“Operational impact on system concepts”

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Abstract:
The next generation optical access (NGOA) system candidates are assessed from an operational perspective. In a companion deliverable D4.2 the assessment from the technical point of view is documented. Criteria for such an operational assessment are defined and subsequently those are discussed for each of the system candidates. In a summarizing table the system concepts are compared in a preliminary assessment regarding to operational aspects.

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Executive summary

For operating large-scale networks covering the area of whole countries, it is important that NGOA systems fulfil the defined operational requirements. The initial NGOA system requirements were defined in deliverable D2.1 [2]. OASE is exploring to what extent node-consolidation can provide an avenue for reducing total-cost-of-ownership (TCO) in next-generation optical access (NGOA). Candidate NGOA systems may not only be required to cater for future bandwidth requirements but also to provide the necessary performance characteristics for enabling node-consolidation. It is anticipated that reduced operational costs associated with node-consolidation will eventually counter balance the higher costs associated more stringent system requirements. The technical assessment of NGOA candidate systems in terms of cost and performance is given in a companion deliverable D4.2 [5]. This document covers the operational aspects of the candidate NGOA systems. Candidate system concepts are analyzed from a number of operational aspects and the work serves as input to the OpEx assessment performed in WP5.

The criteria for the operational assessment are defined based on the eTOM (Enhanced Telecom Operations Map) standard published by TM Forum. These criteria comprise general requirements for different processes of the operations group (e.g. service provisioning and fault network management) as well as the strategy, infrastructure and product group (e.g. open access). Based on this, the NGOA system candidates are discussed and assessed individually with respect to those criteria. Important criteria that were considered include provisioning, maintenance, fault management and troubleshooting, hardware and facilities, open access and cooperation. Main findings for the different concepts are summarized below.

The (Wavelength-Routed) WDM PON with tuneable lasers as well as seeded reflective transmitters offers advantages with respect to maintenance and monitoring, however it lacks open access on the wavelength layer and does not support legacy power-split infrastructure. WDM-PON can also support power-split infrastructure, however at the increased CapEx and also reduced reach.

- The UDWDM-PON, running via partly power-split infrastructure, performs similar to G-PON, however it has comparatively high power consumption.
- The hybrid WDM/TDM-PON is able to achieve very high fan-out ratio through combined power- and wavelength-splitting structure. On the other hand, it also suffers from the broadcast characteristics of power splitter and consequently needs more complicated fault management capabilities.
- The next-generation AON architecture can dynamically provide end-to-end multi-layer unified OAM platform from the access to the core, support highly dynamic networks and could support network virtualization providing simple open access operations.
- The two-stage WDM PON mainly depends on its second stage: if G-PON, AON or WDM-PON are backhauled, the respective OAM characteristics apply, whereas the backhaul part performs in the way that is known from today's WDM backhaul.

A comparison table in the end of the deliverable summarizes the results obtained so far from the operational viewpoint. This comparison does not show the one single "winner" system, but different NGOA candidate systems have different advantages and challenges in the context given by the NGOA time horizon.

Therefore, in the work towards the final version of this deliverable efforts will be made towards forming a shortlist of the NGOA system candidates considered so far in this and the companion deliverable. For this purpose it is necessary to work very closely together with WP5 where the techno-economic assessment is done.

Referred documents

[1] Project Contract - Annex 1 "Description of the Work" *(DoW)*

[2] OASE deliverable D2.1: "Requirements for European next-generation optical access networks", September 2010

[3] OASE deliverable D4.1: "Survey of Next-Generation Optical Access System Concepts", October 2010

[4] OASE deliverable D3.1: "Overview and assessment of existing optical access network architectures", December 2010

[5] OASE deliverable D4.2: "Technical Assessment and Comparison of Next-Generation Optical Access System Concepts", October 2011

[6] Jie Hyun Lee, et al., "First Commercial Deployment of a Colorless Gigabit WDM/TDM Hybrid PON System Using Remote Protocol Terminator", Journal of Lightwave Technology, vol. 28, no. 4, February 15, 2010.

[7] OASE Milestone M3.1: "Preliminary Evaluation of Architectures I", June 2011

List of figures and tables

Abbreviations

ADSL	Asynchronous Digital Subscriber Line
AON	Active Optical Network
APD	Avalanche Photo Diode
AWG	Arrayed Waveguide Grating
BN	Branching Node
BSA	Bit Stream Access
CapEx	Capital Expenditures
CATV	Cable Television
CO	Central Office
CPE	Customer Premises Equipment
CPU	Central Processing Unit
CWMP	CPE WAN Management Protocol
DDN	Digital Data Network
DSL	Digital Subscriber Line
eTTS	einheitliches Trouble Ticket System
EMU	Environment Management Unit
EPON	Ethernet Passive Optical Network
eTOM	Enhanced Telecom Operations Map
FIT	Failure In Time
FSAN	Full Service Access Networks
FSR	Free Spectral Range
FTP	File Transfer Protocol
GE	Gigabit Ethernet
GMPLS	Generalized Multi-Protocol Label Switching
GPON	Gigabit-capable Passive Optical Network
HTTP	Hypertext Transfer Protocol
IEEE	Institute of Electrics and Electronics Engineers
IETF	Internet Engineering Task Force
IPTV	Internet Protocol Television
ITU	International Telecommunication Union
LT	Line Termination
MAC	Medium Access Control
MDU	Multi-Dwelling Unit
MPLS	Multiprotocol Label Switching

MTBF	Mean Time Between Failure
MTTR	Mean Time To Repair/Recover
NGOA	Next Generation Optical Access
NMS	Network Management System
NP	Network Provider
NT	Network Termination
OAM	Operation, Administration and Maintenance
OASE	Optical Access Seamless Evolution
ODF	Optical Distribution Frame
OLT	Optical Line Termination
OLTS	Optical Loss Test Set
OMCI	ONT Management and Control Interface
ONT	Optical Network Termination
OpEx	Operational Expenditures
OSPF	Open Shortest Path First
OTDR	Optical Time Domain Reflectometer
PBB-TE	Provider Backbone Bridge Traffic Engineering
PD	Photo Diode
PIC	Photonic Integrated Circuit
PIN	Positive-Intrinsic-Negative
PM	Performance Monitoring
PON	Passive Optical Network
ROADM	Reconfigurable Optical Add/Drop Multiplexer
SDH	Synchronous Digital Hierarchy
SFP	Small Form-Factor Pluggable
SG	Study Group
SHDSL	Single-Pair High-Speed Digital Subscriber Line
SNMP	Simple Network Management Protocol
SONET	Synchronous Optical Network
SP	Service Provider
SPA	Service Provisioning Administration
TMF	Telecommunications Management Forum
TSS	Trouble Shooting System
UDWDM	Ultra-Dense Wavelength Division Multiplex
VDSL	Very-High Speed Digital Subscriber Line
VoD	Video on Demand

VoIP	Voice over Internet Protocol
WAN	Wide Area Network
WDM	Wavelength Division Multiplex
WSS	Wavelength Selective Switch
WP	(OASE) Work Package
XFP	10 gigabit small form factor pluggable

1. Introduction

Systems for next generation optical access networks have to fulfil the technical requirements collected in D2.1 [2] – like bridged distance, transmitted bit rate etc. –: A related discussion and assessment can be found in the companion deliverable D4.2 [5]. For operating large-scale networks covering the area of whole countries, however, it is important that such NGOA systems also fulfil requirements beyond that which relate to the operational behaviour of those respective systems – which in the end translate into operational expenditures (OpEx). This operational perspective comprises aspects like provisioning, maintenance fault management and trouble shooting, hardware and facilities as well as cooperation requirements.

In the OASE deliverables D3.1 [4] and D4.1 [3] a lot of potential candidates for NGOA architectures and systems have been surveyed and a first assessment has been performed based on the initial set of major requirements documented in D2.1 [2]. On that basis a remaining set of NGOA candidate systems has been established which is to be assessed in more detail in the tasks T4.2 and T4.3 of the OASE WP4.

In task T4.2 and the associated deliverable D4.2 the NGOA candidate systems are assessed from the technical point of view: Major technical properties of the different systems are listed – like reach, bit rate and splitting ratio – and compared. Cost information is collected per system and compared. Also, power consumption is treated in T4.2 (and D4.2) as a technical property of systems, although contributing to energy costs and thus to OpEx. These values are intended to serve as a basis for techno-economic comparisons in WP5.

In task T4.3 and the associated deliverable D4.3 the NGOA candidate systems are evaluated from an operational point of view; an assessment is done from an operational requirement's perspective based on the criteria mentioned above.

A comprehensive survey on optical access network systems is given in [3] and an initial evaluation is performed. In [4] an in-depth discussion of related architectures is presented, together with a first assessment. The remaining next-generation optical access candidate architectures are briefly summarized in [5] forming the basis for the work that follows in this document. In this deliverable document the remaining NGOA candidate systems are assessed and compared from the operational side. The methodology and the assessment criteria are briefly summarized before the actual assessment for the NGOA candidate system is given and the systems are compared from an operational perspective. A summary of the assessment shows main findings.

Since this is a preliminary version of the deliverable D4.3 an outlook sketches the steps that are expected to be undertaken towards the final D4.3 document.

2. Methodology and criteria for the assessment

2.1 Methodology

The purpose of the assessment and comparison in this document is the differentiation between the NGOA candidate systems from an operational perspective. Therefore suitable assessment and comparison criteria are defined in the subsequent section. The NGOA candidate systems are discussed and assessed with respect to those criteria throughout the following chapter of the deliverable. Operational aspects can in many cases be handled not as straight as technical aspects in a numerical manner: Therefore from this deliverable's perspective large parts are discussed on qualitative basis. A table summarizes the assessment and from that a first comparison of the NGOA candidate systems is obtained with respect to operational characteristics.

The scope of the considered network elements is shown in Figure 2-1. The network elements under consideration are the OLT, the optical distribution frame (ODF), splitting elements and the ONT. The OLT is placed in an access node as well as the ODF. The branching nodes (BN) are placed in the field (e. g. passive power splitters or AWGs or remote switches), for instance in street cabinets, and the ONT resides at the customer premises.

Figure 2-1: Scope of the considerations

2.2 Criteria

In order to evaluate and provide a comparison basis for the candidate NGOA systems, the criteria contained in this chapter were selected by consolidation of information of different sources: The basis for the criteria has been derived from deliverable D2.1 [2] as well as operator experiences and practices having in mind the eTOM standard. This standard allows having a clear and complete picture of all the processes required by a provider and to identify the processes that will play an important role to differentiate the different NGOA candidates. Also an important factor in selecting criteria was the fact that they should be quantifiable wherever possible.

- **General requirements on operations**
  - Support functions and systems for operations, administration and maintenance (OAM).

    The support functions should include data collection capability, from various optical fiber administration systems (usually custom developed for operators), TSS (Trouble Shooting System) systems. The administration SPA (Service Provisioning Administration) means the capability to catalogue the various network devices using the Northbound interfaces.
  - Process automation to minimize manual switching and increase process efficiency.

This should be performed based on the support functions. The level of automation should desirably reach the point, where an interface to the customer can be established (for e.g. through the web), thus enabling the customer to order services, which can then be automatically processed and provisioned.

– Standardized systems.

  The reason for this criterion is the multivendor concept. In an optimal case any piece of equipment should be compatible with other vendors' devices. Already existing examples are for example different PON variants, like GPON, xPON.

– High availability.

  A pivotal point in any operations systems is the high availability. The majority of the factors decreasing high availability arises from software related problems.

- **Provisioning**

  – Realisation of network/system termination relies heavily on the level of automation reached.

    Desirable assets include the do-it-yourself installation, the colourless ONT, and the do-it-yourself ordering concept, which relies heavily on the level of SPA. Plug & Play equipment and Zero touch network components provide considerable help in achieving these assets.

  – Installation complexity/time.

    In order to install the various hardware components, a modular construction of the systems is essential. The modularity also enables the operator to optimize capital expenditures (CapEx) spending in the provisioning procedure, with minimizing the procurement of necessary new hardware to connect new customer and establish new services.

  – Configuration complexity/time.

    The main influencing factor is the installation of the software components. Hence, this should mean the quick and simple setting of unique parameters of a given installation, avoidance or safety against software errors.

- **Maintenance (regular operation)**

  – Performance monitoring.

This function enables optimal network and traffic sizing on hardware levels, from data such as: CPU utilisation, Northbound interface capacity etc. Remotely manageable network components should provide the basis for this.

– Network supervision.

A future NGOA system should have its own supervision system. The current accepted practice is that each vendor has its own supervision system on operational level 2 and above. On operational level 1 the systems should be able to work together with umbrella systems (for example eTTS or TSS) through the Northbound interface, also enabling seamless software and component upgrades. The network maintenance should require as little person actions as possible.

This criterion has to support the Network Management System (NMS) with the following functions to support:

- Local and remote equipment activation
- Automatic service management:
  - Service activation
  - Service monitoring
  - Service release
  - Non-disrupted service change
  - Non-disrupted service update

– Signalling in regular operational states.

The system has to be able to communicate, provide information on, and be able to configure its components, both hardware and software, in a normal operation mode, also when otherwise no error is detected.

- **Fault management and trouble shooting**

– Failure signalling capability.

As detailed as possible information on each of the network components is required to aid the localization of failure, in a form that can be interpreted by the network operator. Reaching the smallest components in the network, and interfaces and/or integration of sensing of environmental conditions, or external systems that can do it like air conditioning, power supply or even subscriber devices would be essential, but currently uncommon by vendors.

– MTBF (mean time between failure) / MTTR (mean time to repair)

The lowest possible value, on the level of both devices and systems, is in the mutual interest of the customer, the service provider and the operator. This can be achieved with highly reliable components. On the other hand, the reparation time that impacts the reparation cost should take into account the reparation of the failure itself (replacing card, splicing fiber, etc.) as well as the travelling to the failure location and back. This travelling in NGOA network will be more important than in existing access solutions.

– Failure localization

The most precise localization of the optical failures in the network is desired. Since OLTS (Optical Loss Test Set) and OTDR (Optical Time Domain Reflectometer) devices are currently fairly expensive, either reflectors could be placed at the customer premises and/or the currently existing intelligence (e.g. usage of self diagnostics, CPU capabilities.) of the CPE devices could be used. The limitation with reflectors however is that localization can be done explicitly only to certain points of the network. The usage of already existing intelligence has to be supported by the vendors, or exchange of the equipment is necessary that can support this.

– Fault analysis capabilities

Aside from being able to localize faults and their sources, the system needs to be able to, or at least support automatic analysis, detection and controlling of the different alarms. This is in order to detect the degradation before the interruption occurs, as well as to simplify and to save time and effort in trouble shooting and alarm handling procedures – for example to avoid overlapping alarms.

– Hardware redundancy / Reconfiguration time

The minimum requirement is the duplication of backbone elements. It is up to the actual service provider scenario to decide the critical limit, where the number of customers or services sets this number, but the systems has to have the flexibility to support this. Reconfiguration time is mainly a software issue depending on the complexity of the used software. Integration of applications on hardware levels can aid this considerably, along with dynamic variables and fast software handling. An example for this could be the current GPON ONTs. Common reboot times are around 60 minutes with current OLTs in GPON.

- **Hardware and facilities**

– Power consumption

The lowest possible value is desired in accordance with current trends of eco consciousness along with the desire of operators to keep down operational costs.

– Footprint (space required)

The smallest possible value is desired. The relevance of this increases with external cabinets where operators are highly limited in expanding their usable spaces due to constructional issues.

– FIT (failure in time) rate

FIT gives the expected number of failures that can occur in 10^9 hours of operation. This values may depending on actual service agreements with customers. Usual values are in the range of ... corresponding to an availability which varies between 99.9 % and 99.999%

– Repair time of a particular component

The reparation of a component should be as fast as possible and it is mostly based on the component replacement. The access to the component also plays an important role to the total reparation time (easier in a cabinet than in a manhole)

– Capacity (port density per Line card / Chassis) resulting in footprint and FIT rates

Capacity is in close relation with "scalability". It means that there can be a down and upside for this, depending the setting. For example while installing equipment with many ports could clearly lead to lower installation times and footprint, buying equipment with too many ports only because there are no smaller scaled devices provided by the vendor could also lead to an important waste of resources in small scale installations. To an operator it is obviously quite an important issue, affecting strongly both design and CapEx.

– System complexity

Simplest straight-forward design concept generally aids the operation, but only if necessary functions and features are not eliminated this way.

- **Open access and cooperation (overarching topic, not only operational)**

This is strongly affected by the level of standardization. From an operational point of view it is desirable to have interoperation with different other operators, service providers, and customers with various vendors and systems. Usually most problems occur however on the level of CPE devices, deriving from incompatibility issues. Actual provisioning is highly dependent on the business model. In a typical "open access", one operator has to deal with multiple service providers offering different services over the same network.

2.3 Some necessary Models

2.3.1 Footprint model

Footprint means in this context the surface area that is needed to host system technology (Switches, OLT-shelves) and Optical Distribution Frame (ODF). The footprint is calculated with respect to the access node location (OLT and ODF). In addition, Footprint considers the work space that is required in order to install, maintain, and manage the system technology and the ODF. Footprint is an important OpEx parameter enabling the evaluation of potential hosting costs, e.g. lease costs. In the following a generic footprint model is described for system technology and ODF including work space.

2.3.1.1 System Technology Footprint incl. Work space

A generic shelf and rack model has been defined for all NGOA technologies (D4.2 [5]). The model is based on a 19"-rack that can be populated with up to 4 system technology shelves (Figure 2-2). The rack requires a footprint of 0.18 sqm. In addition, a work space of 0.60 sqm needs to be considered for each system rack. The total footprint per rack (A_{rack}) is 0.78 sqm.

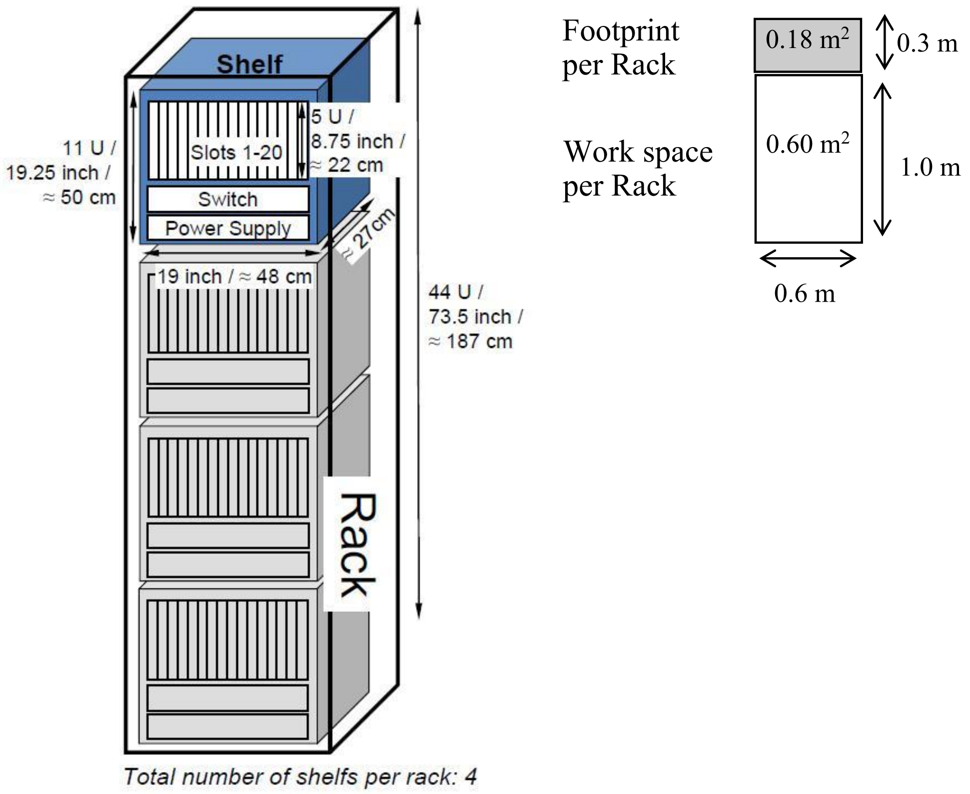

Figure 2-2: Shelf and rack model

The system technology footprint (A_{System}) can be calculated using following formula:

$A_{System} = A_{per\ line}$ x Number of lines

The footprint per line ($A_{per\ line}$) is based on the following formula:

$A_{per\ line} = A_{rack}$ / Max number of ports per rack

The 'Max number of ports per rack' varies for the different NGOA solutions (Table 2-1). It also depends on the max number of shelves per rack that is limited by the system technology heat loss which has a close relation to the power consumption. This model defines a maximum power consumption per rack of 6 kW. Table 2-1 shows the power consumption per shelf, the maximum number of shelves per rack, the maximum number of ports per rack and the surface area per line ($A_{per\ line}$) for all NGOA system concepts.

Table 2-1: NGOA power consumption per shelf and maximum number of shelves per rack

System concept	OLT power consumption per 11U shelf	Max number of shelves per rack	Max number of ports per rack	$A_{per\ line}$ [sqm]
G-PON	1.15 kW	4	1,152 (1:4) 2,304 (1:8)	0.00068 0.00034
XG-PON 1	1.86 kW	3	2,592 (1:16) 5184 (1:32)	0.00030 0.00015
Ethernet p-t-p	0.55 kW (300 Mpbs) 0.63 kW (500 Mbps)	4	1,152	0.00068
DWDM-PON (tuneable lasers)	0.96 kW - 1.37 kW	4	1,920 - 2,880	0.00041- 0.00027
DWDM-PON (seeded reflective; multi-frequency-laser@OLT)	0.68 kW (300 Mbps) 0.79 kW (500 Mbps)	4	1,440	0.00054
DWDM-PON (seeded reflective; wavelength-reuse@OLT)	0.86 kW - 1.28 kW	4	1,920 (80 lambda) 2,304 (160 lambda) 2,560 (320 lambda)	0.00041 0.00034 0.00030
DWDM-PON (seeded reflective; wavelength-reuse@OLT; 100 GHz spacing)	1.1 kW (300 Mbps) 1.21 kW (500 Mbps)	4	2,304	0.00034
Hybrid WDM/TDMA PON	1.34 kW (1:16 / 40 l) 1.43 kW (1:16 / 80 l) 1.34 kW (1:32 / 40 l)	4	3,840 (1:16 / 40 lambda) 4,096 (1:16 / 80 lambda) 7,680 (1:32 / 40 lambda)	0.00020 0.00019 0.00010
UDWDM-PON	0.58 kW - 0.69 kW	4	960 (1:8 / 40 lambda) 1,024 (1:8 / 80 lambda) 1,024 (1:32 / 20 lambda)	0.00081 0.00076 0.00076

2.3.1.2 ODF Footprint incl. Work space

The ODF is a fiber flexibility point enabling flexible access to individual fibers that is needed in order to support, for example, a Multi-Operator scenario with fiber unbundling and a fast system change. Two ODF models have been defined which differ in the level of flexibility (Figure 2-3).

Figure 2-3: ODF Models

Model 1 addresses an ODF without cross-connect functionality. This model can be used for PON and PtP scenarios with moderate quantities of fibers without fiber unbundling approach. An ODF with full cross-connect functionality is covered by Model 2 that can be used for PtP scenarios with high quantities of fibers and Multi-Operator scenarios with fiber unbundling. Model 2 with its fiber cross-connect functionality is not useful in the case of PON due to the sharing of the PON feeder fiber. PON enables access to a group of subscribers (e.g. 64) via one PON feeder fiber but it does not allow a fiber-based access to individual subscriber lines.

This means that PON does not support Multi-Operator scenarios with fiber unbundling (it still allows unbundling on NP level and per PON).

Model 1

Figure 2-4 a) shows the ODF configuration of a PtP fiber architecture without cross-connect functionality. The ODF base unit is a rack that terminates up to 1900 fibers. The access network fibers are terminated by splices and optical connectors. The access network fiber can be connected to an individual port at the system technology rack via patch fiber.

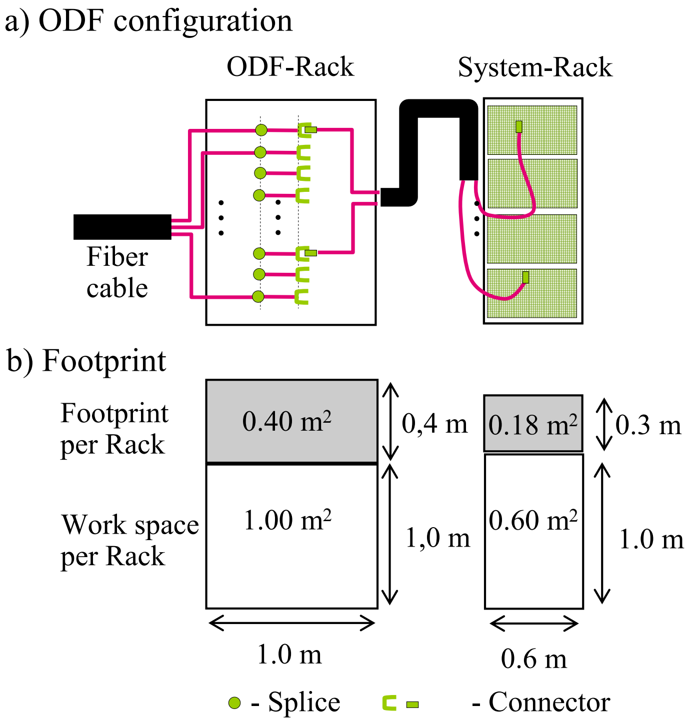

Figure 2-4: ODF Model 1 for PtP based fiber architecture

Figure 2-4 b) shows the footprint of the ODF base unit and one System-rack. The ODF-rack has a footprint of 0.40 sqm and requires a work space of about 1.00 sqm. Table 2-2 lists all relevant parameters of the ODF Model 1 for PtP based fiber architecture.

Table 2-2: Parameters of ODF Model 1 for PtP based fiber architecture

Parameter	Value
Max fibers per ODF-rack	1900
Footprint per ODF-rack	0.40 sqm
Work space per ODF-rack	1.00 sqm
Total Footprint per ODF-rack incl. work space	1.40 sqm
A_{ODF} per fiber	0,00074 sqm

Figure 2-5 a) shows the ODF configuration of a PON architecture. In addition to the ODF-racks and the System-racks this configuration includes Filter-racks providing space for WDM filters which are needed for PON supervision and system upgrades. One Filter-rack offers the space for up to 350 WDM filters. As shown in Figure 2-5 b) the Filter-rack has a footprint of 0.18 sqm and requires a work space of about 0.6 sqm.

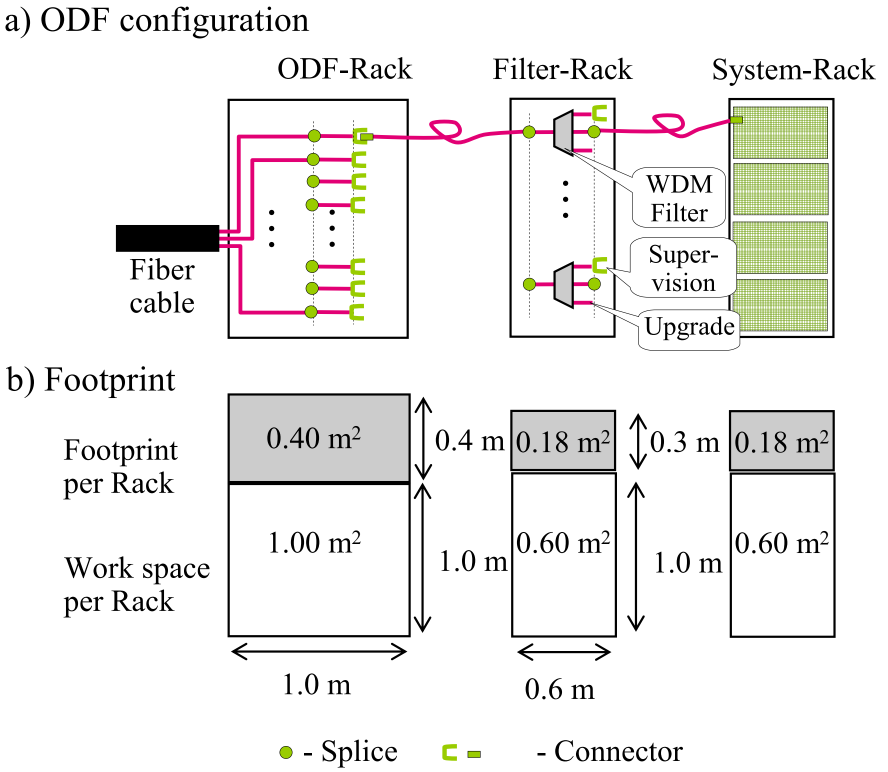

Figure 2-5: ODF Model 1 for PON based fiber architecture

Table 2-3 shows the relevant parameters of the ODM Model 1 for PON based fiber architectures.

Table 2-3: Parameters of ODF Model 1 for PON based fiber architecture

Parameter	Value
ODF-rack	
Max fibers per ODF-rack	1900
Footprint per ODF-rack	0.40 sqm
Work space per ODF-rack	1.00 sqm
Total Footprint per ODF-rack incl. work space	1.40 sqm
A_{ODF} per fiber	0,00074 sqm
Filter-rack	
Max WDM filters per Filter-rack	350
Footprint per Filter-rack	0.18 sqm
Work space per Filter-rack	0.60 sqm
Total Footprint per Filter-rack incl. work space	0.78 sqm
A_{Filter} per WDM filter	0.00223 sqm

Model 2

Figure 2-6 a) shows the ODF configuration of a PtP fiber architecture with full cross-connect functionality. The full cross-connect ODF is composed of the Termination Rack and the Fiber

Patching Rack. Up to 1900 access fibers can be terminated at the Termination Rack. The system fibers are terminated at the Fiber Patching Rack that may be shared between several operators in case of open access. An easy cross-connecting can be realized with patch fibers between Termination Rack and Fiber Patching Rack. Both ODF racks have a footprint of 1.40 sqm including work space (Figure 2-6 b)).

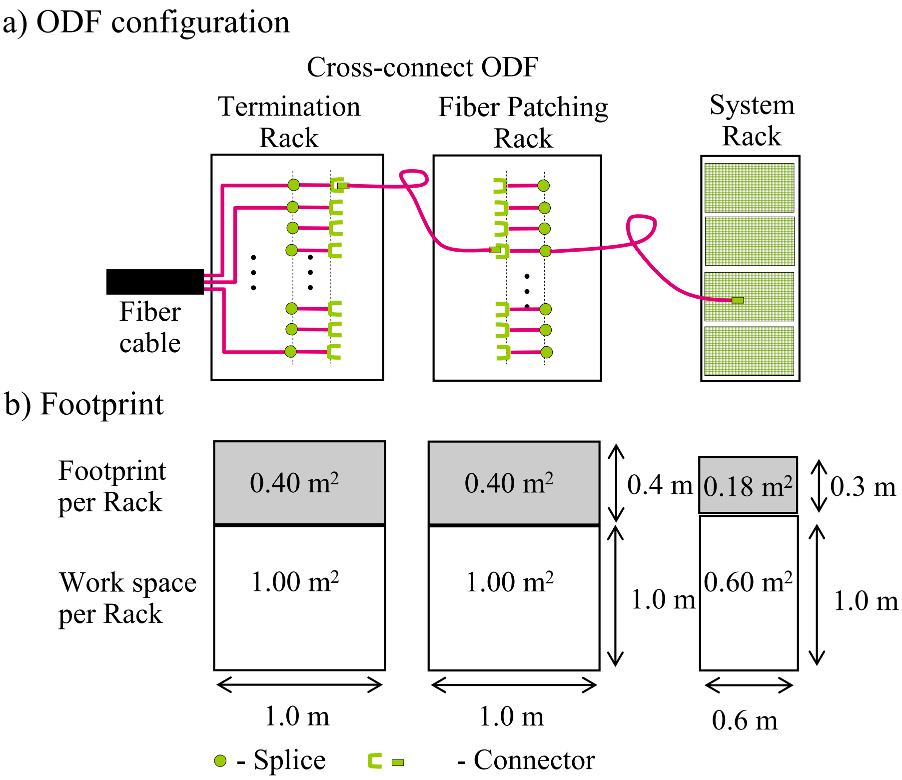

Figure 2-6: ODF Model 2 for PtP based fiber architecture

Table 2-4 shows the relevant parameters of the ODF Model 2 for PtP based fiber architecture.

Table 2-4: Parameters of ODF Model 2 for PtP based fiber architecture

Parameter	Value
Max fibers per ODF Rack	1900
Footprint per ODF Termination Rack	0.40 sqm
Footprint per ODF Fiber Patching Rack	0.40 sqm
Work space per ODF Rack	1.00 sqm
Total Footprint per ODF Rack combo (Termination Rack + Fiber Patching Rack) incl. work space	2.8 sqm
A_{ODF} per fiber	0.00147 sqm

2.3.1.3 Footprint evaluation

Figure 2-7 shows the results of a footprint analysis for different NGOA solutions which are described in D4.2 [5]. This study does not consider protection solutions which are for further study. The footprint has been calculated for an exemplary value of 20,000 lines on the basis of the previously described model considering the surface area of the system technology, ODF and WDM filter equipment.

The results show that the Hybrid WDM/TDMA PON solutions require the least footprint due to the very high splitting ratio. The highest values have been calculated for the Ethernet solutions where the ODF surface area is the biggest part of the total Ethernet footprint. The footprint of the PON solutions is clearly dominated by the surface area needed for the system technology.

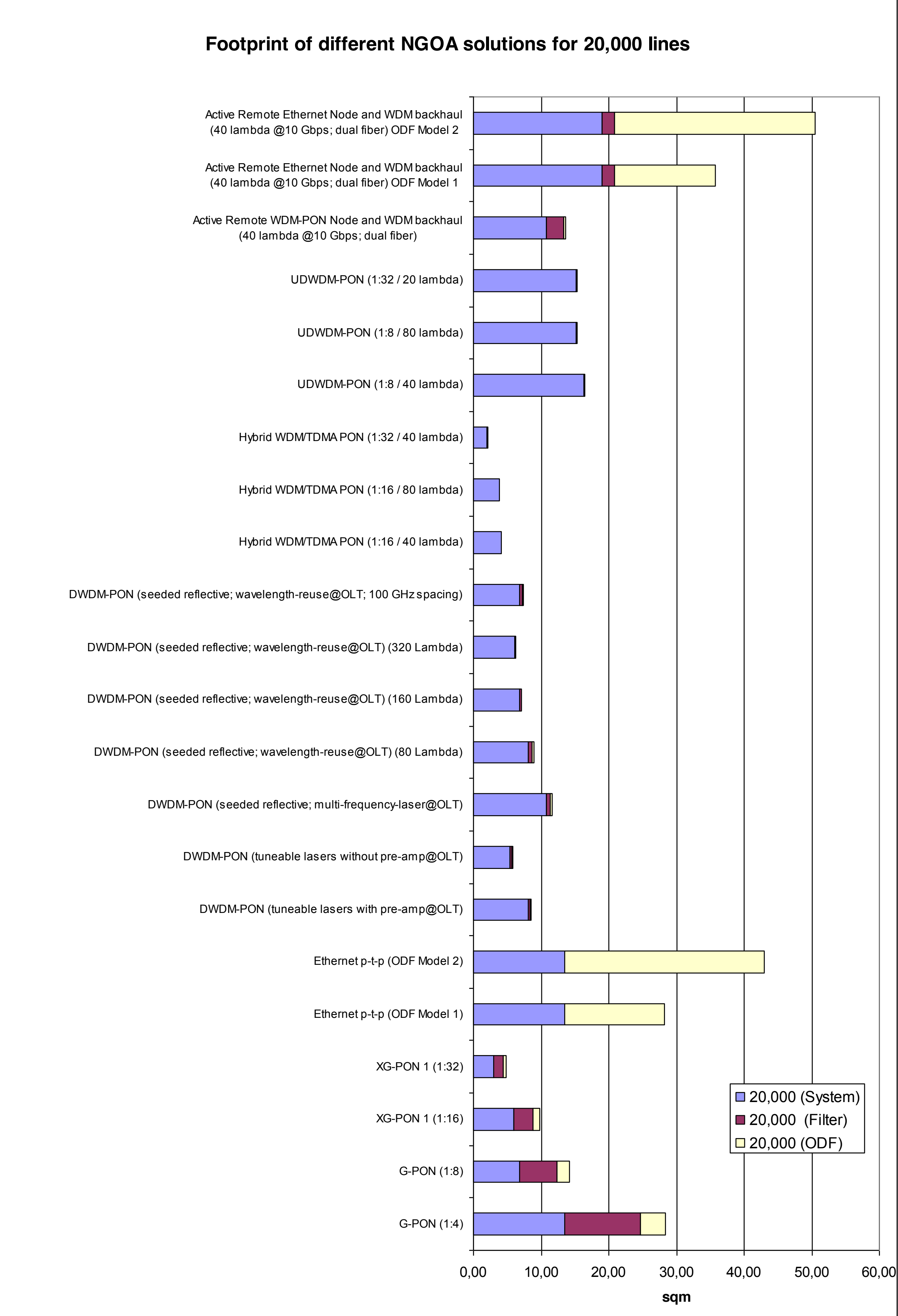

Figure 2-7: Footprint of different NGOA solutions for 20,000 lines

2.3.2 Power consumption per line

Power consumption is the rate at which energy is consumed. It is given in the unit Watts (W) whereas the energy is measured in the unit kWh, the power time function is integrated over the operational time. For the purpose of comparison of the different NGOA systems the power consumption per line is used as a suitable parameter: This includes the power consumption share per line at the OLT, the remote (branching node) as well as the ONT power consumption. The results are obtained under the assumption of fully utilized systems. The numerical results rely on the component's power consumption values detailed in D4.2 [5].The power consumption per line results of the different NGOA systems are summarized in Table 4-1.

3. Assessment of the system concepts

3.1 Reference: G-PON

This section introduces the criteria by applying them to the G-PON used by Magyar Telekom as reference. This forms a comparison basis for the assessment of NGOA system concepts.

General requirements on operation

– Support functions and systems for operations, administration and maintenance (OAM)

Administration and catalogization of, and data collection on optical cables and splices is currently not an available function of the G-PON technology, used by Magyar Telekom. A custom developed standalone external sub-system is taking care of these functions. The administration and change management procedure is performed manually. Northbound interfaces are available and connected in the direction to TSS (Trouble Shooting System), SPA etc. Using the same interfaces the external systems – like for e.g. the TSS – are communicating with the G-PON access network elements and offering solutions for the faults. The available Northbound interfaces are listed in Table 3-1.

Table 3-1: Available Northbound interfaces

NBI	Alarm Reporting	CORBA, SNMP
	Performance	FTP
	Inventory Reporting	TL1, XML
	Service provisioning	TL1, XML
	Test	MML

– Process automation to minimize manual switching's and increase process efficiency.

The possibility of process automation related to various services (Cable TV, VoD etc.) is provided but the billing functions are not fully supported. Thus, not baring the required flexibility and scalability, to provide automated (for e.g. Web based) interfaces for the customer. A project has started aiming to consolidate the billing functions towards the various services in a unified solution.

– Standardized Systems.

The GPON solution used by Magyar Telekom supports

at the OLT level:

- multiple access ways such as FE,GE,VDSL2, SHDSL,G.SHDSL.bis, ADSL2+

- multiple services such as IPTV,HIS,VOD,VOIP 、 ,Web surfing, Internet applications
- to access varies consumers such as residents, enterprises, base stations to network easily

at the ONT Level, the equipment is supporting multiple end user scenarios such as:

- wholesale
- triple play
- CATV
- Family interconnect

Although key elements such as OLT and ONT of the G-PON system are provided by one vendor, still considerable amounts of resources are required through regression tests, to harmonize compatibility issues with various services related equipment connected to the G-PON system. This is caused by the tendency of different vendors producing vendor specific solutions. Reduction of costs is still desired and would be greatly possible.

Provisioning

Provisioning is triggered and controlled by the G-PON's SPA server through both manual and automated (northbound) interfaces and interaction with the various billing, administration, workflow management systems. Installation is modular on the OLT and Plug & Play on the ONT side with fairly simple automated procedures. "Zero touch equipment" would be possible, but is not implemented through lack of support of certain administration and logistical procedures, mainly because of financial issues. Configuration of the equipment is remotely operated through the NMS.

Maintenance

- Performance monitoring is supported by the GPON on the OLT level, but not supported on the ONT level yet

- Network supervision is possible through G-PON's own network management system (NMS) and also connected to the SPA and TSS. Compatibility investigations and consolidation projects are ongoing to other custom and non-custom supporting systems used by Magyar Telekom. Component upgrade is automated through the Northbound interfaces. Local and remote equipment activation is supported. Local service monitoring is not working, also there had been no demand on SLA classification for different customers. Non disrupted service change is not possible with the G-PON technology. To achieve this, in-house solutions are implemented.

- Signalling in regular operational mode is possible through customized chipsets. The G-PON provides this functionality, but currently it is not implemented.

Fault management and trouble shooting

Failure signalling capability can be achieved through in band and out-band techniques and OTDR measurements. In the in-band networking mode, the system uses the service channel provided by the managed device to complete the networking of the network devices. Outband

networking mode includes multiple networking modes and supports digital data network (DDN), E1 line, and routers.
With the help of an EMU (Environment Management Unit) panel the OLT is capable of providing status information on heat dissipation energy consumption, power units etc..

- General MTBF (Mean Time Between Failure) / MTTR (Mean Time To Repair) indexes for the network devices are indicated in Table 3-2.

Table 3-2: General MTBF/MTTR indexes for the network devices

Mean time between failures (MTBF)	≥ 0.5 year
Mean time to repair (MTTR)	≤ 60 minutes
Availability	≥ 99.99%

MTTR is simple action of installing new ONT in the majority of the cases.

- Failure localization

Reflector based localization techniques were investigated but not implemented, due to fairly high cost of OLTS and OTDR devices and limited localization possibilities. OLTs have optical uplink interfaces, but if failures occur usually the complete device falls out of service. The ONTs have currently no failure signalling possibilities.

- Fault analysis capabilities

Alarm correlation is featured, but currently not operating in the G-PON NMS system.

- Hardware redundancy / Reconfiguration time

The power units and the control units are duplicated on the OLTs.

Hardware and facilities

- Power consumption is around average 12 Watts on the ONTs and 200-300 Watts on the OLTs. They are continuously transmitting laser signals.
- Footprint (space required) is generally described in chapter 2.3 and is applicable for the Magyar Telekom G-PON network as well. 16 customers per frame and 15U per shelf are common values.
- Capacity (port density per Line card / Chassis) is 16 384 / chassis.

Open access and cooperation

Theoretically open access via bit stream access is possible via Northbound interfaces and over Ethernet Interfaces at the OLT. In practice no open access has been implemented in Magyar Telekom's network.

3.2 WDM-PON ARCHITECTURE

3.2.1 WDM-PON with (Tuneable) Lasers and Laser-Arrays

Following, the assessment for wavelength-routed WDM-PON with direct detection, based on tuneable lasers (ONU) and OLT multi-channel transceiver PICs, is given according to the list in deliverable D4.2 [5].

General requirements on operations

Regarding general operations requirements, the generic characteristics inherent to all (purely) wavelength-routed WDM-PON apply. Basically, a WDM-PON can be transparent for the higher-layer protocols. As such, it can support diverse higher-layer OAM functionality. It may support Ethernet OAM functions or proprietary OAM functions (to be applied on a generic WDM-PON basis or a specific system/vendor basis). In particular, OAM protocols standardized by Broadband Forum or ITU can be adopted, i.e., CWMP (TR-069) or OMCI. Further options which can be supported include SNMP, as well as supplementary operations via (S)FTP or HTTP(S). For OMCI and TR-069, specific adaptation to WDM-PON will be required (as has been done by Broadband Forum for G-PON and EPON, which was derived from the respective DSL standard). This adaptation shall consider the fact that a WDM-PON does not require a common MAC layer and shared resources. Hence, the respective protocols can be simplified.

Process automation is also inherently possible with WDM-PON. All required configurations and management can be performed remotely via Layer-2 in the OLT. This can be automated via the respective management systems. Also, ONUs are self-installing (-tuning).

WDM-PON so far has not been standardized in a system-wide context. Should a decision in favour of WDM-PON be made in FSAN, it will be strictly standardized. Supportive standardization is on-going in ITU SG15 Q6 (G.sdapp). In addition, WDM-PON Forum may decide at a certain point in time to enter pre-standardization activities, possibly similar to FSAN.

High availability (multiple vendors) will be given for WDM-PON – as it is for G-PON/EPON – should a decision in favour of WDM-PON be made in FSAN. Should this decision not be made, the number of WDM-PON vendors may be smaller. It is expected though that WDM-PON *will be* available by several vendors in any way as is clear by different news feeds. This will be driven by requirements in (wireless, DSL, HFC) backhaul and business access.

Provisioning

A pure WDM-PON is inherently relatively simple, as compared to TDMA-PONs and other approaches with common MAC layers and higher per-wavelength bit rates. This is due to the fact that client bit rates (and hence client provisioning) do not depend on other clients – the individual wavelength is not a shared medium. In addition, physical problems (like SNR, dispersion) are avoided by the lower per-wavelength bit rates. This eases installation and, to certain extent, also network planning. ONUs will be self-installing, and they will not be wavelength-specific. The lasers are broadband-tuneable, and tuning will be performed automatically (e.g., supported by the OLT, but without manual action). Depending on the specifics of the laser type and the tuning mechanism, installation may take several seconds. Depending on the specific requirements on number of channels (e.g., 80, 160, 320) and reach (e.g., up to 20 km, 40 km, 60 km), there may be more than one ONU (transceiver) variant. Two (2) variants may make sense with regard to optical power budget (PIN-PD vs. APD), and potentially two (2) variants may be required, should the S-Band also be used for channel additions. Reduction to a single variant will inevitably mean that the more expensive APD variant be used for short-reach applications as well, and unification with regard to wavelength band will lead to the requirement of an ultra-broadband-tuneable laser (upper S-Band plus C-Band). First such devices exist, however it is unclear at the time being if these devices will be cost-effective over an approach which will accept two different lasers.

Maintenance

Performance monitoring (PM), network supervision, and signalling are generally simpler or more feature-rich in a *wavelength-routed* WDM-PON than they are in a purely power-split (G-PON-type) approach. PM can be provided, using standard means, on a per-wavelength basis, using either in-band or out-band techniques. In-band relates to, e.g., Ethernet or OMCI methods. Out-band relates to, e.g., pilot-tone methods which carry signalling information on the same wavelength but fully transparent to any payload. Together, this covers the full spectrum of today's technologies and implementations. In addition, wavelength-routed WDM-PON – *unlike any PON with power splitters* – can make specific use of OTDR measurements. These measurements can be performed non-service-affecting in one dedicated cyclic filter band of the AWGs. This band can be the U-Band (~1630 nm) or the O-Band (~1310 nm), for example. Both bands are standard wavelength ranges for OTDRs. In the particular case of the wavelength-routed WDM-PON, *tuneable* OTDRs will be required to tune across the individual distribution fibre ports of the AWG. Today's OTDRs typically are not tuneable. However, tuneability of an OTDR can easily be achieved, and it can be expected that this functionality will not increase the OTDR cost significantly. Then, due to wavelength routing in the AWG and tuning of the OTDR, *individual distribution fibers can unambiguously be measured down to the ONU*. To support this, the respective OTDR wavelength band should be reflected at the ONU line termination. Unambiguous OTDR measurement is not possible after power splitters in cases where several distribution fibers have similar lengths within the special resolution of the OTDR (i.e., in multi-dwelling units). Unambiguous identification of faulty distribution fibers (outside MDUs) can reduce truck-rolls. In the case of failures inside MDUs, the truck roll is typically always up to the MDU regardless of the affected fiber. The OTDR-waveband blocking-filter can be implemented as a simple (partial) waveband reflector (e.g., a thin-film or FBG reflector), which can be cost-effectively integrated into a *passive line termination* (LT). This allows monitoring of passive fiber plant, down to the passive termination, even without clients connected, as shown in Figure 3-1. Note that the split of the LT between a passive LT and an active (ONU) LT is a frequent requirement from large network operators. Monitoring aspects, such as wavelength band, tuneability of OTDR, passive LT, are relevant for WDM PON standardization.

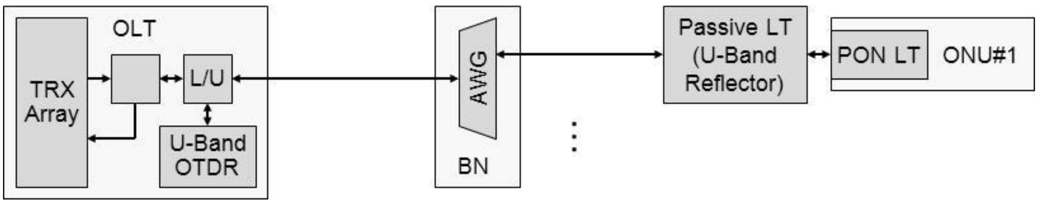

Figure 3-1: OTDR monitoring in wavelength-routed WDM PON

Fault management and trouble shooting

Failure localization and signalling capabilities in WDM-PON are feature-rich, as previously explained. Signalling can be done per-wavelength, using in-band and/or out-band techniques. In the OLT, this can be supported by fault correlation in order to identify failures of the feeder fibre (multiplex section) etc. Again, it must be noted that only a wavelength-routed WDM-

PON has the unique capability of unambiguously identifying and localising individual distribution fibre faults by means of OTDR measurements. This potentially has very high impact on OpEx (through avoidance of wrong truck rolls).

WDM-PON supports various resilience (protection, dual-parenting) mechanisms. This applies to end-to-end resilience as well as to resilience down to a remote node only. In the relevant case of feeder fibre (duct) fault, switch-over to the resilient feeder fibre can be *triggered* within the usual 10 ms, using techniques for Loss-of-Signal monitoring. Complete switch-over may take longer than 60 ms (as known from SONET/SDH) due to necessary re-tuning. Since re-tuning is required by +/- one channel using 2:N cyclic AWGs, the individual tuning time is expected to be in the single-digit seconds range. Tuning across all wavelengths can be done simultaneously. Hence, even in a system with high channel count, switch-over should be completed in clearly less than one minute. This is for further study, since samples of lowest-cost tuneable lasers are not available at the time being (they are expected for 2012 timeframe).

MTBF of a WDM-PON mainly is a function of the respective system complexity. Since WDM-PON is inherently relatively simple, MTBF can be expected to be relatively high. Exact figures for MTBF are not available today because of lack of precise components figures with respect to the relevant components (i.e., the tuneable ONU laser and the OLT PIC). Hence, all calculations are based on best estimates, with the respective components MTBF figures having been derived from similarly complex existing components. Since repair in almost all cases is based on replacement of components on card or (sub-) system level, MTTR is *not* a function of the PON system implementation, but rather a function of the respective MTTR class *assignment* (e.g., 4h vs. 8h). Exact details on MTBF or mean end-to-end path availability are shown in detail in D4.2 [5]. As an example, an 80-channel WDM-PON (without any fibre in-between) can achieve a mean path availability in the range of 0.99967. For short distribution fibre lengths < 5 km, this path availability can almost be maintained with feeder fibres up to 30 km length by adding resilience between the OLT and the RN (leading to path availabilities in the range of 0.99965).

Hardware

A detailed analysis with regard to power consumption, footprint, and capacity/density per rack is available in deliverable D4.2 [5], and in Ch. 2 of this document. From there, it can be derived that WDM-PON with tuneable lasers (and multi-channel PICs in the OLT) performs relatively good as compared to other NGOA solutions. In particular power consumption is relatively low. This effect is the higher, the higher the dedicated sustainable per-client bit rate requirement is (e.g., 300 Mb/s vs. 500 Mb/s vs. 1 Gb/s).

Part of the characteristics of WDM-PON with regard to cost, reach and power consumption results from inherent modularity. This applies, for example, to number of channels, type of receivers (PIN-PD vs. APD), and options like additional amplifiers, S-Band extensions etc. Altogether, these options provide a high number of variants. This might be regarded a disadvantage. On the other hand, it offers to choose cheaper configurations in those applications where only less demanding requirements have to be fulfilled. It must be noted that such options do not exist in many other NGOA systems. For example, in most hybrid PONs it is necessary to always use the highest power budget which is available (e.g., 35-dB transceiver class). In other words, in some NGOA systems, *cheap* options do not exist.

Open access and cooperation

In low-cost implementations of WDM-PON, open access is limited to Layer-2. On this layer, access is possible without additional restrictions. Access to individual wavelengths at the OLT will be complicated and costly. It is possible, with the related hardware effort and cost impact, to add and drop individual wavelengths at the OLT and to replace them with individual services (e.g., higher bit rates). On large scale, this is regarded inefficient with regard to cost because added CapEx for the single-channel add/drop filters and lower form factor due to the space requirement for these filters have to be considered. Generally, the concept of highly integrated multi-channel transceiver PICs for the OLT is required in order to account for the cost, footprint, and power-consumption requirements, respectively.

Since uplink (northbound connection) is standards-based, WDM-PON (like every other solution) is able to interoperate with any relevant equipment. The same is true in general for the related management systems and an optional control plane.

3.2.2 WDM-PON with seeded Reflective Transmitters

Many, but not all characteristics of WDM-PON with seeded reflective transmitters at the ONU are similar to WDM-PON based on tuneable lasers at the ONU. Hence, focus is laid on the differences. With respect to maintenance, fault management, trouble shooting, open access and cooperation, same considerations as for WDM-PON based on tuneable lasers apply.

General requirements on operations

Regarding general operations requirements, the generic characteristics inherent to all (purely) wavelength-routed WDM-PON apply. Process automation is also inherently possible. As for all wavelength-routed WDM-PON systems, high availability (multiple vendors) will be given if there is a decision in favour of WDM-PON in FSAN. Should this decision not be made, the number of WDM-PON vendors may be smaller. It is expected though that WDM-PON *will be* available by several vendors in any way as is clear by different news feeds. This will be driven by requirements in (wireless, DSL, HFC) backhaul and business access.

Provisioning

A pure WDM-PON is inherently relatively simple, as compared to TDMA-PONs and other approaches with common MAC layers and higher per-wavelength bit rates. This is due to the fact that client bit rates (and hence client provisioning) do not depend on other clients – the individual wavelength is not a shared medium. in other words WDM-PON can be seen as a virtual point-to-point solution. In addition, problems (like SNR, dispersion) are avoided by the lower per-wavelength bit rates. This eases installation and, to certain extent, also network planning. Another advantage is that reflective devices are very low cost from now respect to tuneable lasers solutions. Reflective transmitters enable WDM-PON solutions with large client-count that are based on a single ONU-variant. ONUs are self-installing, and they will not be wavelength-specific.

Hardware

A detailed analysis with regard to power consumption, footprint, and capacity/density per rack is available in deliverable D4.2 [5]. It is seen that WDM-PON based on reflective transmitters offers low power consumption compared to other NGOA alternatives. Footprint is comparable to WDM-PON based on tuneable lasers. For WDM-PON based on reflective transmitters similar power management capabilities as for GPON are applicable. Due to separate wavelength channels, sleep mode scheduling of individual ONUs is somewhat simplified and can be arranged as a loose rendezvous. For WDM-PON systems based on reflective transmitters a slightly more constrained rendezvous is required in the sense that the OLT transmitter must be powered on before the ONU can transmit.

3.2.3 UDWDM

Following, the assessment for UDWDM-PON (polarization-diverse, digital intradyne/heterodyne QPSK with coherent multi-channel SCMA in the OLT) is given. Many, but not all characteristics, are similar to other WDM-PON. Hence, focus is laid on the differences.

General requirements on operations

Characteristics are similar to WDM-PON (with tuneable lasers). Generic characteristics inherent to all wavelength-routed WDM-PON apply. UDWDM-PON can support diverse higher-layer OAM functionality. OAM protocols standardized by Broadband Forum or ITU can be adopted, i.e., CWMP (TR-069) or OMCI. Further options include SNMP, as well as supplementary operations via (S)FTP or HTTP(S). For OMCI and TR-069, specific adaptation to UDWDM-PON will be required. This adaptation shall consider the specifics of coherent UDWDM-PON (example: a dedicated downstream wavelength must be present for an ONU to switch on and control its upstream transmitter).

Process automation is also inherently given for WDM-PON. All required configurations and management can be performed remotely via Layer-2. This can be automated via the respective management systems. Also, ONUs are self-installing (-tuning).

WDM-PON so far has not been standardized. Should a decision in favour of WDM-PON be made in FSAN, it will be strictly standardized.

High availability (multiple vendors) is not fully clear at the time being. UDWDM is followed seriously by one vendor only (NSN), and this approach is covered by relevant IP (Intellectual Property), which might limit other vendors to adapt the same approach given no licensing or standardization agreement is made.

Provisioning

UDWDM-PON is inherently relatively simple, as compared to TDMA-PONs and other approaches with common MAC layers and higher per-wavelength bit rates. Clients, including provisioning, do not depend on other clients since individual wavelengths are not shared between several clients. This eases installation and, to certain extent, also network planning. The latter is also supported by inherent high-reach capability. ONUs will be self-installing, and they will not be wavelength-specific. The lasers are broadband-tuneable, and tuning will be performed automatically (supported by the heterodyning mechanism) without manual action. Depending on the specifics of the laser type and the tuning mechanism, installation may take several seconds. High performance (fibre-loss budget) is always available, even in short-reach or low-channel-count networks. Hence, only few systems variants may exist. This may come at increased cost for all less-demanding applications.

Maintenance

Performance monitoring (PM), network supervision, and signalling are generally simpler or more feature-rich in a wavelength-routed WDM-PON than they are in a purely power-split (G-PON-type) approach. Hence, UDWDM-PON can make use of most per-wavelength signalling and monitoring techniques, however, OTDR measurements will be limited much the way they are in G-PON/EPON. Due to the fact that power splitters are required in a UDWDM-PON, individual clients cannot be resolved in OTDR measurements if distribution fibres are approximately equally long, which could reduce truck rolls for the cases these distribution fibers are located outside an MDU (refer to the Maintenance section of wavelength-routed WDM-PON with tuneable lasers).Similar limitations may be true for simpler techniques (for passive line terminations) which are based on partial signal reflectors (because the reflected signal portions of different ONUs overlap). Due to the fact that all LTs behind one power splitter will react simultaneously, discrimination between the individual clients may become difficult.

PM and signalling can be provided on a per-wavelength basis, using either in-band or out-band techniques. In the OLT, this can be supported by fault correlation in order to identify failures of the feeder fibre (multiplex section) etc. Again, it must be noted that only a purely wavelength-routed WDM-PON has the unique capability of unambiguously identifying individual distribution fibre faults by means of OTDR measurements.

UDWDM-PON supports various resilience (protection, dual-parenting) mechanisms. This applies to end-to-end resilience as well as to resilience down to a remote node only. In the relevant case of feeder fibre (duct) fault, switch-over to the resilient feeder fibre can be triggered within the usual 10 ms, using techniques for Loss-of-Signal monitoring. Complete switch-over may take longer than 60 ms due to necessary re-tuning (when using 2:N AWGs). Similar to WDM-PON, complete switch-over may take several seconds if re-tuning is involved. Due to its high fibre-loss budget, UDWDM can also support resilience configurations which are based on 2:N power splitters. Without tuning, switch-over within 60 ms is regarded feasible.

MTBF of a UDWDM-PON mainly is a function of the respective system complexity. Since UDWDM-PON is somewhat more complex than wavelength-routed WDM-PON with direct detection, MTBF can be expected to be slightly lower. This, however, will have only little effect on path availabilities which also take the fibre downtime into consideration. Without any fibre, calculated end-to-end path availability is 0.99965.

Hardware

A detailed analysis with regard to power consumption, footprint, capacity/density per rack is available in deliverable D4.2 [5], and in Ch. 2 of this document. Power consumption is slightly higher than in other NGOA solutions. This effect is related to the use of ADC/DAC and DSP per channel.

With regard to systems variants, it must be noted that the basic configuration supports high channel count and long reach (e.g., 60 km with 320 clients, taking EOL penalties into account). This eases network planning and, to certain extent, logistics. It also means that no lowest-cost variant is available for applications which require low channel count and short reach only.

Open access and cooperation

In commercial low-cost implementations of WDM-PON, open access is limited to Layer-2. On this layer, access is possible without additional restrictions. Access to individual wavelengths at the OLT will be extremely complicated and costly due to the ultra-densely spaced nature of the channels. Hence, replacing individual channels for example with higher bit rates is regarded (commercially) impossible. The channels are ultra-densely spaced. Higher bit rates would require higher-order modulation which in turn corrupts the power-budget capabilities. In addition, individual channels would have to be blocked and replaced in the OLT, which again is complicated due to the coherent densely-spaced nature of the system. This also means that general channel upgrades, e.g., to 10 Gb/s are either not possible, or require a severe reduction in channel count. Generally, the concept of highly integrated multi-channel transceiver PICs for the OLT is required in order to account for the cost, footprint, and power-consumption requirements, respectively.

Since uplink (northbound connection) is standards-based, WDM-PON (like every other solution) is able to interoperate with any relevant equipment.

3.3 HYBRID WDM/TDM-PON ARCHITECTURE

3.3.1 Passive hybrid WDM/TDM-PON

In this subsection, we provide the assessment of passive hybrid WDM/TDM PON (where there are no active components in the outside plant) in terms of the general requirements on operation, provisioning, maintenance, fault management and trouble shooting, hardware and facilities and open access and cooperation. Here, we consider the most common configuration for passive hybrid WDM/TDM PON which consists of several TDM PONs embedded in a WDM PON system.

General requirements on operation

Passive hybrid WDM/TDM PON can support diverse higher-layer OAM functionalities. It may support Ethernet OAM functions or proprietary OAM functions. Similar as WDM PON (with tuneable lasers), passive hybrid WDM/TDM PON can also adopt OAM protocols standardized by Broadband Forum or ITU, i.e., CWMP (TR-069) or OMCI.

Process automation is also inherently possible with passive hybrid WDM/TDM PON. All the components in the outside plant are passive which inherently do not require any configurations. Similar as WDM PON (with tuneable lasers), the requested configurations and management at the CO and the user side can be performed remotely via Layer-2 in the OLT.

Hybrid WDM/TDM PON so far has not been standardized in a system-wide context. It has been commercially deployed by Korea Telecom to provide commercial services in Gwangju, Korea, since March 2009, after successfully passing through the benchmark test [6]. This is the first commercial deployment of a hybrid WDM/TDM hybrid PON. It is expected that passive hybrid WDM/TDM PON will be available in different vendor's products (e.g. Alcatel Lucent).

Provisioning

Passive hybrid WDM/TDM PON will use self-installing ONUs which will not be wavelength-specific. Similar as in WDM PON (with tuneable lasers), the lasers are broadband-tuneable and tuning can be performed automatically. Installation and configuration may just take several seconds depending on the specifics of the laser type and the tuning mechanism. In a passive hybrid WDM/TDM PON, the users connecting to the same power splitter can share the same wavelength channel. Therefore, to support large client count (e.g. 320, 640 or beyond), the number of wavelength channels is not necessary to be high (e.g. >80, or >160) and the extra waveband is not required. Thus, one ONU (transceiver) variant is sufficient in most cases. In case the reach extender is deployed in ODN, the required optical amplifiers only need to cover one waveband.

Maintenance

Performance monitoring (PM), network supervision, and signalling can be provided on a per-wavelength basis, using either in-band or out-band techniques. Within the same embedded TDM PON (where all the connected ONUs share the same wavelength), the complexity of maintenance is similar as in a purely power-split approach. OTDR measurements will be limited due to the fact that the power splitters are still required at the remote node. It is because similar as in Co-UDWDM PON individual user is hardly resolved in OTDR measurements if its distribution fibre which connects between the splitters and ONUs is cut.

Fault management and trouble shooting

Most of the fault management techniques proposed for WDM PON are also valid for hybrid WDM/TDM PON. Like, WDM PON, hybrid WDM/TDM PON has high availability.

Passive hybrid WDM/TDM PON can easily support end-to-end resilience as well as resilience down to a remote node only. Several resilience schemes with protection down to the first remote node (i.e. PCP5) have been included in Milestone M3.1 [7]. With fast switching technology, switch-over to the protection path can be done in the range of 10ms. In order to avoid extra power-loss budget for protection provision in hybrid PON, two approaches can be considered (see [7]): 1) using a 2:N AWG at PCP5 to connect working and protection feeder fibres; and 2) to configure the first stage of remote node (i.e. PCP5) with a combination of one 2:2 power splitter and two 1:N AWGs and place a 1:M/2 splitter at the second stage of the remote nodes (i.e. PCP4).

MTBF of a hybrid WDM/TDM PON mainly depends on the system complexity. Since hybrid PON is more complex than TDM PON and wavelength-routed WDM PON, MTBF can be expected to be slightly lower. However, it only has a small impact on connection availability if the fibre part is also under the consideration. With 25 km unprotected fibre (20 km feeder fibre and 5 km distribution fibre), the calculated connection availability for passive hybrid WDM/TDM PON is 0.99852. With protection down to the first remote node (i.e. PCP5), the connection availability can be increased to the range of 0.99965 [7].

Regarding the failure localization, the precise places of the optical failures occurred in the distribution fibres which connect between the splitters and end users cannot be measured by OTDR. This limitation would introduce some additional cost for fault management.

Hardware and facilities

Due to the large customer base, the power consumption and cost is shared amongst many users and thus hybrid WDM/TDM PON has low power consumption and cost figures per user. A detailed analysis in terms of performance on cost, reach and power consumption is available in deliverable D4.2 [5]. From there, it can be derived that to support large number of clients per feeder fibre (e.g. 640), hybrid WDM/TDM PON performs relatively good as compared to other NGOA solutions. This is because of the high sharing ratio. Furthermore, compared with all the other considered system concepts, the hybrid WDM/TDMA PON solutions require the least footprint due to the high splitting ratio (see Figure 2-7).

Open access and cooperation

The passive hybrid WDM/TDM has good option for open access. Both bit stream and wavelength open access can be easily achieved. Compared with a pure WDM option, for the passive hybrid WDM/TDM PON supporting bit stream open access will be significantly less complicated and less costly due to its inherent request on a common MAC layer and shared resources in the time domain. Open access on the wavelength layer is also possible, as e.g. different network providers can reach an individual customer on separate wavelengths (one per NP). The customer can then select its network provider by tuning to the right wavelength. Furthermore, it should be noted that security may be the concern for providing open access in hybrid scenario because of the broadcast characteristic of the deployed power splitter.

3.3.2 Semi-passive (wavelength-switched) hybrid WDM/TDM-PON

The focus in this section is laid on the differences of the semi-passive or wavelength-switched hybrid WDM/TDM PON compared to the passive hybrid WDM/TDM PON.

General requirements on operation

Semi-passive hybrid WDM/TDM PON can support diverse higher-layer OAM functionalities. It involves the use of active elements like wavelength selective switches (WSS) which exploit several advantages of flexibility like energy efficiency, migration, planning and extensibility. Semi-passive hybrid WDM/TDM PON so far has not been standardized in a system-wide context and is not yet available today.

Provisioning

Semi-passive hybrid WDM/TDM PON will use self-installing ONUs which will not be wavelength-specific but may require a wider tuning range to exploit the advantages of flexibility. At the second remote node (i.e. PCP4), it makes use of active elements like WSS. The WSSs may not be broadcast capable. The WSS are used together with cyclic AWGs to make use of several cyclic bands capable to reach the same customers. The WSS has to be controlled through outband signalling schemes through the OLT. The free spectral range (FSR) of AWGs must be chosen such that a gap between the cyclic bands (or filter orders) exists.

Maintenance

The maintenance of semi-passive hybrid WDM/TDM PON has more challenges than the passive hybrid WDM/TDM PON. The use of WSS at the second remote node (i.e. PCP4), makes it more challenging. However, the use of WSS itself will ease the network planning, migration of customers, extension of the network and minimising energy consumption as discussed below:

- **Network planning:** The WSS can be used to configure a different number of wavelengths feed at the input of the first remote node (i.e. PCP5) and thus will enable power splitters with different splitting stages (assuming the same bandwidth demand per customer). The urban scenario will require less reach and more splitting stages and the rural scenario will require more reach and less splitting. And thus, variable numbers of wavelength inputs are important, according to the network demand. Also, the NGOA architecture should have the provision for narrowband services, and thus the concept of different bandwidth feeds will ease the network planning according to the scenario and requirements.

- **Network migration:** Note that the wavelength given to the power splitter can have different capacities like 10 G and 1 G. Also, the users behind the power splitter can have either 10 G or 1 G. Thus, it will support an easy customer migration. Also, the WSS will enable the dynamic configuration of wavelengths.

- **Network extensibility:** If during the network design, the customer base is low, and then gradually more users add up, it is possible to accommodate all new users by assigning a proper wavelength to them. A WSS will help in easy wavelength routing. Thus, the use of WSS will reduce OpEx.

As you can test the different PON segments on different wavelengths for different optical loses and impairments; performance monitoring (PM), network supervision, and signalling are generally simpler and richer in semi-passive hybrid WDM/TDM PON than they are in a purely passive power-split approach. However, OTDR measurements will still be limited.

Fault management and trouble shooting

The resilient techniques for semi-passive hybrid WDM/TDM are proposed in Milestone M3.1 [7]. To minimise insertion loss while providing protection, a 3 dB coupler is used with 2 WSSs. In this way, we can still serve the same customer count while not increasing the insertion losses. With 25 km unprotected fibre (20 km feeder fibre and 5 km distribution fibre), the calculated connection availability for semi-passive hybrid WDM/TDM PON is 0.997586. With protection down to the first remote node (i.e. PCP5), the connection availability can be increased to the range of 0.999798 [7].

Hardware and facilities

Due to the large customer base, the power consumption and cost is shared amongst many users and thus semi-passive hybrid WDM/TDM PON has low power consumption and cost figures per user. A detailed analysis in terms of performance on cost, reach and power consumption is available in deliverable D4.2 [5]. From there, it can be derived that to support a large number of clients per feeder fibre (e.g. 640), semi-passive hybrid WDM/TDM PON performs relatively good as compared to other NGOA solutions. This is because of the high sharing ratio.

Open access and cooperation

The semi-passive hybrid WDM/TDM PON offers the same possibilities for open access as the passive hybrid WDM/TDM PON.

3.4 Next-Generation AON Architecture

Ethernet has become the ubiquitous service delivery technology that can be supported over any transport network. Gigabit Ethernet was deployed in backbone network links initially. Nowadays higher bandwidth 10 Gigabit Ethernet is replacing 1 Gbit/s as the backbone network and has begun to migrate down to high-end server systems, and also 100 Gigabit Ethernet standards has been approved (June 2010). IEEE Gigabit fibre standards1000BASE-LX10 and 1000BASE-BX10 were part of a larger group of protocols known as Ethernet in the First Mile. The next-generation AON architecture could also include other transport protocols, e.g. MPLS, but also be a hybrid solution with active fully optical elements.

General requirements on operation

The next-generation AON architecture should provide the same well known and proven OAM protocols and methods that are currently in use in the core and metro network. This means the operator can have a unified OAM architecture, which simplifies operations, training and therefore reduces costs. Well known OAM protocols from IEEE, such as 802.1AG, could be used as well as OAM protocols from IETF, such as SNMP. Devices on the customers premise may be controlled by for example TR69.

Operating and maintaining two or several different systems cross from core network to access network potentially incurs relatively high OpEx for network operators in terms of controlling and managing (C&M) inventories of network equipment. Currently operators are using several separated C&M systems. In the end-to-end scenario it would add complexity if there are additional technology layers. E.g. there should be synergy effects if similar technologies are used in the access, metro and core network. CapEx implication could be the need of interworking between different NMS systems used in the different domains. OpEx implications could be synergy effects of technicians if similar technologies are used end-to-end.

For a large access network where multiple technologies and network equipment from different vendors may co-exist, it is important that all ONTs or OLTs are well managed and can inter-operate correctly. AON has good compatibility and inter-operating ability to work with other technologies and network equipment as AON uses standardized Ethernet interfaces.

Management of future AON network can be fully automated, unified end-to-end, including resource allocations and path computation. This can be accomplished with control plane solutions such as IETFs GMPLS protocol stack, currently deployed in the backbone networks. This protocol stack provides the operator with high grade of control of their network, fine grade traffic engineering and a system that can control future transport technologies. The future access and metro/aggregation network could also use split architecture solution such as OpenFlow. In such a solution each device is controlled by one or more “controllers” which directs the operations of each device. This means that devices could be simplified and more advanced aspects are moved to the “controller”, which may reduce cost and energy use of the devices. It also gives the operator a high amount of flexibility as it's up the controller to decide how the devices behave, and is therefore not limited to what functionality the device manufacturer chooses to implemented.

The future AON network may also utilize a hybrid network architecture, which includes active fully optical network nodes and optical nodes with packet switching functionality, all controlled by a common control plane. Such architecture can provide low energy consumption while still providing a high amount of network flexibility.

With a highly dynamic traffic pattern and large amounts of traffic locally in the network it becomes even more interesting to consider the metro/aggregation part of the network instead of just the pure access part for the AON. For instance more meshed topologies will lead to better utilisation of resources, the future AON solution can handle this type of flow.

Provisioning

The provisioning of a FTTH network includes both physical hardware/infrastructure connectivity provisioning and service configuration provisioning. The physical provisioning involves physically connecting / disconnecting fibers from end-user site to CO site, line tests, etc; while service provisioning mainly concerns software configuration of customers’ service profiles.

For AON architecture, the network dimensioning and physical connectivity provisioning is flexible. The number of network equipment can be economically dimensioned according to the take rate of subscribers. At CO the physical provisioning of customers, for homerun architecture can be flexibly addressed to each individual subscriber. However this flexibility on the other hand gives rise to more fibre connectivity and management work. In an active star architecture the flexibility advantages can be shown in the remote node as well, the number of active equipment and connectivity provisioning can be easily done with regards to how many homes take service.

AON has high service granularity and capacity, allowing the carrier to deliver Ethernet services more efficiently at any bandwidth level (ranging from 1Mbps up to 1Gbps with adjustable increment of kilobit) according to what customer needed.

At end-user side, the ONU/ONT of AON can be easily self-installed and automatic configured by network management system because of its simplicity. Intelligent and unified control plane could simplify end-to-end Ethernet provisioning and monitoring.

Upgrade

As the AON has a modular structure, subscriber interfaces can be upgraded to include more bandwidth. It is often sufficient to just switch the fiber optic lead to be able to operate it again. By converting boards, subscribers can obtain an upgrade, without the network architecture or the service of other subscribers having to be changed.

Maintenance, Fault management and trouble shooting

Maintenance and fault management in AON is feature-rich, especially when using a control plane. The control plan may provide root-cause-analysis to give the operator automated and detailed reports when a failure occurs. This might include not only physical failures, such as cable breaks and power loss, but also degradation of the quality of service, for example increases in latency. Because AON provides a unified technology solution, from the access network to the backbone network, the operator can more easily detect and troubleshoot problems no matter where the real cause of problem is located. For example a problem might be detected in the access network while the problem is located in the metro network. This reduces the complexity of the operation for the operator, provides better availability and reduces costs. In an AON active star case the maintenance is relatively higher because the active remote nodes require a relative stable and robust location with power supply.

Access node failure impact

For AON homerun architecture the impact of certain sub-system faults in the central access node can be fairly low. Due to the point to point topology every individual end-user connecting to the central access node with separated optical interfaces, and the subscriber density of the interface card is relatively low compared with e.g. a TDMA PON-OLT, therefore relatively few subscribers are affected if there a port or card malfunctions.

For AON active star architecture, due to the point to multi-point topology, a group of users in the first access node (remote node) have been aggregated into one feeder fibre towards the central access node. Hence when faults happen in the central access node AON active star architecture that utilizes a single interface on the feeder fibre, it has similar impact as TDMA PON since one port in central access node is corresponding to a group of users. By having multiple WDM interfaces one can mitigate the risk of interface failure. Feeder fibre failure could be mitigated by connecting multiple active remote nodes and CANs together in a ring or mesh network topology, thus a highly protected network is established.

Resilience

Resilience in AON network can be accomplished by providing path protection, not only segment protection, even from the customer to the backbone. This is done by establishing fully or partly disjoint paths in the network, for example with the use of a PCE, and then detecting the faults via one of the many fault detection protocols available to the AON architecture. The two most common protocols includes IEEE's Continuity Check Protocol and IETF's Bidirectional Forwarding Detection, the later is also transport independent and could operate on virtually all packet based system. The operations of resilience can be wholly automated by using one of the control plane techniques described above. The limiting factor for the failure recovery times in both these protocols are the amount of resources used for the fault detection process, low detection time requires sending heartbeat messages at a higher rate with consumes more resources. These protocol can both be tuned to the right trade-off point between resource use and detection times, giving the operator the best balance for their needs. Both these solution can provide complete failure recovery (fault detection and switch over) in well below 20ms.

Fiber connectivity failure

AON homerun architecture can locate faults though whole network span, but typically it cannot locate the fault precisely on the fiber unless an OTDR mechanism is implemented. The implementation of OTDR in each point to point fibre link may involve a lot of recourses, it can be solved by utilizing power splitter concept in the CO, and thus one OTDR can be shared among a number of fibre links. For AON active star case, the whole network span splits into two sub-spans, the fibre faulty path can be easily identified in which sub-spans. If faults happen between remote node and CO, OTDR can be applied. If faults occur between subscriber and remote node, it might require some additional field personnel to travel to the remote node and measure.

To repair fibre cuts may involve travel, splicing, civil work, etc. the cost and time spend on repairing of fibre is normally depending on the location of the fibre cut, the size of the fibre cable or the number of fibres need to be repaired, and the techniques used to repair. There are more fibres used in AON homerun network, when fibre cut happens it might affect more fibres and hence it will need more effort to repair.

Patch failure is another type of fault which makes fibre loss connectivity, it is important for all access networks to have easy access to where fibre patched or connected. Patch failures in AON network can be easily fix since all connectors and patch panels are accessible. For PON networks some of passive splitter or AWG buried underground when patch failure happens it might take more effort to repair them.

Hardware failure

Ethernet is a mature technology today and has been widely used in various networks for many years. The related hardware equipment and components are well developed with high reliability. AON network equipment has minimal technology layers comparing to other access network systems from end-to-end network point of view, only a packet layer and for example no TDM layer etc. It therefore minimizes the number of layers where potential failures can occur.

The hardware failure can be identified by performance monitoring, network management system (NMS alarm function), etc. The hardware failure mainly involves replacement of subsystems, cards, pluggable interfaces.

Faulty ONT is much easier controlled in AON architecture, since AON network is easy to carry out an end-to-end diagnosis to the subscriber's home, NMS can assess dedicated optical transmission path to configure or de-active ONT, while in TDM PON case a faulty ONT cannot be deactivated by the NMS. A field technician is needed to visit the customer.

In AON active star case when hardware failure happens in the active remote nodes, it will also require a field technician to visit remote node to repair.

Technician personnel

Ethernet is widely used; many technicians are experienced with the Ethernet equipment or have good knowledge of them, therefore they can replace or repair the fault quickly.

When access network is running with Ethernet AON solution, the whole network from access, metro aggregation network till core network are Ethernet transparent. The technicians who had worked with core network or other Ethernet based networks can work in the access network as well without any training, hence the technicians can be shared among access, metro and core networks, so that either the total number of required technician can be reduced or amount of training cost for the technician to getting to master other technologies can be saved.

Future work

Current control plane technologies do not scale well over approximately 200 nodes, primarily limited by the control plane routing protocol, most commonly OSPF. This is currently worked on by IETF and will also be worked on in the OASE project. Potential solutions include different update frequencies for different information, split the network in smaller routing domains and creating a split or semi-split architecture solution. And other issue scalability issues may be path computation in very large networks and extensions to the control plane for metro/access use, which also will be worked on in OASE.

Hardware

A detailed analysis with regard to power consumption, footprint, and capacity/density per rack is available in deliverable D4.2 [5] and section 2.3 in this document. The energy efficiency of AON network can be improved in future by addressing following hardware points:

- Sleep mode (full shut down, activation through out-of-band control /management plane channel)
- Doze mode (low power mode, periodically checks status)
- Power scalability (low baseline power that scales with interface, load adaptive per interface and/or switch fabric)

The AON architecture can also increase energy efficiency by supporting multitenant solution, for example in an open-access use-case, though network virtualization. This leads to less redundant equipment as the tenants share the infrastructure and increases the utilization of the equipment, which both leads to better energy efficiency.

Energy efficiency can further be improved with an end-to-end energy aware control plane. This control plane can improve energy efficiency by optimizing how the resources are allocated, and thereby reducing the energy use of the whole network. The future control plane solution for the AON network may also improve energy use by using hybrid optical-active network architectures that provide both highly dynamic network attributes with good energy scalability. Such solution will be investigated in the OASE project.

Open access and cooperation

Service provisioning of a FTTH network can largely differ from one business model to another. In an open access model, when multiple service providers can offer the same or different services over single network provider. The service provisioning can be done in several ways, two of which are:

Service providers (SP) order personnel of the network provider (NP) to perform service provisioning. Only the network provider has full control of the network equipment including ONTs, and it therefore fully in change of most network aspects.

Service providers have access to a slice of the network, including network links, nodes and ONTs. This means that service provider can integrate the open-access network in to the service provider's own private network. This simplifies management and troubleshooting as only one party are responsible for the configuration and management of network, and not two entities as in a).

The second way requires that the NP gives the SPs a slice of the network. This requires that NP can separate the service providers in the network. The AON architecture can provide network separation and isolation, in all layers above the physical. This includes the ability to be semi transparent to the higher-layer, for example by encapsulating the traffic in MPLS pseudo-wire or Ethernet PBB-TE (Provider Backbone Bridge Traffic Engineering). This frees the service providers to use arbitrary packet transport solutions. If the AON network includes active optical nodes, for example ROADM nodes, the AON network may provide also separation in the physical layer.

The network nodes in the network may also provide direct access to the service providers by using a virtualization solution. Giving the service provider full access to a slice of the network node on which there customer are connect to. This gives the SP the ability to run their own control plane and OAM solutions on their slice of the NPs network nodes.

3.5 WDM-PON BACKHAUL

3.5.1 Hybrid active WDM-PON

Following, the assessment for hybrid active WDM-PON) is given. Most characteristics are similar to wavelength-routed WDM-PON with tuneable lasers. In the backhaul part, the assessment of the WDM-PON with tuneable lasers applies (since the backhaul WDM-PON is based on tuneable XFPs or similar interfaces, and wavelength routing). Differences occur in dependence on last-mile technology (Ethernet P2P, WDM-PON, G-PON). Hence, focus is laid on the differences.

General requirements on operations

The backhaul part can support all OAM which was described for WDM-PON with tuneable lasers already. In addition, this part can also be regarded a passive derivative of standard WDM backhaul systems. Again, the standardized OAM features of these systems apply.

The last-mile (access) part also supports standardized OAM, and the related protocols. This specifically holds for CWMP (TR-069), OMCI, SNMP, (S)FTP and HTTP(S). For OMCI and TR-069, specific adaptation may be required (this applies to WDM-PON access).

Process automation is also inherently given for WDM-PON. All required configurations and management can be performed remotely via Layer-2. This can be automated via the respective management systems. Also, ONUs are self-installing (-tuning).

WDM-PON so far has not been standardized. Should a decision in favour of WDM-PON be made in FSAN, it will be strictly standardized. Supportive standardization is on-going in ITU SG15 Q6 (G.sdapp).

High availability can be expected. This is particularly true since last mile is based on several options (including Ethernet P2P, G-PON), and passive WDM is used in backhaul already.

Provisioning

Provisioning in hybrid active WDM-PON is relatively simple. Simplicity stems from the fact that the active remote node also performs regeneration, which eases network planning in particular for long-reach requirements. Last-mile provisioning depends on the specifics of the respective solution (Ethernet P2P, G-PON, WDM-PON), where only minor differences are seen in the overall systems context.

ONUs will be self-installing, and they will not be wavelength-specific in the case of the WDM-PONs. Lasers are broadband-tuneable, and tuning will be performed automatically without manual action. Depending on the specifics of the ONU type, laser type and the tuning mechanism, installation may take several seconds.

Due to the integrated backhaul/access combination, potentially many variants exist. This may provide an undesirably large solutions space (in terms of variants, logistics, also training for staff), but covers a broad applications space from short reach / few clients up to very long reach and very many clients (up into the range of 10,000 per feeder fibre).

Maintenance

Performance monitoring (PM), network supervision, and signalling are generally simpler or more feature-rich in a wavelength-routed WDM-PON than they are in a power-split approach. Hence, the WDM backhaul part can make use of all techniques mentioned before, including unambiguous OTDR measurements. In particular, the active remote node can be fully supervised much the way it is in any WDM transport system. For last mile, the individual solutions' characteristics apply. In the case of Ethernet P2P, fully individual monitoring down to the client is possible. However, fault localisation on individual distribution fibres may be impossible. For WDM-PON and G-PON, it is expected that no OTDR measurement facilities will be available at the active RN. Hence, clients can be monitored, but in cases of fibre failures, no monitoring or fault localisation can be provided. (In case a (low-cost) OTDR is available at the RN, the assessment as discussed before applies.)

PM and signalling can be provided on a per-wavelength basis, using either in-band or out-band techniques, in WDM-PON (backhaul, access). In the OLT, this can be supported by fault correlation in order to identify failures of the feeder fibre (multiplex section) etc.

Several resilience (protection, dual-parenting) options exist. This primarily applies to resilience down to the active remote node. In case of feeder fibre (duct) fault, switch-over to the resilient feeder fibre can be triggered within 10 ms. Complete switch-over may take longer than 60 ms due to necessary re-tuning (when using 2:N AWGs). Alternatively, the complete backhaul part can be 1+1-protected, using disjoint fibres down to the remote nodes. In this case, standard 60-ms switch-over is easily possible.

MTBF again is a function of the respective system complexity. Since both parts (backhaul, access) are simple each, resulting MTBF is potentially high. This holds specifically if the backhaul is 1+1-protected. MTBF is slightly affected by the active RNs. Without any fibre, calculated end-to-end path availability is 0.99965 for protected backhaul and unprotected access. Hence, despite the use of active RNs, MTBF is not seriously affected as long as the backhaul part is protected.

Hardware

A detailed analysis with regard to power consumption, footprint, capacity/density per rack is available in deliverable D4.2 [5]. Despite the use of active RNs, power consumption can be relatively low. This is driven by low-power-consuming client interfaces, and depends on the client count specifically in the access part. It also has to be noted that hybrid active configurations can achieve the highest client-count-per rack ratio of the NGOA solutions assessed.

Systems variants and configurations cover a very broad range, with very many potential variants. This may complicate planning, training and logistics, but is compensated by the reach / client-count / cost (CapEx) characteristics.

Open access and cooperation

Access can potentially take place in the backhaul OLT or the active RN. In the backhaul, access to individual wavelength (carrying 10 Gbit/s each or more) is simple and (unlike the other WDM-PONs) is seen as a viable option. This is enabled by the use of individual interfaces (tuneable XFPs) in our model. Should integrated multi-channel arrays be used, the problems mentioned in the (UD)WDM-PON sections apply. Alternatively, access is possible in the backhaul OLT on Layer-2. Hence, this part of the network can be regarded as "open". For the access part, the characteristics of the individual solutions (WDM-PON, G-PON, Ethernet P2P) apply. This means, access can be provided on Layer-2, mainly.

Similar considerations apply for cooperation. In particular, the backhaul OLT shall in no way differ from any other systems / network elements as used in backhaul and WDM transport networks.

4. Preliminary assessment of the system concepts

In Table 4-1 the assessment of the NGOA candidate systems from the operational perspective is summarized. Based on the criteria a short synopsis of main characteristics of the different system concepts is given.

Table 4-1: System concepts assessment from operational perspective

	WDM PON			Hybrid WDM/TDM-PON		NG AON	Two-stage WDM PON
	Tuneable Lasers / Laser-Arrays	Seeded reflective Transmitters	UDWDM	Passive	Semi-passive		
General requirements on operations	+ Supports standard OAM protocols and procedures	+ Supports standard OAM protocols and procedures	+	+ Supports standard OAM protocols	+ Supports standard OAM protocols	+ Supports standard, unified OAM protocols with mature low cost implementations	+ Supports standard OAM
Provisioning	Colourless ONT + ONU self-install (may take 1s for auto-tuning), SW-assisted OLT provisioning	Colourless ONT + Simple, self-installing	Colourless ONT +	Colourless ONT + ONU self-installing	Colourless ONT + ONU self-installing	Colourless ONT + more fibre connectivity and fibre management work	Colourless ONT + ONU self-install, SW-assisted OLT provisioning
Maintenance	+ Simple, specially in wavelength-routed case with additional OTDR	+ Simple	+	+ Simple	+ Simple (very good if extensibility, migration is considered)	+ Simple	+ Simple, specially in WR-case
Fault management and trouble shooting	+ See above, passive low-cost NT possible	O Simple and feature-rich fault-localization w/ OTDR	-	- Fault localization for last mile (after splitters) is hard.	- Fault localization for last mile (after splitters) is hard.	+ Simple	O Simple and feature-rich (WR-case) w/ OTDR and passive NT
Hardware: Power consumption per line	From O to - 5.8 W 80Ch 31km 5.8 W8 160Ch 23km 7.3 W 80Ch 60km 7.3 W 160Ch 52km 7.2 W 320Ch 30km	O 5.9 W to 6.9W e.g. 96Ch 100GHz, WL reuse: 6.6 W @ 300 Mbit/s 6.8 W @ 500 Mbit/s	- 8.0 W @ 300 Mbit/s 8.5 W @ 500 Mbit/s	O 6.9 W @ 625 / 312 Mbit/s down / up and 1280 per feeder 6.8 W @ 625 / 312 Mbit/s down / up and 640 per feeder	O 6.9 W @ 625 / 312 Mbit/s down / up and 1280 per feeder 6.93 W @ 625 / 312 Mbit/s down / up and 640 per feeder	O 5.4 W @ 300 Mbit/s 5.7 W @ 500 Mbit/s	O to - 5.5W to 9.7W for >40km reach and >1000 clients
Footprint Hardware and ODF	+	+	O	++	++	--	O

Open access and cooperation support	BSA + Unbundling - Mainly L2, wavelength layer possible but requires effort	BSA + Unbundling - Mainly on L2, wavelength layer possible but requires effort	BSA + Unbundling	BSA + Unbundling - Bit stream and wavelength layer possible	BSA + Unbundling - Bit stream and wavelength layer possible	BSA + Unbundling + (PtP)	BSA + Unbundling - Depends on last-mile part (AON, GPON, WDM-PON)

Legend:
++ very good
+ good
O medium
- poor
-- very poor

As a major result, Table 4-1 shows that several concepts are suitable NGOA candidates from an operational perspective. There are general requirements on network operations which have to be fulfilled by all NGOA candidates, e. g. OAM functions and automation. Also, each of the concepts has to allow for certain provisioning aspects, like automated and do-it-yourself installation. Here each of the system concepts may use different technical solutions and implementations — eventually causing different costs, but all have to fulfil those requirements. Hence, from this viewpoint no significant differentiation is possible.

Maintenance differs for the system concepts in a sense that there are components used for a large number of customers and others that affect only a small customer number. Similar thoughts apply to fault management and trouble shooting.

Regarding power consumption per line the systems are in a similar range of 5–7 W, except the variants UDWDM PON and two-stage WDM PON with potentially higher power consumption of roughly 9–10 W per line.

Regarding the footprint in the access node there are on the one hand in particular the variants UDWDM PON and NG AON which require a relatively high space; on the other hand the two stage WDM PON exhibits a low footprint. The footprint of the other system concepts is in a medium range.

Cooperation on layer 1 is per definition not possible in PON variants. In the AON case it depends on the definition of the cooperation access point – where a cooperation partner can have access to the infrastructure. So, in an AON case with active remote nodes where only cooperation access is allowed at the CAN site, also no layer 1 unbundling is possible. Instead, at layer 2 all variants support cooperation. It is envisaged to investigate the cooperation options in more detail in the upcoming final version of D4.3.

5. Conclusion and outlook

The preliminary assessment of the NGOA candidate systems from an operational perspective in this deliverable document shows that the different candidate systems have in general advantages and challenges.

That is why a concise decision on one or more preferred NGOA system can not be taken at this stage out of the work documented in this deliverable. Instead, it is necessary to continue the assessment together with the other tasks and work packages to form a system candidate shortlist.

General and provisioning requirements have to be fulfilled by all system candidates and hence allow for no differentiation. However, the technical effort to achieve this may differ and hence it is proposed to dedicate future techno-economic work in WP5 to this problem. The detailed modelling of the most critical processes (fault management and service provisioning) will allow evaluating the impact of the different capabilities of each system candidates. Also, regarding maintenance as well as fault management and trouble shooting detailed techno-economic investigations are proposed in particular with respect to the number of active and passive equipment used in the several system concepts – where specifically the remote node site is expected to have major impact.

Therefore, the next steps concerning the evaluation and assessment of the candidate NGOA systems will be to bring together the findings from D4.2 (technical system perspective) and D4.3 (operational system perspective) in a suitable manner and also include the results from the techno-economic calculations from WP5: This way a shortlist of remaining candidate NGOA systems will be established during the remaining work regarding the final deliverable versions (D4.2 and D4.3).

Some results up to now rely on a single-provider basis, e.g. the footprint model of the optical distribution frame (ODF). The upcoming work targets at including cooperation support and multi-provider environments in those calculations, e.g. in an ODF model incorporating multi-provider scenarios.

In further work the WP5 feedback concerning added cost (OpEx) associated with central office floor space, active remote nodes, different fault-localization capabilities, multiple ONU variants, will be considered. In addition WP6 feedback on most feasible business models and required cooperation interfaces will be also included into the investigations. This way a close interaction between the OASE work packages is expected to lead to an NGOA system candidates shortlist as mentioned above.

— End of Document —