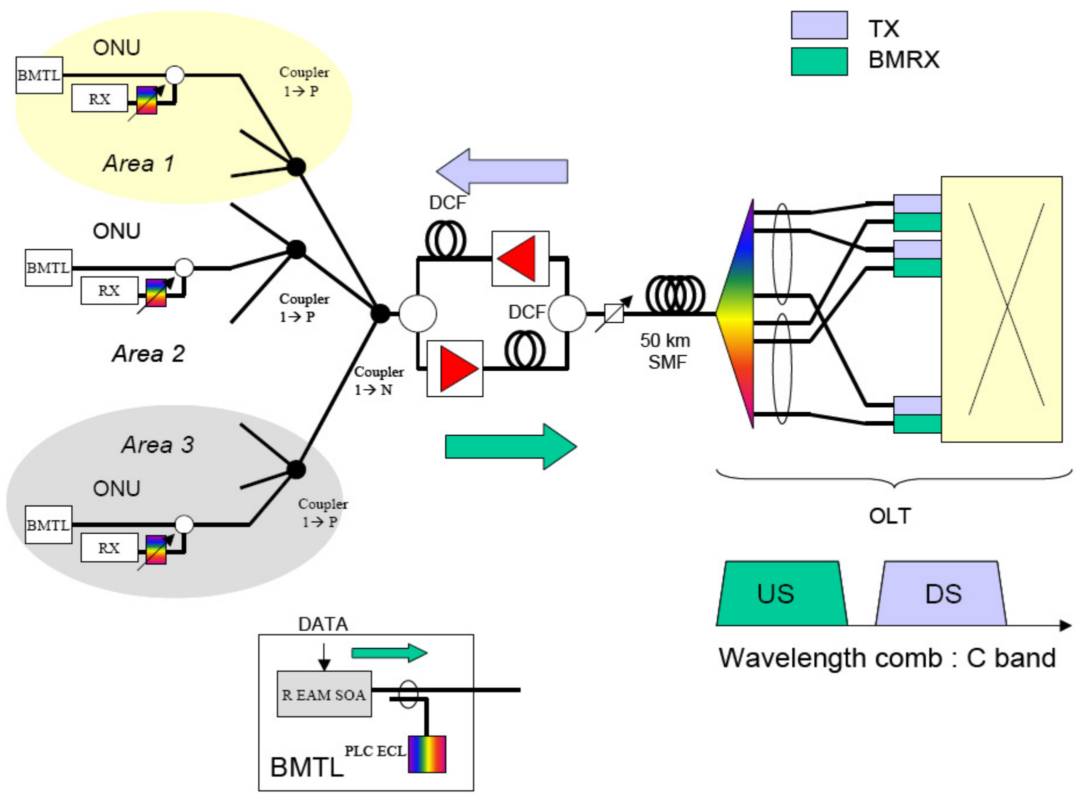


Figure 2: WDM 10G TDM PON reference network as studied in WP2

3.2.1 ONU key components

The ONU envisaged in the WDM 10G PON system comprises:

- a tuneable laser, an external modulator (bi-fibre: electroabsorption modulator (EAM) or single fibre type: R EAM) and one semiconductor optical amplifier (SOA) gate (included or not to the external modulator) for a burst mode operation for the transmitting part,
- a linear receiver compliant with radio over fibre (RoF) transmission for the receiving part.
- the electronic part to manage the i/o traffic.

For the transmitting part we adopted an existing external cavity laser on a planar lightwave circuit (ECL PLC) tuneable source + R EAM SOA modulator technology that could be in a next future an integrated new source including a tuneable laser, an external modulator (EAM or Mach-Zehnder interferometer (MZI)), and an optical gate.

The receiver site will utilize commercially available photodiodes with an objective in terms of proof of concept through the test of a real RoF connection.

3.2.2 OLT key components

There is no big different compared to a classical OLT designed for a 10G GPON solution except that the transmitters and receivers are coloured and aligned on the C band grid to be compliant with the optical mux/demux used to aggregate all the wavelengths on a same fibre.

The key component of the OLT is the burst mode receiver. It is possible to use either an off-the-shelf burst mode receiver or a proprietary one. The new specification with respect to a burst mode receiver for a GPON or a EPON system, is a higher tolerance to an optical signal to noise ratio.

3.2.3 MAC protocol

The combined use of the time and wavelength dimensions as shared resources will require new media access control (MAC) protocols and mechanisms. These protocols and mechanisms must be considered together because their goals, requirements, and constraints depend on the specific physical characteristics of each architecture.

For example a futuristic PON, in which each ONT has a fast tuneable laser, would require dynamic time/wavelength bandwidth allocations controlled by sophisticated (and complex) mechanisms.

In the frame of the ALPHA project we have envisaged two types of mechanisms: one transported on a separate wavelength, and one transported in downstream control packets. The wavelength at the ONU side is adjusted regularly, transparently to the user, to offer the larger bandwidth at any time, without risking a service interruption for the other clients already connected to a service.

4 Standardisation organisations and process

This Chapter provides an overview on the relevant standardisation organisations, respective technology definitions and roadmaps as well as on the standardisation process and its applicability within ALPHA.

4.1 Overview of standardisation organisations

The main standardisation bodies dealing with optical access networks are ETSI, FSAN, ITU, BBF and IEEE.

ETSI (European Telecommunications Standards Institute) early starter of the PON technology till 1994 withdrew from specification and is now centred on interoperability Plugtest™ events and environmental conditions. This aspect has to be carefully addressed since the energy efficiency constraints are becoming more and more important, especially since FT signed the EC BroadBand Code of Conduct (a.k.a. BBCoC) on access network power consumption.

FSAN (Full Service Access Network) started in 1995 as a group of ILEC operators aiming to go as fast as possible to a Full Service Access Network. Based on a good will basis with help of major vendors, it is searching consensus, writing "white papers" on technologies that are carried by some of its members into ITU-T. A-PON, B-PON, G-PON and XG-PON have been directly developed by ITU-T on material brought in from FSAN. Finally FSAN speeds up development of the industry helping to focus the requirements by common technical specifications, once the basic technology has demonstrated its maturity in test events and showcase co-organized with diverse SDOs.

ITU-T (International Telecommunication Union) in Q.2/15 (question 2/study group 15) addresses full scope of optical access transmission solutions PON as well as point to point solutions. ITU-T is also working towards convergence of management of optical systems through unified remote ONU management channel and information base (OMCI aka as G.988). To help simplifying the available features for operations & management feature, the access network operator, ITU-T has also been pioneering from 2005 on energy efficiency in optical technologies, which resulted in several documents and features now embedded in the systems.

BBF (Broadband Forum) is the latest starter that concentrated on network architectures enabling the smoothest migration from copper based transmission to optical. It inherited from interoperability preliminary work of FSAN and ITU-T and is now heading towards an ONUs conformance of asserting process by independent test labs. But compared to copper where interoperability issues are on the physical layer, on optics, testing of interoperability is difficult because each architecture has its own OMCI implementation.

IEEE 802.3 (Institute of Electrical and Electronics Engineers) is a working group since 1972 defining the physical layer and the MAC of wired Ethernet. The fibre aspect is considered over point to point and point to multi-point architectures. E-PON and 10G E-PON have been directly developed by this working group.

4.2 Technology definition & Technological roadmap

4.2.1 ITU-T

At 22nd October 2010, ITU-T approved the full set of G.987 series recommendations (available from November 2010). They are based on the requirements and implementation choices retained by the FSAN under the name of XG-PON1 (an asymmetric 10G-PON solution), after a 4 years investigation period. Starting from that time developers and manufacturers have been able to design a full set of enabling components and building blocks necessary for building complete systems. It is anticipated that early G.987 compliant designs will appear on the market in 2H2011, so it is already time to define all necessary test cases to assert sound working and interoperability.

The FSAN community believes that within the XG-PON1 development period a significant cost gap will remain between 10Gbit/s burst mode devices required by IEEE and 2.5Gbit/s ones easily derived from GPON. However, the community anticipates that line rate symmetry of XG-PON1 might be a limitation in some years time depending on the XG-PON1 use case.

Therefore, after the co-existence capability on a common optical plant embedded in the XG-PON technology, an investigation of the capability to have multi-rate scheme enabling XG-PON1 and an extended XG-PON2 working without additional wavelength filters, through time division multiple access (TDMA) techniques. XG-PON2 could feature 5Gbit/s upstream or possibly 10Gbit/s. The operator would only have to replace the PON OLT interfaces where XG-PON2 is requested and install an XG-PON2 ONU at the requesting end user. All other G-PON and XG-PON1 users would remain unaffected. After several meeting addressing the technologies for XG-PON1 enhancements, solutions have been identified with low uncertainty level and technology developments required have been consolidated.

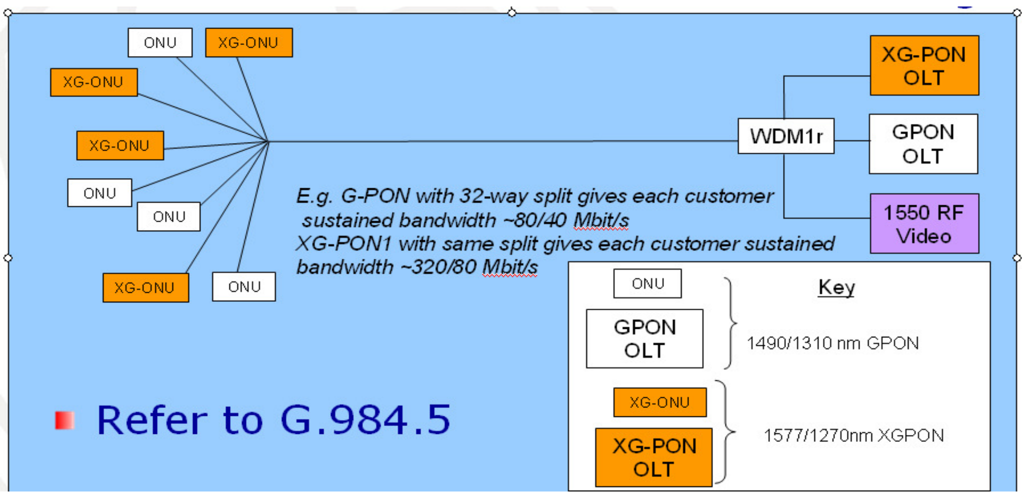


Figure 3: Schematic view on coexistence of GPON and XG-PON

In order not to delay XG-PON1 building blocks developments, FSAN decided to put a hold on all XG-PON1 enhancement options.

In parallel, FSAN is working on a further NG-PON2 generation at first intended for new optical plants, but now reoriented to be compatible with existing fibre plants - or optical distribution network (ODN). NG-PON2 is supposed to be able to deliver at the ONU a sustainable bit rate of 1Gbit/s through an aggregate line rate at the output of the OLT of

40Gbit/s. Early operator requirements are supposed to be consolidated and gathered in an FSAN white paper in 2Q2011. The objective is to have a recommendation available for systems ready in 2015.

At the same time ITU-T SG15/Q.2 is concentrating on extensions for XG-PON1 that enables a higher available optical power budget in order to facilitate network consolidation (by-passing copper requested DSLAM point of presence with OLT location higher in the network). In order to be compatible with architectures where both GPON and XG-PON are "reach extended", different reach extenders are under study (see Figure 4).

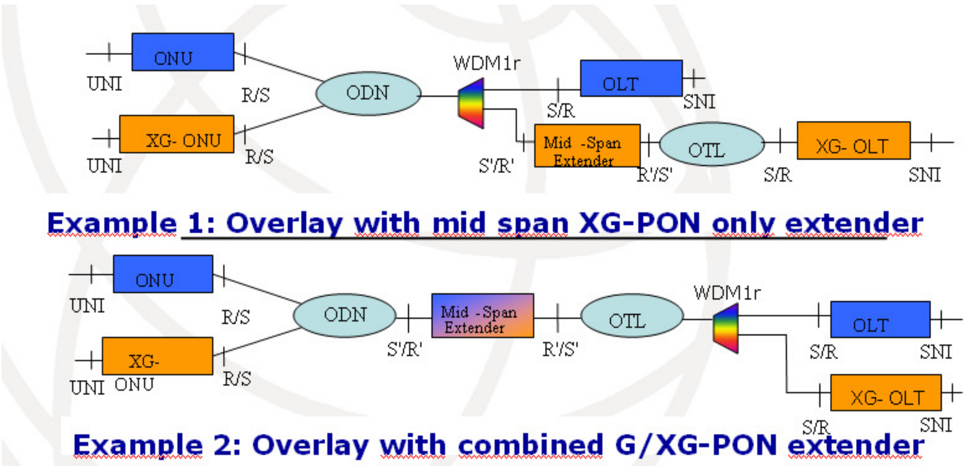


Figure 4: Various strategies for using reach extenders with GPON and XG-PON

Finally, new initiatives about WDM technologies in the access are emerging in ITU, but also in two forums reachable through "LinkedIn", WDM PON forum (LG-Ericsson) and the Open Lambda initiative (OλI Leadership by NSN) fuelled by vendors that haven't been so far able to find a market for their developments. Although unsuccessful so far, their outcomes might set up a blueprint for optical wavelength grid in the access and therefore must be monitored.

As a conclusion, see the roadmap of PON systems evolution as foreseen by FSAN in Figure 5.

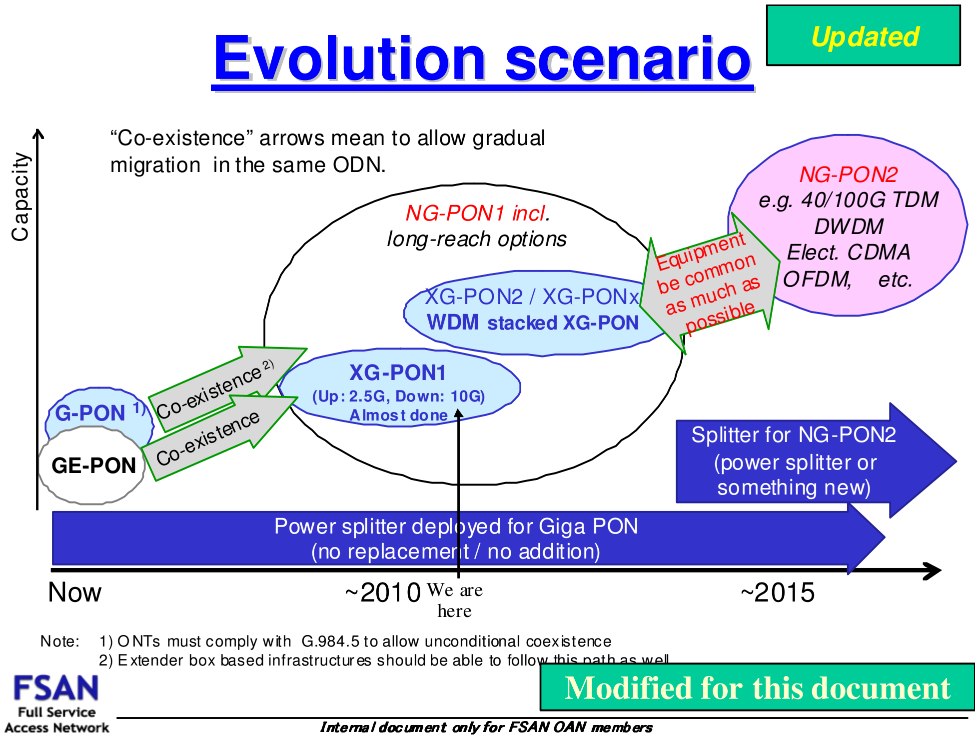


Figure 5: FSAN roadmap defined by operators

4.2.2 IEEE

In September 2009, the work of the IEEE P802.3av 10G-EPON Task Force ended as the standard defining IEEE 10Gbps optical access systems, IEEE Std 802.3av^{TM} was approved.

Below we summarize main characteristics of this standard.

Asymmetrical and Symmetrical bitrates are studied:

- 10 Gbit/s for downstream / 1 Gbit/s for Upstream under the name PRX--
- 10 Gbit/s for downstream / 10 Gbit/s for Upstream under the name PR--

For each of those cases, the wavelength allocation is the same for the downstream which is at 1577 nm in the band 1575 nm – 1580 nm. It was stated, that OLT transmitter laser should be an EML (electroabsorption modulated laser) because of strong chromatic dispersion effects (20ps/nm/km) at this wavelength.

For the upstream, different choices have been offered:

- Asymmetrical PRX-- upstream: 1310nm +/-50nm; the same as G-EPON
- Symmetrical PR-- upstream: 1270nm +/-10nm; this window gives lower dispersion effects at 10Gbit/s which permits to keep low cost lasers at ONU.

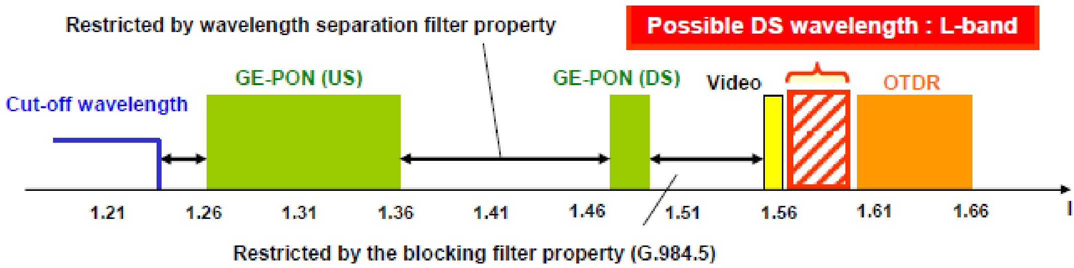


Figure 6: Wavelength plan for IEEE standardised PON systems

Optical Budgets available:

Three classes of optical budgets are available for 10G-EPON (symmetrical (PR--) and asymmetrical (PRX--) as presented below:

- PR(X) 10 : 5 dB to 20 dB for a reach of 10 km and splitting ratio of 1:16
- PR(X) 20 : 10 dB to 24 dB for a reach of 20 km and splitting ratio of 1:16
- PR(X) 30 : 15 dB to 29 dB for a reach of 20 km and splitting ratio of 1:32; also PR30 assure compatibility with G-PON class B+ infrastructure (13 dB – 28 dB). To provide coexistence in overlay of the two technologies G-PON class B+ / 10GE-PON PR3 it is necessary to insert in front of the OLT a WDM mux/demux (1 dB loss); This is not possible with PRX-- because of a same upstream wavelength allocation for G-PON and PRX-- 10GE-PON (1310 nm).

Above budget categories may be assigned various split ratios and reach classes, according to matrix presented in Table 1.

Table 1 – Optical budget classes for 10G-EPON systems

	1:16	1:32
10km	PR10 , PRX10	PR20 , PRX20
20km	PR20 , PRX20	PR30 , PRX30

As shown in the next figure 7, to reach the highest budget (PR(X)30), an avalanche photodiode (APD) receiver is considered at the ONU in association with a high power EML at the OLT. Otherwise, a PIN receiver is proposed at the ONT. The use of FEC (forward error correction is also considered as an option to improve the transmission performances.

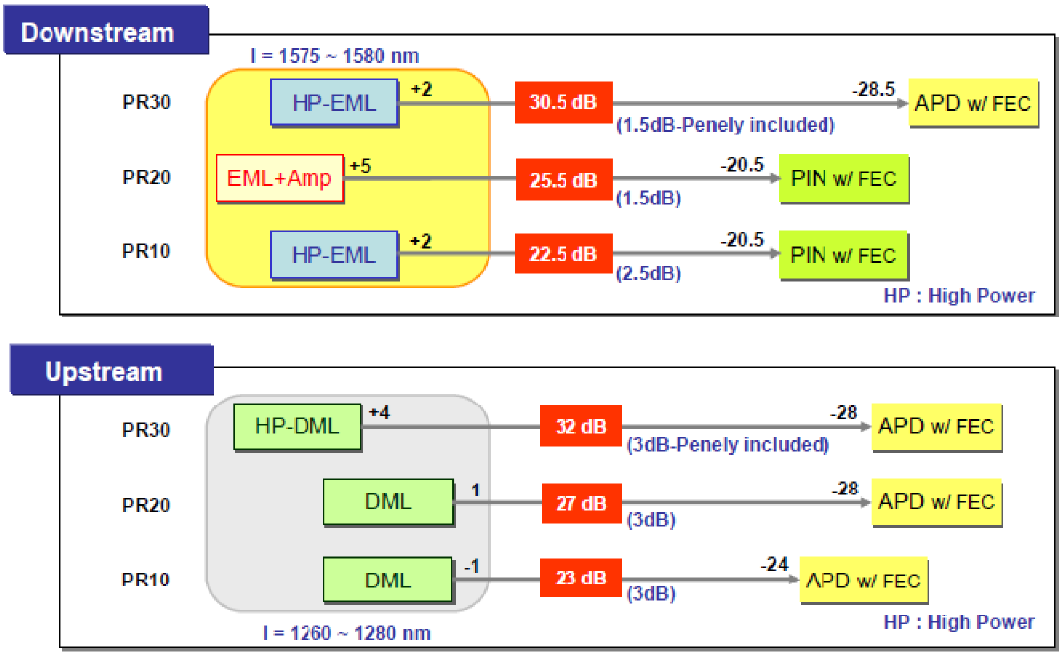
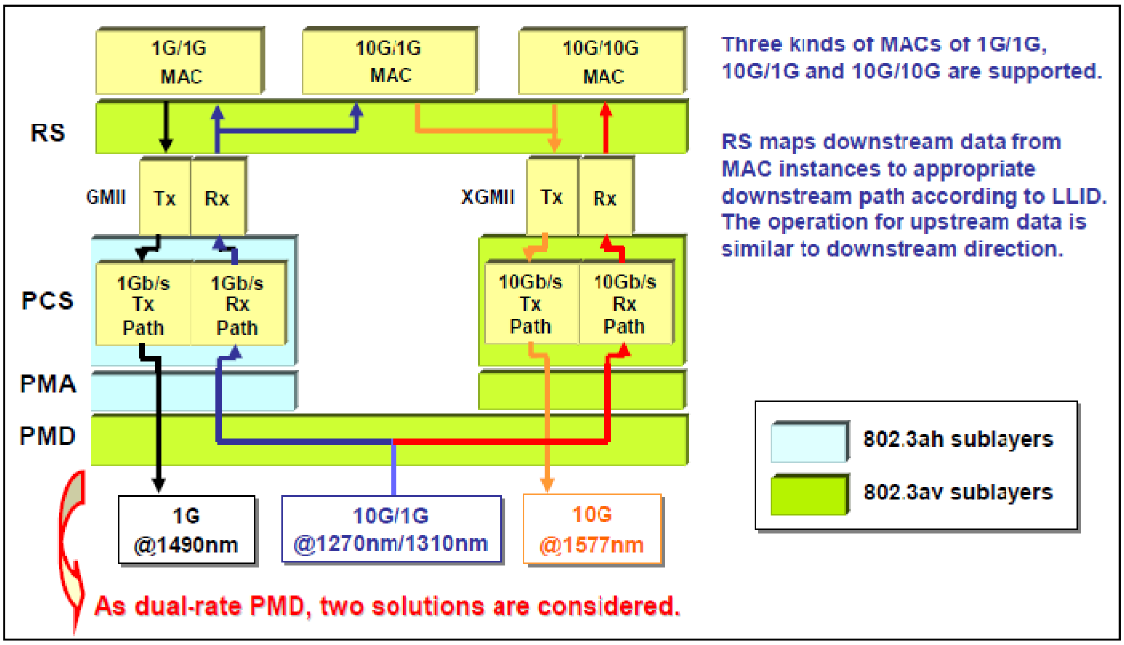
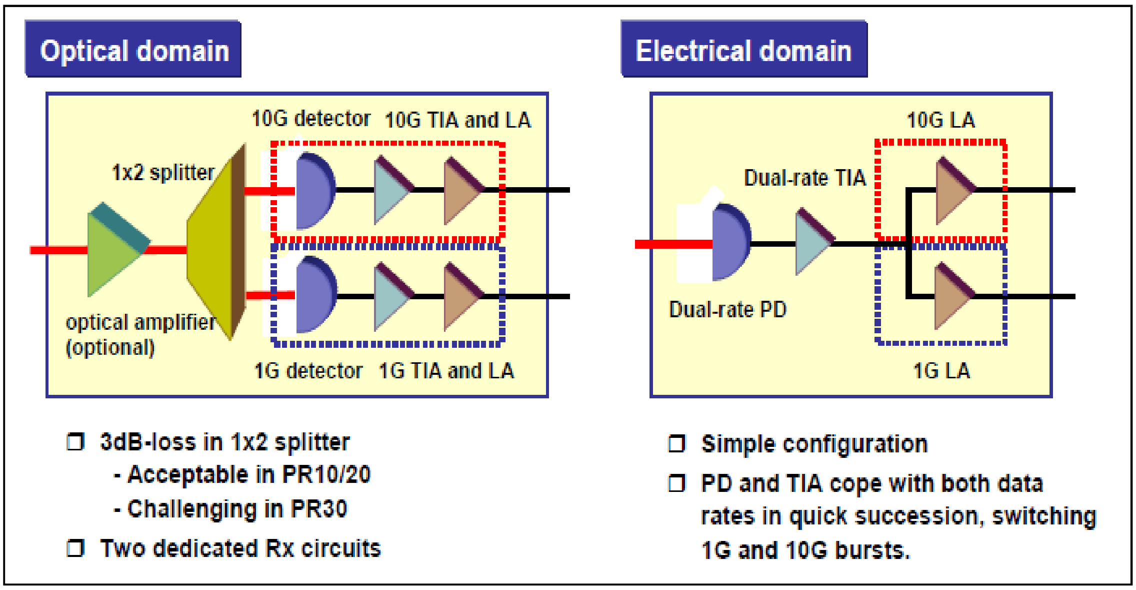


Figure 7: Graphical presentation of building blocks for various 10G-EPON interfaces

In order to support the co-existence of 1G-EPON and 10G-EPON systems on the same optical infrastructure, IEEE defined 10G-EPON equipment able to manage 1G-EPON systems (via MAC components for 10G/1G, 1G/1G and 10G/10G). The upstream reception has to be able to support 1Gbps and 10Gbps bursts. Concept of 1G-EPON + 10G-EPON co-existence is presented at Figure 8 below.



a) *1G-EPON managed by 10G-EPON systems*



b) Upstream 10G-EPON burst reception channel: dual rate management (1G and 10G)

Figure 8: Concept of 1G-EPON + 10G-EPON co-existence on the same fibre infrastructure

4.2.3 Differences between ITU-T and IEEE standards

The main differences between NG-PON1 systems defined by IEEE and ITU-T lie in interoperability, migration/co-existence, and optical budget extension.

After an important action in the definition of recommendations allowing GPON interoperability, the FSAN will continue in this way in order to assure XG-PON1 interoperability of PMD and TC layers. Moreover, FSAN operators took into account the architectures defined by the BBF TR-156 as any migration from GPON towards XG-PON1 will impose to keep to them.

IEEE launched a new task force (IEEE P1904.1) in charge of defining the standard for service interoperability in Ethernet passive optical networks (SIEPON task force). The purpose of this standard is to build upon the IEEE 802.3ah (1G-EPON) and IEEE 802.3av (10G-EPON) and data link layer standards a system-level and network-level standard, in order to propose a full “plug-and-play” interoperability of the transport, service and control planes in a multi-vendor environment. The aim is to describe the use of OMCI for the management of IEEE EPON (1G and 10G) systems to be mapped in ITU-T G.988. Indeed, recently ITU-T Q2/SG15 has integrated in the annex to G.988 two frame formats for the transport of OMCI messages on IEEE EPON systems. Moreover, IEEE PON technology manufacturers undertook an effort in BBF (WT-200) to define conditions to meet an interoperability level similar to the one obtained for ITU-T recommendations.

In order to perpetuate the operators’ optical infrastructure, ITU-T defined a solution for smooth migration and co-existence of GPON and NG-PON solutions by conserving GPON line cards. But it is not the case of IEEE which defined a solution where the co-existence of EPON and 10G-EPON ONUs is possible but involves the replacement of EPON line cards by a dual rate one. Finally, it could be possible to consider GPON and 10GE-PON PR30 co-existence by wavelength overlay (the maximum optical budgets of the B+ class GPON and 10GE-PON are 28 dB and 29 dB, respectively).

Only ITU-T defined some additional tools in order to allow an increase of the optical budget, as the extender boxes (mid span extender) defined by ITU-T G.984.6.

All the differences and similarities between ITU-T and IEEE standards have been presented in Table 2.

Table 2 – Summary of parameters for various ITU-T and IEEE access standards

<table>
<tr><th>Name (Sorted by class)</th><th>Downstream Data bitrate (OLT→ ONU Gbit/s)</th><th>Upstream Data bitrate (ONU →OLT Gbit/s)</th><th>λ_{down} (OLT→ ONU (nm))</th><th>λ_{up} (ONU→ OLT (nm))</th><th>Optical Budget (dB)</th><th>Splitting Ratio</th><th>Reach</th><th>Approved by organization/date</th></tr>
<tr><td>IEEE 802.3av-PRX10</td><td rowspan="6">10,3125</td><td rowspan="3">1,25</td><td rowspan="8">1577 (2/+3)</td><td rowspan="3">1310 +/-50</td><td>5 - 20</td><td>16**</td><td>10 km</td><td rowspan="6">IEEE/Sept 2009</td></tr>
<tr><td>IEEE 802.3av-PRX20</td><td>10 - 24</td><td>16**</td><td>20 km</td></tr>
<tr><td>IEEE 802.3av-PRX30</td><td>15 - 29</td><td>32**</td><td>20 km</td></tr>
<tr><td>IEEE 802.3av-PR10</td><td rowspan="3">10,3125</td><td rowspan="4">1270 +/-10</td><td>5 - 20</td><td>16**</td><td>10 km</td></tr>
<tr><td>IEEE 802.3av-PR20</td><td>10 - 24</td><td>16**</td><td>20 km</td></tr>
<tr><td>IEEE 802.3av-PR30</td><td>15 - 29</td><td>32**</td><td>20 km</td></tr>
<tr><td>ITUT-I XG-PON1</td><td rowspan="2">9,95328</td><td>2,48832</td><td>N1 : 14-29
N2 : 16-31
E1 : 18-33
E2 : 20-35</td><td rowspan="2">Up to 1023 (logically)</td><td>20-60 km</td><td rowspan="2">ITU-T/June 2010</td></tr>
<tr><td>XG-PON2</td><td>9,95328</td><td>TBC</td><td></td><td>20-60 km</td></tr>
</table>

(**) Minimum specified by the standard, In IEEE keep in mind that manufacturers implementations can go beyond the standard (it is the case for IEEE 802.3ah standard for E-PON, where the splitting ratio is specified for 1/16 with implementations of 1/32 as it is the case in Japan)

4.3 Standardisation process and its applicability within ALPHA

Despite good knowledge of the technologies and standardisation bodies described above, standardisation for individual organizations is still a complex issue. We will here exemplify the difficulties – some of which were experienced by ALPHA partners.

No matter which standardisation body is targeted one has to understand the principal written and unwritten rules of standardisation work. Since standards are expected to support the development of competition and compatibility, any standards have to fulfil some requirements, namely:

- Component/methods to be standardised have to be available from various sources. This may not always be a formal requirement, but it is indeed a de facto requirement.
- Any intellectual property rights (IPRs) comprised in standards should be offered to third parties at non-discriminatory basis.
- Standard documents should be agreed upon by respective standardisation body members over the course of revision and formal voting process.

Listed above are screening criteria for technologies which may be standardised by either creating new standards of incorporating them into existing standards. Taking into account that the vast majority of work in ALPHA project was research at very early stage one may note that results of such a work (no matter how promising) cannot fulfil major conditions of technology to be standardised.

While looking deeper into the structure of various standardisation bodies one may note that the activity of some of them overlaps which makes it sometimes difficult to make decision on which organization should be targeted. Moreover various standardisation bodies keep different status – some of them being national (eg. BSI, DKE, JSA), international non-governmental (e.g. ISO, IEC, CENELEC, ETSI) and 'industrial' (e.g. FSAN, BBF, IETF).

Depending on type of organization participation is either formally restricted and limited (national and international level) or members are being charged yearly fee for membership. Furthermore, being successful in standardisation often requires identifying and getting acquainted with key organisations and/or persons which may function as informal leaders. While it is relatively simple (but perhaps rather expensive for a small player) to become a member of a standardisation body, the above criteria make it very difficult to become effective in any standardisation body during lifetime three year if consortium partners are not members of the body at that time.

Small organisation may have resource problems in terms of economy and time to drive a solution through to a standard. On the other hand, large organisations with plenty of resources may encounter internal problems in terms of bureaucracy or the fact that their research departments and product units may have different standardisation agendas – and it is rarely the research department that gets the final word. Last but not least, due to long lasting formal procedures it is difficult to propose and maintain any complex technical solution over the lifetime of any European project. Full time preparation of a standard normally takes at least three years while acceptance of any revision based on submitted technical proposal usually must be in line with document maintenance plan (which takes place each few years). This in turn makes it very hard to complete any activity of that kind over the course of a three year European project like ALPHA.

5 Standardisation activities in access networks

The summary of ALPHA standardisation activities in access networks are presented here.

5.1 NG-PON2 proposal

To bring a significant benefit compared to "older" technologies, NG-PON2 shall become a "must-have" solution by delivering a bundle of services over a sustainable downstream 1 Gbit/s on an ONU and for upstream 0.5 to 1 Gbit/s. The line rate or aggregate bit rate for such a solution depends on the multiplexing choices. The previous optical access solutions were based on a PON architecture using time resource allocation, an ODN based on passive and achromatic optical splitters, and a wide wavelength (diplex) multiplexing for up- and down-stream transmission.

These properties are derived from the necessity of deploying fibre cables inside ducts where space is limited due to the coexistence of copper and fibre cables. The NG-PON2 basic requirements could be based on a similarly passive optical infrastructure with 64 or more terminations sharing over 40 Gbit/s aggregate capacity at the central office equipment interface. The basic reach is also conditioned by the typical length of the ducts between the central office and the optical terminations. This is the reason why a 20 km basic reach could be proposed for the NG-PON2 and 40 km as a preferred reach. Nevertheless, many operators consider the central office "consolidation" that the fibre offers by increasing the eligibility area (low signal attenuation of fibre vs. copper) thanks to maximum haul extension that reaches up to 60km or beyond. This extended reach is possible with or without a mid-span reach extender. The large scope of potential network "users" (residential, business, SME, backhaul) and "consolidated" network come with a requirement for solutions assuring a higher service resiliency.

The enhanced security (≥ XG-PON1) and high service availability (e.g dual-homing, fast-protection) should be included inside a range of cost effective resilience option. These options allow each operator to build the best suited service architecture for their specific market and geography. The low power consumption issue is also a driver a choice for NG-PON2 technological choice and a working mode to be considered for the ONT.

The basic requirements of NG-PON2 also considered that the legacy ODN compatibility is desirable. This issue show that operators want to be conservative with their optical splitter based infrastructures. The time frame for NG-PON2 deployment is for after 2015.

France Telecom elaborated inputs to FSAN [1], [2] incorporating many proposals of network architecture solutions aiming to offer connectivity flexibility. Proposals included hybrid PON (static or tunable WDM + TDM) fitting into evolution scenario presented in Figure 8.

5.2 IETF multi-layer control plane

The unified control plane candidate chosen to control the access and aggregation network described in section 3.1 was the IETF generalized multi-protocol label switching protocol suite (GMPLS), i.e. GMPLS would be used as the basis for needed extension of a multi-layer Ethernet architecture. The GMPLS protocol suit was chosen because it has benefits when it comes to e.g. an established focus on multi-layer architectures, traffic engineering, migration/inclusion of other data plane technologies (e.g. MPLS, dynamic OTNs). Some elements of work results might be considered as parts of possible future standards. Initially we identified results of work on GMPLS controlled multi-layer (ML) Ethernet, as possible input to standardisation bodies. The solution utilizes and extends existing protocols standardised by the Internet Engineering Task Force (IETF), such as OSPF-TE (open shortest path first – traffic engineering, defined in RFC4203) and RSVP-TE (resource reservation protocol - traffic engineering, RFC 3209). The extensions considered as suitable for standardisation include at least the following:

- **ML Ethernet layer definitions and procedures**

  OSPF-TE contains definitions for each data plane type, inside the interface switching capability description (ISCD) object. This object was extended to support the new multi-layer Ethernet data plane. This includes two parts, definition of the ML Ethernet switching capability constant and the switching capability specific information for the data plane. The switching capability specific information was defined as a series of rules which describes the attributes of the Ethernet port. This information is vital for function of the GMPLS controlled Ethernet data plane.

  Another standardisation goal is the procedure for handling the information provided in the ISCD definition, which includes sample methods for detecting Ethernet frame changes and methods for creating and announcing forwarding adjacency label switched paths (FA-LSPs).

- **Label definition for ML Ethernet**

  Resource allocation is in GMPLS done by the RSVP-TE protocol and during its operation the protocol needs to have information about what resource to allocate. This information is commonly known as a label, and such a label does not exist for ML Ethernet and was therefore defined and could be standardised.

- **Path request object extensions in the PCEP protocol solution**

  The path computation element communication protocol (PCEP) is used for communicating with a path computation element (PCE), primarily for requesting paths through a GMPLS enabled network. Included in the protocol is the ability to request several disjoint paths from the same source and destination and is used for network recovery.

  The current definition for requesting such disjoint paths are inflexible as it only provides attributes for requesting fully disjoint paths, which presents a problem in the access network where fully disjoint paths may not be possible. The protocol was therefore extended to support requesting a ratio of “disjointness”, defined as a new protocol request sub-object. This extension could be useful in multiple areas and it would therefore be both suitable and useful to standardise this as an extension to the PCEP standard (RFC5440).

All the GMPLS work in ALPHA was based on existing standards and on the proposed extensions described above. None of these extensions were brought to the IETF (which moreover was never planned), but the work has been published, and any organisation can formally propose them in the IETF. Indeed, the idea of collapsing the access and the distribution network into one entity *will* require extensions similar to those proposed above.

5.3 XMD Multi Source Agreement (MSA)

One of the main goals of opto-electrical (OE) component development fulfilled within ALPHA project addressed OE module standard evolution. OE component/module standard evolution is mainly driven by three factors: Compactness improvement, power consumption, and cost reduction. For applications identified within the ALPHA project (RoF systems for WLAN & WiMAX, NGPON), the module development was heavily based on standardisation evolution.

Considering standardisation trends observed in high bit rate modules for 10Gb/s application, SFF (Small Form Factor) TOSA (Transmitter Optical Sub Assembly), and ROSA (Receiver Optical Sub Assembly) formats will be more and more implemented in new products/modules. This evolution has been reflected first in digital applications where TOSA and ROSA modules, as compliant with the XMD (10 Gbit/s miniature device) MSA standard, have been commonly accepted regrouping the component industry market leaders.

3S Photonics participated to MSA technical meetings with main Japanese component manufacturers providing notable input to technical group work.

XMD MSA outcomes have been implemented in ALPHA related activity of 3S Photonics starting with the first version of a high performance analogue transmitter module fabricated in order to assess performances requirements of partner’s demonstrator. This first version used Butterfly package (which is up to now the package standard), and such modules have been packaged, tested, and delivered to partners. For the second step a compact TOSA version (according to new standard) has been considered. The package format has a very high compactness comparatively to Butterfly one: 8.4x5.6x5.5mm instead of 30x12x8mm for standard Butterfly package (the TOSA package volume is less than 10% of the Butterfly package). Such analogue modules in TOSA format have moreover been packaged, tested, and delivered to partners. Performances demonstrated within the ALPHA project through partner evaluation are equivalent to the previous one. To our knowledge this is the first analogue TOSA (SFF) module developed! More recently ROSA modules have been designed with package format similar to TOSA.

6 Conclusions

Over the course of ALPHA project some access technologies were identified as reference technologies. Choice of technologies was based not only on the basis of technological advancements, but also was supported by techno-economic analysis showing its economical feasibility prospects for the future.

Since it is well understood that the only way for any new technology to be worldwide accepted is by standardising it, the consortium members took efforts to promote the selected ALPHA access network reference architectures in respective standardisation bodies. Considering standardisation was an integral part of the work on access networks within the project, and three such examples were given in this Deliverable:

- ALPHA concepts by means of key parts of the WDM/TDM PON reference architecture were presented during the FSAN standardisation meetings in November 2009 and August/September 2010.
- Standardisation was actively supported by hardware manufacturers involved in the ALPHA project, particularly by 3S Photonics. By closely following the XMD MSA standardisation activity 3S Photonics was able to transfer their results to the respective technical workgroup while at the same time implement and productify the most recent standardised technology (SFF TOSA).
- The GMPLS work by Acreo on a unified control plane for a collapsed access/distribution network was based on existing standards, and a number of specific extensions have been proposed and published.

Furthermore, the Deliverable contains an overview of the important optical access technologies and standardisation bodies active within the area; particularly FSAN/ITU and IEEE which are the most important in the ALPHA context. Also, a description of practical issues in the standardisation work was given to exemplify that deep understanding of the area and the standardisation bodies is the first step for successful standardisation.

Appendix: P-OADM metro network

As indicated in section 3.1 and also further discussed in ALPHA Deliverable D1.3 it is very likely that the access and metro/distribution networks will be much more converged than what is the case today concerning data plane, control plane, practical operations etc. To achieve such a converged scenario standards and interoperability are crucial. Long term evolution (LTE) networks are MPLS enabled in the backhaul, so in order to achieve fixed-wireless convergence in the access and distribution networks a packet network is required. In this appendix a solution for a metro network is described that could handle such convergence scenarios. Moreover, future standardisation activities are outlined here.

1. Introduction

The introduction of 10G xPONs systems in the access network opens new opportunities for a new generation of 10Gbit/s metro packet network.

The ALPHA project has in the network roadmap (D1.3) integrated a scenario where a packet add-drop multiplexer (P-OADM) technology could be part of this extended access network model: a WDM 10G TDM PON (Section 3.2 in this deliverable) for the access part and a p-OADM technology for the metro (or distribution) area.

The principle of the P-OADM technology is based on the following assumptions:

- optical transparency is exploited to bypass nodes in the optical domain in a ring topology,
- packet switching/transport granularity is adopted to exploit statistical time and spectral multiplexing techniques, to optimise the resource allocation.

This technology is converging two technologies: a reconfigurable optical add-drop multiplexer (R-OADM) technology exploiting mainly the optical transparency, but in a circuit mode, and an Ethernet technology operating at a packet switching granularity, but demodulating all the packets at each node.

Figure A1 shows the ring metro network envisaged, Figure A2 describes the structure of the P-OADM studied, and Figure A3 shows the data and the control protocols:

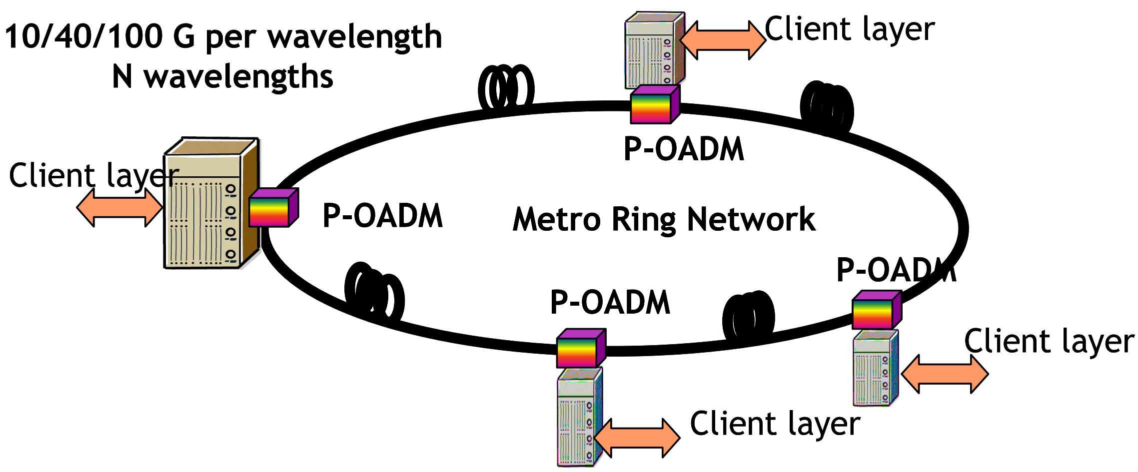


Figure A1: Ring metro network with nodes including two parts: a legacy electronic interface and an optical interface called: Packet –OADM

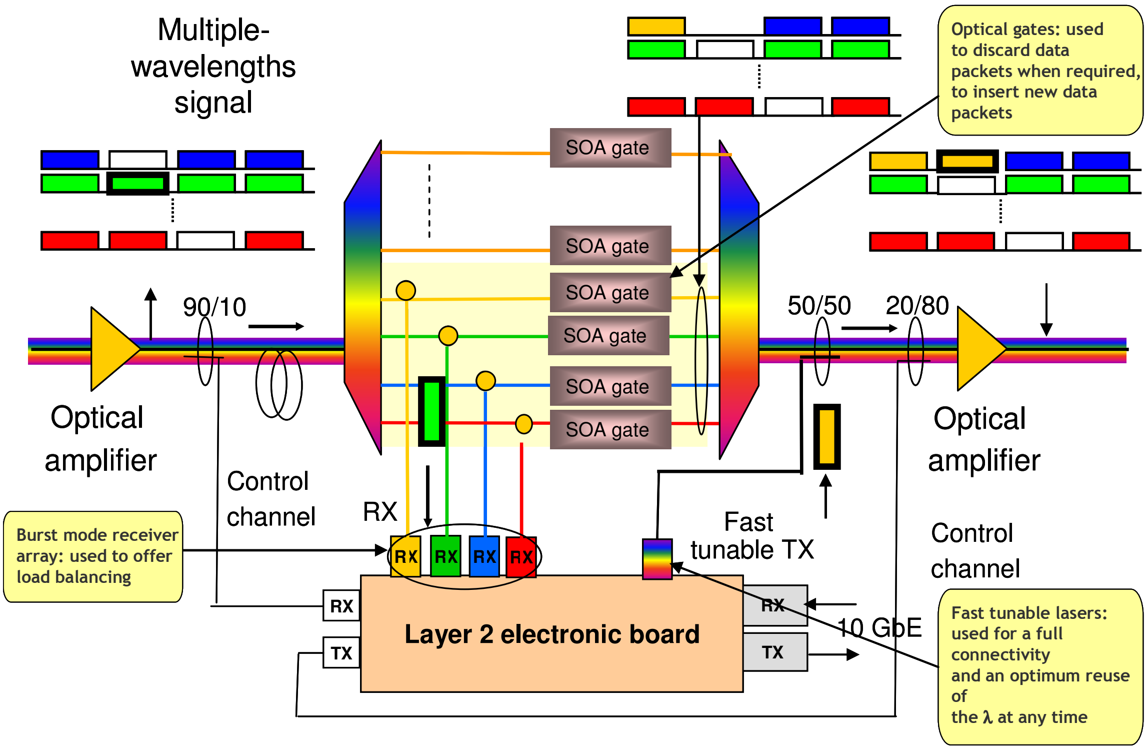


Figure A2: Structure of the P-OADM

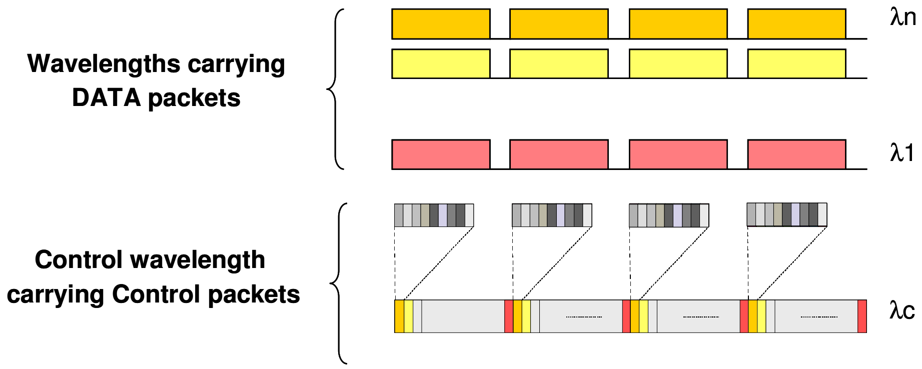


Figure A3: DATA and control protocols

2. Building a logical mesh topology on the top of a physical ring topology

To reduce the end-to-end latency, extremely sensitive in this part of the network, and because a part of the traffic stays within the ring, we propose to adopt a mesh topology on the top of a physical ring topology. If two nodes want to communicate, they establish a direct virtual connection without the need to go into a hub node that centralises the connections. This assumption does not exclude a hub operation, but offers the possibility to establish direct node to node connections.

The ring nodes include two main building blocks: one electronic interface interconnected to the client layer, and an optical interface for the packet-OADM. The packet-OADM can drop, insert new packets, and manage transit traffic directly in the optical domain (without any optical to electrical to optical (OEO) conversion). The advantage of this approach is to don't process all the incoming packets: only the add/drop packets are processed.

3. Packet-OADM functions

The packet-OADM structure described in Figure A2, can offer the following functionalities:
For the transit traffic:

- An optical coupler offering easy multicast/broadcast with only one packet
- Possible deflection of premium packets in the electronic boards to avoid any strong contention problem with two premium packets. The contention resolution is then made in the electronic domain, thanks to a small electronic buffer for the transit part.
- Use of optical gates to do:
    - Optical amplification to optimise the power budget of the network and ease the cascade of nodes
    - Space reuse: Optical switching at the packet level, to be able to discard a packet, in order to reinsert a new packet.
    - Class of service management: If best effort is blocking the insertion of high priority packets, possibility to discard the in line best effort packet. The network can then fulfil the resources at any time and at any node with best effort packets without creating a blocking risk for the premium traffic that need to be inserted.
    - Fast packet power equalisation packet per packet: to guarantee high signal quality at any node reception.

For the drop traffic:

- Use of burst mode receivers tolerating any phase misalignment between consecutive packets and accepting small packet per packet power variations.
- Possibility to drop up to four packets in parallel through the use of an electronic buffer.
- Electronic interface detecting the packets for the nodes, and cancelling in line the packets not belonging to the node.
- Limited electronics for packets that need to be stored in an electronic memory, before reinsertion in the ring.

For the add traffic:

- Use of fast tuneable lasers, covering the C band, to be able to insert any packet on any wavelength and at any time.
- The possibility to insert a packet on four different wavelengths, to provide some load balancing functionalities.
- Fast optical gating, just after the tuneable laser to suppress all transient effect during the switching of the tuneable lasers and enable the mix of wavelength in the pure transmission regime and wavelengths transporting packets.

4. Data and control protocols

Figure A3 shows the protocols adopted.

We have proposed a separation of the headers and the payloads to be compliant with the concept of optical transparency. Since all the headers have to be demodulated to analyse the incoming traffic and each ring node level, by adopting one wavelength transporting all the headers we can then through one demodulation analyse the incoming traffic. The headers are then transported on a wavelength called the control channel. The bit rate of this control channel is fixed, and its value depends on the number of information we want to transport on this channel: headers + tags + sync patterns + centralised protocols like operations, administration, and management (OAM), signalling, CAC, …)

In order to not impact the fibre infrastructure of existent networks (fibres + erbium doped fibre amplifiers (EDFAs)), we have adopted a continuous time slot stream with useful time slots and dummy time slots. In this concept we don't need specific burst mode EDFAs like in optical burst switching concepts.

To guarantee the phase relation with the headers, the data packets are sent synchronously with the control channel. Both data packets and control packets are transported in the same optical fibre of a ring topology. If chromatic dispersion compensation is regularly implemented at each node level, there is no risk of phase lost between the headers and the payloads. It is equivalent to a packet network where headers are attached to the payloads.

5. Advantages of the approach

The advantages of the approach are the following:

- To increase the capacity, we generally increase the number of wavelengths in a network and then the bit rate per wavelength. By adopting a time slotted approach we remove the bottleneck of the scheduling part, since the number of events (number of headers to process during a time window) is maintained constant.
- The separation of the headers and the payloads opens new possibilities at the transport level, like the possibility to have packets at different bit rates and transporting different client protocols on one wavelength. This is a new functionality that does not exist in current product lines, but that can provide new advantages in terms of bandwidth allocation optimisation.
- The separation of the transit traffic can reduce the node size and implicitly the power consumption and the cost of the node. In addition, the use of a tuneable laser makes the number of TRX/line cards independent of the number of nodes in the ring in a logical mesh topology. This is completely new when compared to an Ethernet concept or a R-OADM concept for a multi-connectivity functionality.

6. Perspectives for a standardisation activity

Such a solution requires new standards to create a multi-vendor environment.

The topics of interest for standardisation are:

- the description of the network,
- the interoperability with the external world (client layer) and the management of the traffic,
- the packet format and the control packet format description including the MAC layer,
- the centralised control protocols,
- the class of service envisaged in the optical layer and their associated quality of service,
- the monitoring and the protection aspects,
- the power budget per network section,
- a network performance for different traffic patterns,
- GMPLS compatibility.

The following is proprietary to each constructor of equipment:

- the design of the node
- the design rules of the network

The relevant standardisation bodies to target are primarily ITU and IETF.

Table A1 shows a time schedule proposed for further standardisation activities.

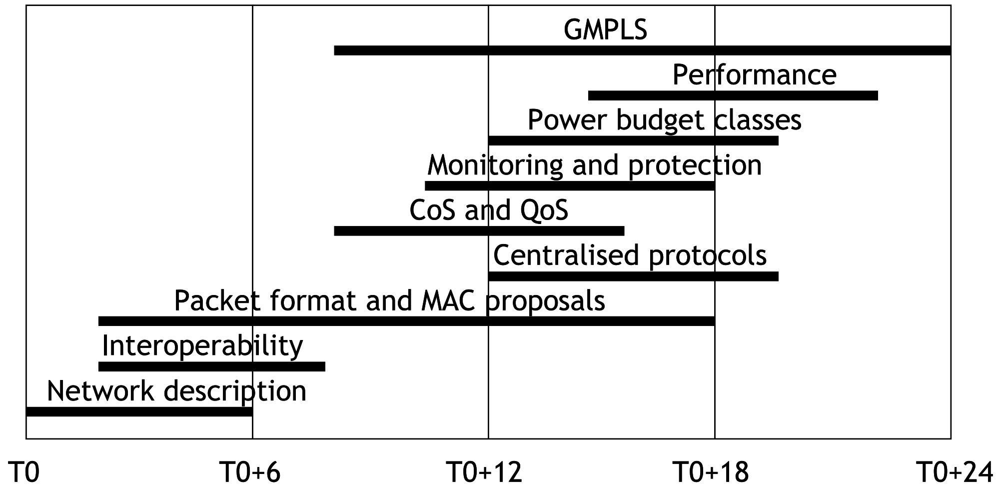


Table A1: Different topics proposed for discussion in standardisation bodies, targeting a two year period

7. Conclusion

The evolution towards 10Gbit/s in access networks creates a bit rate convergence in the access and metro areas. This bit rate convergence, which makes it difficult for the aggregation process to smoothen the traffic profile, pushes equipment manufacturers to find new solutions in the metro area. A packet network has been then proposed in line with the roadmap presented in the D1.3. This new technology called packet OADM based metro network combines optical transparency for the transit traffic and packet switching granularity to increase the network efficiency.

In this appendix we have described the key elements of this network concept: the general structure of the network, the structure of the packet-OADM and the main directions adopted for the data and the control protocols. Finally a table describing a chronology of topics to be discussed in standardisation bodies is proposed.